Climate Scenario Analysis by Jurisdictions

Initial findings and lessons

15 November 2022

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Executive summary

As part of the FSB's July 2021 Roadmap for Addressing Climate-Related Financial Risks,[1] and as a follow up of the NGFS "Scenarios in Action" progress report published in October 2021,[2] this Financial Stability Board (FSB) and Network for Greening the Financial System (NGFS) joint report focuses on climate scenario analyses undertaken by financial authorities to assess climate-related financial risks.

This joint report provides a synthesis of the findings from climate scenario analysis exercises undertaken by financial authorities at the individual firm level, at the level of the different financial sectors, and at the overall financial system level. It has been informed by a survey of FSB and NGFS member authorities. The aim is to draw lessons for effective scenario analysis and sketch out the global perspective stemming from the various national/regional exercises conducted to date.

Overview of main messages

- The NGFS Scenarios play a critical role in supporting financial authorities' climate scenario analysis exercises. While a majority have used or adapted the NGFS Scenarios, many of the remaining exercises have also taken those scenarios as a point of reference (e.g. in terms of scenario narratives or the alignment of key variables).

- Climate scenario analysis exercises by financial authorities vary widely in terms of scope and objectives, and have explored a range of physical and transition risk drivers to identify potential financial system vulnerabilities. As this area remains relatively new, most of the exercises aim at raising awareness and developing capabilities and capacity in climate scenario analysis. While many authorities included the assessment of financial stability as an explicit objective of their exercises, most also identified data and methodological limitations that posed hurdles in conducting such assessments robustly.

- Given the differences in the objectives of participants in conducting climate scenario analysis, as well as the nascent stage of work in this area, authorities have adopted a variety of exploratory design choices in formulating their exercises. These differences do not allow for a straightforward comparison of results. The exercises do however provide a comprehensive picture on vulnerabilities. While most jurisdictions emphasise the importance of ensuring comparability across different exercises at international level, many also point to the need to tailor the analysis to their specific context and objectives.

- Many exercises do not find severe impacts under an orderly scenario, but report more significant GDP and financial losses for disorderly transition scenarios, as well as more sizeable losses in the case of a no-transition scenario with high physical risks. The overarching message of these initial exercises for financial stability is that, while the impacts of climate risks are not small, they seem to be concentrated in some sectors

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1 FSB (2021), *FSB Roadmap for Addressing Climate-related Financial Risks*, July.

2 NGFS (2021), *Scenarios in Action: a progress report on global supervisory and central bank climate scenario exercises*, October.

and overall, at least for now, contained from the perspective of domestic financial systems. However, the tail risks associated with climate change may not be as manageable, while the exercises are largely exploratory in nature at this stage and are therefore not comparable to traditional stress tests that assess resilience to tail risks.

- In addition, many respondents highlight that measures of exposure and vulnerability are likely understated. One of the reasons is that, in many cases, metrics are not capturing second-round effects, potential climate non-linearities, and the costs and potential further externalities from risk management measures taken by financial and non-financial firms. Many exercises also did not consider other potentially large sources of risk, such as those stemming from an abrupt correction in asset prices when transition shocks result in fire sales of assets in exposed sectors. The scarcity of available data and modelling limitations and uncertainties are other key reasons mentioned by authorities to suggest that these preliminary results might significantly understate actual climate-related risks and impact.

- While the findings of the exercises do feed into discussions by relevant financial stability bodies, in most cases they do not translate into micro- or macro-prudential responses at this stage. Many respondent authorities indicated that better assessments of potential losses for financial firms and the overall financial system are necessary to gauge more precisely the financial stability implications of climate risks and to inform policy decisions.

- Data gaps remain a key challenge for climate scenario analysis. Respondents cited limitations in both data availability and consistency/comparability. Data accessibility across jurisdictions is also an important consideration for a proper analysis of cross-border transmission of climate shocks.

- While authorities are taking steps to bridge data gaps, such as working more closely with financial institutions (especially with bottom-up approaches), engaging with third-party data providers, or doing further modelling, they also welcome initiatives at the global level aiming at bridging gaps, especially those of a cross-border nature.

- There is a need for greater cross-border cooperation, especially due to the early stage of the climate scenario analysis work across jurisdictions. The exchange of experiences in the development of new modelling methods and in the application of climate scenarios will be crucial in facilitating improvements. More precisely, the sharing of knowledge and practices, in addition to the issuance of robust guidelines on how to conduct climate scenario analysis, would decisively support capacity building efforts. In this regard, respondents emphasised the role that international organisations or fora, such as the NGFS, the FSB or the International Monetary Fund (IMF), should play in this area.

1. Introduction

Climate-related events and their associated risks are subject to significant uncertainty in terms of their timing, frequency, or severity. At the same time, forward-looking assessment approaches are crucial to adequately account for the unprecedented nature of climate change. Against this backdrop, scenario analysis is a critical tool for assessing the potential implications of climate change on economies and financial systems.

Work under the FSB's July 2021 Roadmap for Addressing Climate-Related Financial Risks[3] on systematically assessing and better understanding climate-related financial vulnerabilities continues to progress along three strands – ongoing monitoring, development of conceptual frameworks, and further development of scenario analysis.[4] Starting in 2018, the NGFS has been working toward the development of macro-financial climate scenarios (NGFS Scenarios) to enable scenario based risk analysis of climate-change-related developments in the financial sector. Experience with developing and applying climate scenario analysis continues to evolve. The NGFS in 2021 released a second vintage of reference scenarios for central banks and supervisors. In October 2021, the NGFS published its "Scenarios in Action" progress report[5] examining 31 NGFS members' experiences in conducting climate scenario analysis. The report highlighted the diversity of design choices and analytical approaches adopted by members, alongside key technical challenges and how those members addressed them. The report also observed that since climate scenario analysis remained a relatively new field of activity for central banks and supervisors, further improvements would likely take place in the years to come.

The NGFS is committed to strengthening its efforts to improve the resilience of the financial system to climate-related and environmental risks. In September 2022, a third iteration of the NGFS Scenarios was released,[6] including enhancements in the modelling of acute and chronic physical risks, as well as more detailed sectoral granularity. The scenarios were accompanied by two technical documents: a paper[7] assessing the sensitivity of the results to assumptions related to fiscal and monetary policy and a guide[8] providing central banks and prudential supervisory authorities with a practical framework for assessing acute physical risks.[9] The NGFS will continue to enhance its climate scenarios, in particular by improving physical risk modelling, adding more sectoral and geographical granularity, and developing short-term scenarios. Regarding data gaps, the NGFS published its Final report in July 2022,[10] alongside its directory of climate-related metrics and data sources.[11]

This FSB-NGFS joint report to the 2022 G20 meeting builds on the NGFS "Scenarios in Action" progress report by providing a synthesis of climate scenario analysis exercises undertaken by

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3 FSB (2021), *FSB Roadmap for Addressing Climate-related Financial risks*, July

4 FSB (2022), *FSB Roadmap For Addressing Financial Risks from Climate Change: 2022 Progress Report*, July.

5 NGFS (2021), *Scenarios in Action: a progress report on global supervisory and central bank climate scenario exercises*, October

6 NGFS (2022) *NGFS Climate Scenarios for central banks and supervisors*, September.

7 NGFS (2022), *Climate Scenarios Sensitivity Analysis to Macroeconomic Policy Assumptions*, September .

8 NGFS (2022), *Physical Climate Risk Assessment: Practical Lessons for the Development of Climate Scenarios with Extreme Weather Events from Emerging Markets and Developing Economies*, September.

9 The NGFS also released a note exploring the effects of the current energy crisis stemming from the war in Ukraine, and how they relate to the latest iteration of the NGFS scenarios.

10 NGFS (2022), *Final report on bridging data gaps*, July.

11 Available at *The NGFS Directory (masdkp.io)* .

financial authorities, as well as an attempt to evaluate the implications of climate-change-related developments for the financial system as depicted in climate scenarios. In doing so, it draws lessons for effective climate scenario analysis and aims to contribute to capacity building by advancing a common understanding of the impact of climate change on financial stability, putting together a global perspective from various national and regional climate scenario analysis exercises.

Further development of the use of climate scenario analysis will help inform supervisory and regulatory actions. Over time, the use of these analytical tools will facilitate the identification and assessment of risk exposures and potential impacts of physical and transition risks on financial institutions and the wider financial system, and allow a forward-looking and flexible approach through examining different scenarios. Deepening the use of these tools and expanding their scope will contribute to identifying the risks arising from climate change and understanding the financial impacts. For financial stability purposes, further development of scenario analysis and stress tests will be needed, to develop a truly system-wide approach that covers key financial sectors, interdependencies between risks and systemic risk aspects such as indirect exposures, risk transfers, spillovers and feedback loops, including with the real economy. This report represents a contribution towards this goal.

The report is structured as follows. Section 2 provides an overview of scenarios, models, data and metrics used by FSB and NGFS member authorities in their climate scenario analysis exercises. Section 3 presents a synthesis of relevant findings and of the comparability of jurisdictions' scenarios and outputs. Section 4 describes the main identified data gaps and approaches for addressing them, while Section 5 concludes.

2. Overview of climate scenario analyses

2.1. General overview of the exercises

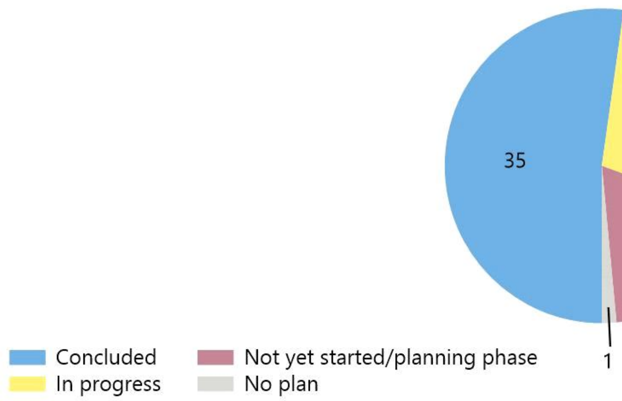
The findings in this report are based on responses to a survey (Annex 1) of 53 institutions from 36 jurisdictions[12] across the FSB and NGFS membership that have completed, are currently conducting, or are planning to conduct a climate scenario analysis exercise (Annex 2). Information on a total of 67 climate scenario analysis exercises was obtained. At the time of the survey, 35 exercises were completed, 19 exercises were in progress, while 12 exercises were in the planning stage (Graph 1).[13] It is worth noting the increase in the number of exercises completed in the past year (35 versus the 4 reported in the NGFS earlier report), which gives an indication of the collective progress and extensive efforts across jurisdictions in undertaking climate scenario analysis.

[12] Beyond financial authorities from the 36 jurisdictions represented, there were also 3 respondents from other international organisations. Please see Annex 2 for the full list of climate scenario analysis exercises covered in this report. Please note that Annex 2 includes a total of 69 exercises, including those of two jurisdictions that have submitted information at a later stage by means different from the response to the questionnaire. These are not reflected in the numbers underlying the charts in the report.

[13] In the previous NGFS report, 4 exercises were completed, 19 exercises were in progress, while 6 exercises were in the planning stage.

The rest of this section focuses on the scenarios, models, data and metrics used by respondents in their exercises. Given the differences in the objectives of participants in conducting climate scenario analysis, as well as the nascent stage of work in this area, respondents have adopted a variety of exploratory design choices in formulating their exercises.

Current status of climate scenario analysis exercises examined **Graph 1**



Source: FSB-NGFS survey

2.2. Main features of climate scenario analyses

2.2.1. Purpose and scope of scenario analysis exercises

For most survey respondents, climate scenario analysis serves more than one objective (Graph 2). As this area remains relatively new for financial authorities, most of the exercises are aimed at raising awareness and developing capabilities and capacity in climate scenario analysis. In addition, the majority of respondents aim to assess how climate risk could impact individual financial institutions and the financial system as a whole, as well as identify vulnerabilities in the non-financial corporate sector. A small number of respondents indicated that their exercises could also help in the formulation of climate-related government policies, such as national emissions reduction strategies and regional adaptation measures.[14]

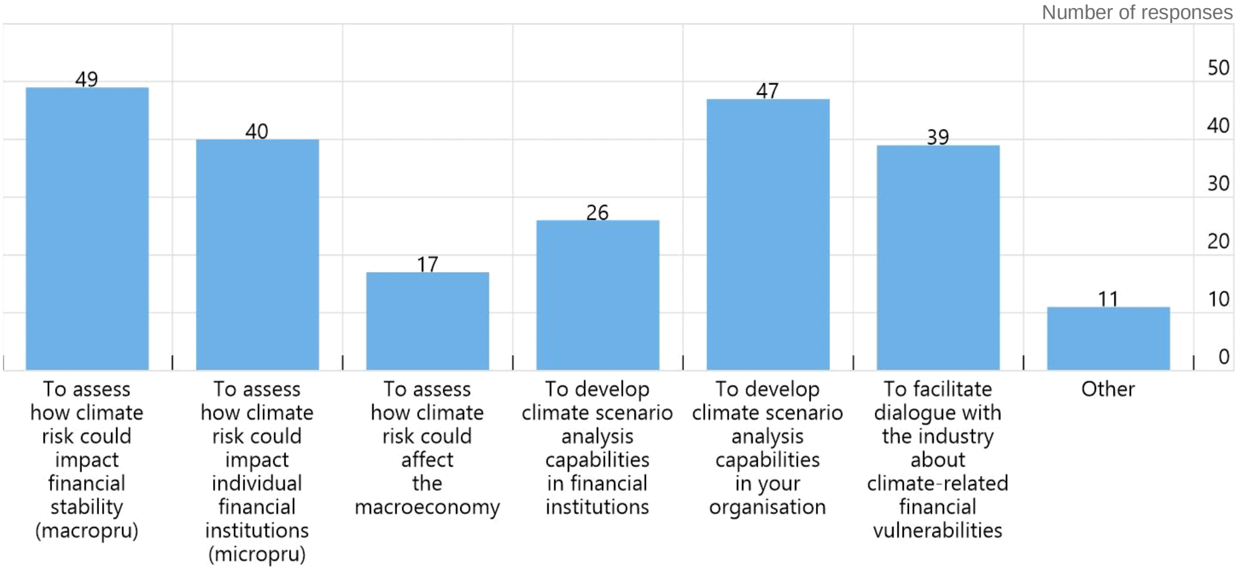
Respondents' exercises also covered a wide range of financial and non-financial sectors in their analysis. In terms of financial sector coverage, most exercises included the banking sector, about one-third of exercises included the insurance sector, and a few included investment funds and pension funds. Meanwhile, in terms of real sector coverage, a majority of exercises included non-financial corporates, about half included households, while about one-third included governmental or public authorities.

In terms of the granularity of the analysis, more than half of the exercises featured involve analysis at either a sectoral or counterparty level. The number of sectors represented varies greatly depending on the exercise and is determined by factors such as the modelling framework used. Some jurisdictions focused their analysis on a subset of sectors; for instance, the Bank of Canada and the Office of the Superintendent of Financial Institutions (OSFI) considered the ten

[14] For example, Bank of Greece and Bank of Iceland.

most emissions-intensive sectors in Canada. Meanwhile, many of the counterparty-level analyses relied on assessments conducted by financial institutions. For example, the exercises by the Bank of England, the Bank of Japan / Japan Financial Services Agency and the Hong Kong Monetary Authority (HKMA) requested participating financial institutions to factor individual firms' risk profiles into their assessments, for instance by leveraging information obtained through counterparty engagement.

Main purpose of climate scenario analysis exercises **Graph 2**



Source: FSB-NGFS survey

2.2.2. Overview of the scenarios used

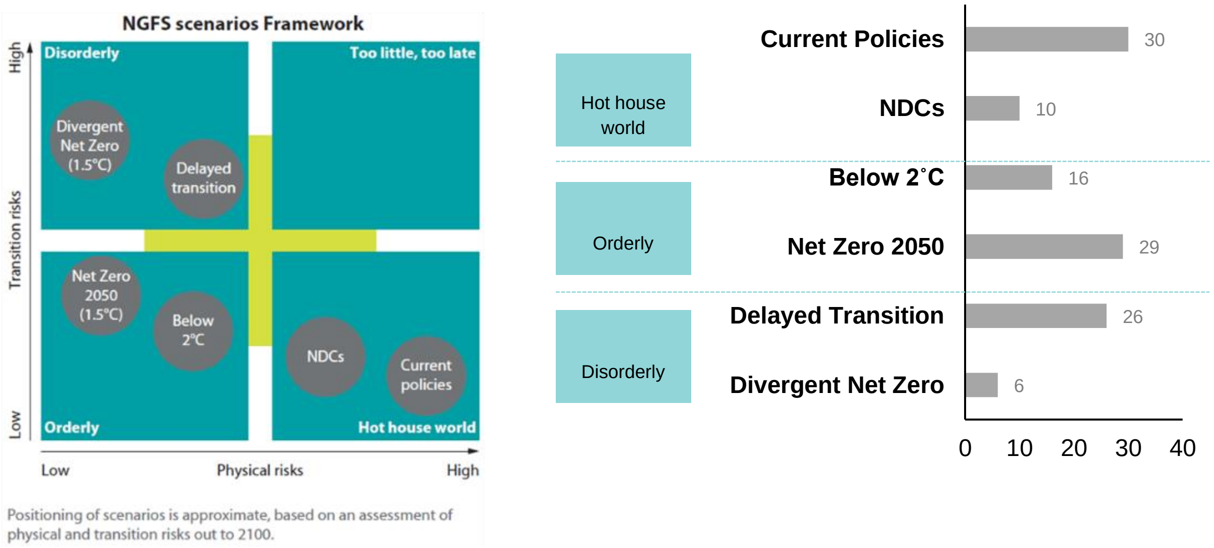
The majority of the climate scenario analysis exercises featured in this report have used, or plan to use, the NGFS Scenarios. Designed in partnership with an expert group of climate scientists and economists, the NGFS Scenarios provide a common reference point for understanding how climate change, climate policy and technological trends could evolve in the future.[15]

Of the six NGFS scenarios shown in Graph 3, the most commonly used are Current Policies, Net Zero 2050, and Delayed Transition. These scenarios explore three quadrants of the NGFS scenarios framework, namely Hot house world, Orderly transition and Disorderly transition. The Current Policies scenario is the most adverse in terms of physical risks, while the Net Zero 2050 scenario reflects a relatively smooth transition to net zero emissions by 2050. In the Delayed Transition scenario, emissions are only reduced after 2030, and hence require more rapid adjustments to limit the most severe physical impacts. A good number of respondents (17 exercises)[16] used all three of these NGFS scenarios, to examine potential outcomes under varying levels of physical and transition risks.

[15] More information on the Scenarios can be found at the NGFS Scenarios Portal (https://www.ngfs.net/ngfs-scenarios-portal).

[16] For more details see the exercises by Colombia, EBRD, ECB (exercises 1-3), ESMA, Germany (exercises 2-4), BoJ and JFSA, Mauritius, Portugal, Singapore, Switzerland, UK, IADB and OCC in Annex 2.

Use of NGFS Scenarios in survey respondents' exercises — Graph 3



Source: NGFS

Of the exercises that used the NGFS Scenarios, more than half (22 exercises across 17 jurisdictions) involved downscaling or adjusting the scenarios for jurisdiction-specific circumstances.[17] Such efforts included the generation of additional scenario parameters, both in terms of enhancing the granularity of NGFS' scenario outputs (e.g. in terms of sectoral, geographical or temporal coverage) as well as estimating new parameters unavailable in the NGFS Scenarios (e.g. financial variables such as corporate bond yields).

A few jurisdictions also opted to use scenarios other than those by the NGFS for their exercises. One possible reason is to cover jurisdiction-specific climate risk drivers (e.g. acute physical risk) that are better accounted for under localised alternative scenarios. For example, the Bank of Finland used data provided by the Finnish Environment Agency on flood-risk areas to assess the impact of acute physical risk on the credit risk faced by banks. The HKMA adopted the projection of climate patterns by the Hong Kong Observatory for banks to estimate the impact of physical risk. To evaluate the effects of chronic physical risk, Banco de la República (Colombia) plans to use a scenario from the Colombian Institute of Hydrology, Meteorology and Environmental Studies that projects changes in precipitation until 2100.

17 For more details see the exercises by Australia (exercises 1-2), China, Denmark (exercise 2), ECB (exercises 1-3), ESMA, France, Georgia, Germany (exercise 2), Iceland, Italy (exercise 2), BoJ and JFSA, Korea, Malaysia, Mauritius, Singapore, UK, AMRO in Annex 2.

2.2.3. Climate-related risks and time horizons considered in scenario analysis exercises

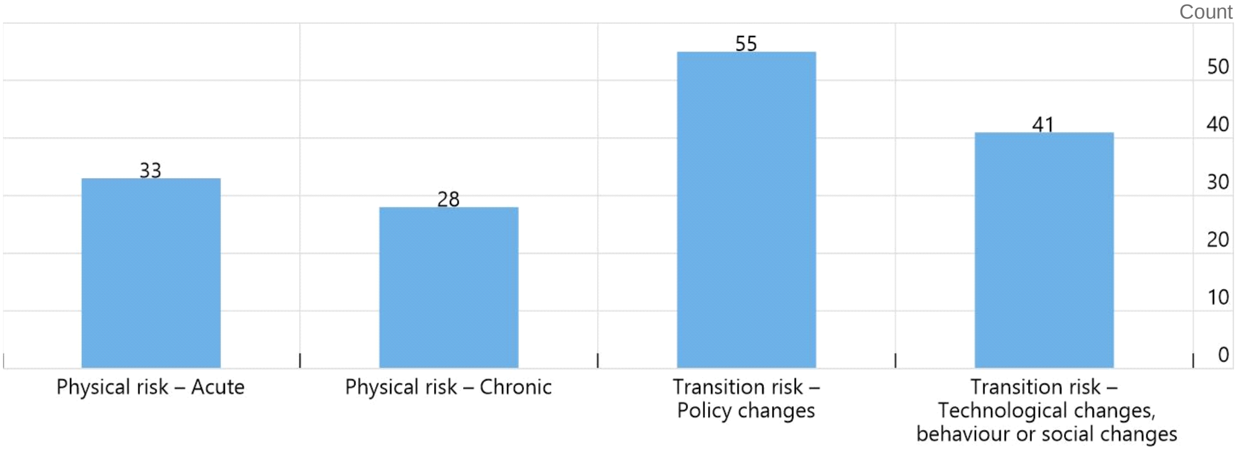
In terms of the coverage of climate-related risks, almost 90% of the exercises explored the implications of transition risk, and about two-thirds explored physical risk (Graph 4).[18,19]

In terms of transition risk, in the literature, many studies use carbon prices or carbon taxes as a key variable that drives the transition. This is also performed in the NGFS Scenarios through the inclusion of a shadow carbon price in the modelling framework.[20]

In terms of physical risk, around half of the exercises explored acute physical risk, such as the impact of floods and droughts, prioritising them based on potential higher materiality. That said, some respondents also indicated that methodological or data gaps (e.g. geolocation data, insufficient information on historical damage estimates) made such physical risk assessments challenging (See Section 3, focussing on data gaps).

Many of the exercises featured in this report cover more than one of the various physical and transition risk drivers presented in this chart.

Climate risks considered in the exercises **Graph 4**



Source: FSB-NGFS survey

The scenario horizon of exercises varied widely across respondents and was dependent on factors such as the nature of climate-related risks considered. Shorter scenario horizons were often adopted for exercises featuring acute physical risks or transition risks arising from policy changes. On the other hand, longer scenario horizons were more suited for assessing chronic physical risks, or medium-term structural shifts arising from a climate transition. Some

18 Some respondents conducted distinct exercises to separately assess the implications of physical and transition risk. Please refer to Annex 2 for more details.

19 The physical risk driver most commonly cited is floods and other common drivers mentioned are drought/heat stress, rising temperatures, rising sea levels, cyclones/typhoons/hurricanes, wildfires. That said, it is unclear whether the selection of these physical risk drivers reflects whether they are viewed as most pertinent from a financial stability perspective by authorities. The choice may also reflect other factors such as the relative availability of data and methodologies.

20 In the NGFS Scenarios, carbon prices reflect the policy ambition that is specified by the scenario (e.g. Net Zero by 2050) and serve as a measure of overall policy intensity, and are sensitive to factors such as the level of ambition to mitigate climate change, the timing of policy implementation, the distribution of policy measures across sectors and regions, and assumptions relating to technology (e.g. the availability and viability of carbon dioxide removal).

respondents noted that shorter time horizons would allow them to leverage conventional stress testing models and frameworks for their exercises. For some jurisdictions, the choice of time horizon was also influenced by timelines for climate-related commitments (e.g. 2050 net zero targets).

2.3. Models, data approaches and challenges

While considerable progress has been made in the area of climate risk assessment, survey respondents note that further work has to be undertaken to refine modelling assumptions, enhance methodologies, and address data gaps. This subsection briefly covers the approaches and challenges reported in relation to modelling and data.

2.3.1. Overview of the models used

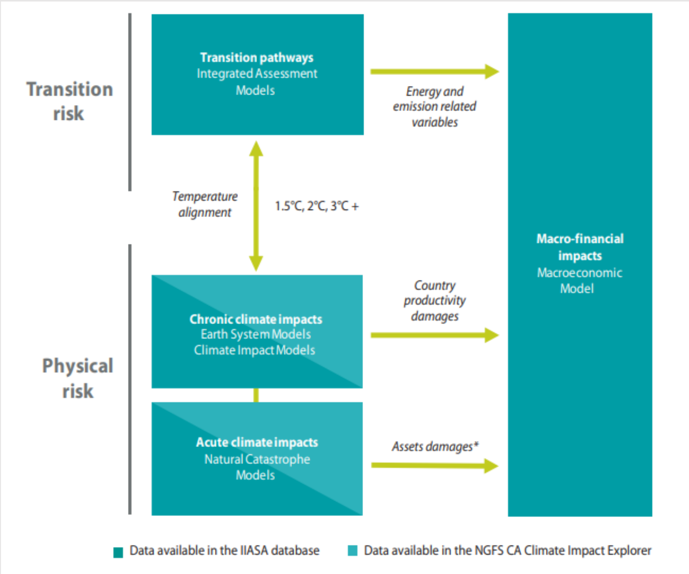
Around one-third of the exercises[21] use macroeconomic variables from the macroeconomic model NiGEM, as these variables were provided in the NGFS scenarios. More information about NiGEM and the NGFS' suite of models approach can be found in Box 1.

[21] EBRD, ECB (exercises 1-3), France, Germany (exercises 2 & 6), Italy (exercise 2), BoJ and JFSA, Malaysia, Netherlands (exercise 1 & 3), Portugal, Singapore, South Africa (exercise 2), UK, US (exercises 2, 4 & 6).

Box 1: NGFS suite of models approach

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, energy prices or carbon prices. NiGEM then translates these outputs into a large set of macroeconomic and financial variables.[22] Users are then able to incorporate and adapt the outputs from the IAMs and NiGEM as inputs into their climate scenario analysis exercises.

NGFS suite of models approach **Graph A1**



Source: NGFS, 2022

To complement their use of the NGFS scenarios, some respondents conducted further modelling to meet the specific design needs of their exercises. For example, as the NiGEM model does not currently include Iceland, the Central Bank of Iceland plans to use their own macroeconomic models to adapt the NGFS scenarios, taking reference from NGFS parameters for neighbouring economies and major trading partners. Meanwhile, the Bank of England incorporated an additional short-term macroeconomic disruption on top of the NGFS Delayed Transition scenario. Some respondents also raised the importance of complementing the NiGEM parameters in the NGFS scenarios with additional physical risk impacts that are relevant to their economies. For instance, the Monetary Authority of Singapore examined the macroeconomic implications of acute physical risk by simulating the effect of a severe flood, taking reference from damages associated with past flooding events in the South-East Asia region.

For respondents who did not use the NGFS scenarios, a few used alternative macroeconomic models, including in-house models. For example, the Bank of Canada used the MIT-EPPA[23] computable general equilibrium model alongside two other macroeconomic models, to examine

[22] NiGEM is a multi-region macro-econometric model that is widely used in the financial community for the forecasting of macroeconomic variables, such as GDP, unemployment, and inflation. This model includes endogenous policy responses from both fiscal and monetary authorities for each region and includes some macro-financial variables (e.g. long-term interest rates).

[23] Emissions Prediction and Policy Analysis model.

the impact of transition risk on the Canadian, United States, and global economies: their scenario narratives and paths for global emissions are generally aligned with those developed by the NGFS. Meanwhile, Banco de España used their in-house CATS[24] general equilibrium model to get a detailed sectoral breakdown for parameters of interest.

In order to generate granular data (e.g. sectoral data), survey respondents often linked different models together using selected common model parameters. For instance, the Bank of Korea used parameters such as carbon prices, sectoral emissions and carbon sequestration to link the NGFS IAMs with an in-house microeconomic model to generate sectoral estimates under the NGFS Scenarios. Meanwhile, the Bank of England's calibration of sectoral Gross Value Added pathways was informed by academic publications and additional datasets (e.g. sectoral embodied emissions). The Bank of Canada / OSFI conducted model enhancement work to enable its ToTEM III[25] macroeconomic model to take in carbon price pathways under various transition scenarios.

Around one third of respondents did not employ a macroeconomic model in their scenario analysis exercise. In many cases, this is because the scenarios chosen did not require a macroeconomic overlay. For example, the Malta Financial Services Authority aimed to evaluate transition risk following the introduction of a hypothetical carbon tax that could arise from the revaluation of asset components held by banks, insurance undertakings and investment funds licensed in Malta. To study climate vulnerabilities related to real estate, De Nederlandsche Bank sourced inputs specific to this type of exposure.

2.3.2. Top-down and bottom-up approaches

Around half of the scenario analyses conducted by authorities were based on a top-down approach (Graph 5). A top-down exercise[26] allows the authority to cover a large sample of institutions, including many smaller players which might not have the expertise to perform bottom-up assessments. Overall, a top-down approach increases the consistency and comparability of the results, while minimising the regulatory burden on financial institutions.

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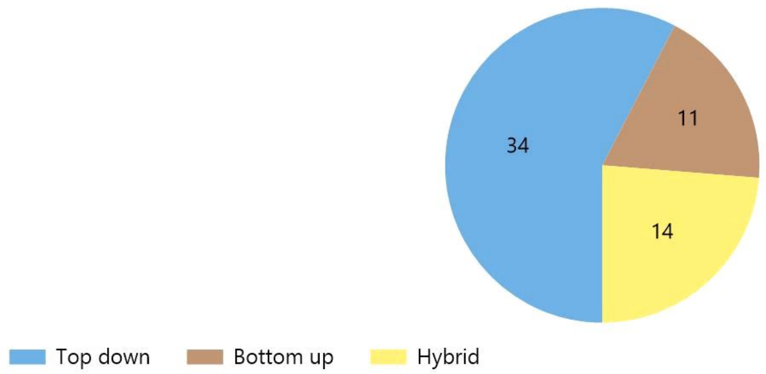
24 Carbon Tax Sectoral model.

25 Terms-of-Trade Economic Model.

26 Top-down exercises are desktop, model-based exercises run in-house by authorities. Bottom-up exercises are based on financial institutions submitting their own assessment of the implications of the scenarios.

Top-down vs bottom-up approach **Graph 5**



Source: FSB-NGFS survey

On the other hand, bottom-up approaches were often used to understand how individual institutions would respond to the climate scenarios, and to evaluate and develop their climate risk assessment capabilities. Given the nascent field of scenario analysis and the increasing need to account for climate risks, developing financial sector capabilities in this area is an important outcome of these exercises.

In addition, many bottom-up approaches involved financial institutions directly engaging their counterparties to better assess climate-related counterparty risk. This generated important data on firm-level exposures that regulators and financial institutions did not previously have, and hence facilitated new analyses to better understand the risks to financial firms as well as the overall financial system. As financial institutions gather better data, a more widespread use of bottom-up approaches could be expected over time.

Some exercises adopted a hybrid approach, combining elements of both top-down and bottom-up approaches. For example, the Swiss National Bank (SNB) and the Swiss Financial Market Supervisory Authority (FINMA) conducted a top-down assessment to estimate sectoral shocks and asset valuations under its climate scenarios, and complemented it with bottom-up assessments reported by participating banks.

2.3.3. Static and dynamic balance sheets

One key assumption required for scenario analysis exercises relates to the choice of a static or a dynamic balance sheet. A static balance sheet assumption generally assumes that financial institutions' balance sheets remain constant over the scenario horizon in terms of size and composition and hence explores the vulnerability of today's business model to future shocks. Meanwhile, a dynamic balance sheet assumption can incorporate future business expectations, and allows for management actions to be undertaken by financial institutions in response to events over the scenario horizon.

Approximately 80% of exercises adopted a static balance sheet approach. Many respondents faced methodological and data limitations when considering dynamic balance sheet approaches; this included the lack of internal resources and expertise, both in terms of modelling as well as validating shifts in the composition of financial institutions' balance sheets. A static balance sheet approach is useful for an initial assessment of the vulnerability of financial institutions' current business models to climate risk and may also provide a more conservative assessment of potential risks, since some mitigating actions (under a dynamic approach) may not be feasible in practice.

Around 20% of exercises adopted a dynamic or a hybrid balance sheet approach. This was mainly motivated by the consideration of conducting a more realistic climate scenario analysis exercise, especially over longer time horizons. For instance, the ACPR / Banque de France used a hybrid approach, involving a static balance sheet assumption for the first five years (2020-2025) and dynamic for the rest of the scenario horizon (2025-2050). Meanwhile, the Australian Prudential Regulation Authority adopted both a static and a “proportional” balance sheet approach. Similar to the dynamic balance sheet approach, APRA’s “proportional” approach allowed banks to adjust their exposure to different sectors of the economy, but with these adjustments constrained such that they remain broadly proportional to changes in the structure of the economy (in terms of overall economic growth and sectoral Gross Value Added) to the year 2050.[27]

2.3.4. Modelling approaches for capturing systemic risk

While many respondents included the assessment of financial stability as an explicit objective of their exercises, most were only able to account for first-order effects given data and methodological limitations, as well as time constraints. Many respondents found it challenging to develop a detailed analysis of second-order effects given the complexity and uncertainty associated with modelling these feedback loops and interactions and indicated that they would consider incorporating such effects in more detail in future exercises. In this regard, the Bank of Canada and OSFI highlighted the importance of greater collaboration across financial authorities to develop a deeper understanding of systemic climate risk transmission channels, as this would help to better focus future data collection and modelling initiatives.

Nevertheless, some respondents did undertake exploratory work relating to second-order effects as part of their exercises. For instance, as part of its Climate Biennial Exploratory Scenario, the Bank of England asked financial institutions to assume that their competitors were taking similar actions to them, and to explain the (second-order) impact on their responses to the scenarios. Meanwhile, the European Central Bank and the European Systemic Risk Board applied a network analysis approach to assess contagion channels arising from interconnectedness across financial and real economy sectors (see Box 2). In particular, the ECB/ESRB modelled both the effects of the initial exogenous shock (under the NGFS scenarios) and the endogenous system-wide amplification on the different sectors.

Some respondents have also used metrics to assess the potential propagation of systemic impacts arising from climate risk. For instance, the Bank of Canada and OSFI is considering how common exposures and financial interlinkages between financial institutions could amplify climate-related shocks. Meanwhile, the Polish Financial Supervision Authority considered how

[27] The banks generally considered the proportional approach to be more realistic compared to the static approach given the longer time horizon of the scenario. However, the banks noted that both proportional and static approaches were challenging given the complicated assumptions required for a 30-year time horizon.

a reduction in re-insurance supply could affect insurers that offer insurance coverage to firms in carbon-intensive economic sectors.

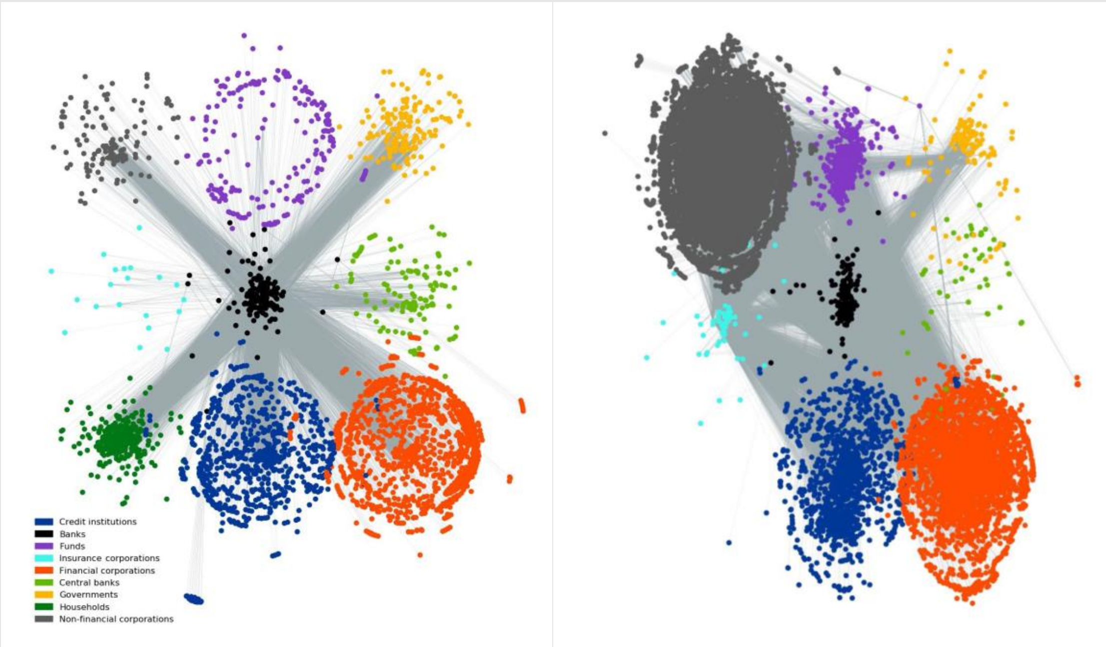
Box 2: ECB/ESRB's approach for modelling second-order effects of climate-related shocks[28]

To capture interconnectedness and amplification effects across the financial system arising from climate-related shocks, ECB and ESRB used granular supervisory and proprietary datasets to consider interlinkages between financial institutions (i.e. credit institutions, banks, funds, insurers, financial corporations), central banks, governments, households and non-financial corporations. The diagram below shows the loans and security holdings exposure networks constructed by ECB and ESRB.

Loans and security holdings exposure networks in the euro area **Graph B1**

An edge represents a loan from a bank to another entity in each sector

An edge shows that a bank/fund/insurer holds assets issued by another entity in a given sector



Source: ECB/ESRB authors' calculations.

In terms of the initial shock, the financial system is impacted by the NGFS scenarios via an increase in credit risk for banks' corporate loan portfolios and asset revaluations of tradable securities held by insurers and investment funds. Second-round effects then propagate throughout the network, including through market losses and corporate defaults.

2.3.5. Overview of the data used

Given the cross-cutting nature of climate change, respondents employed a wide range of non-financial and financial data in their scenario analysis exercises.

In terms of non-financial data, the majority of respondents used estimates of greenhouse gas (GHG) emissions for their analysis of transition risk. That said, given data availability issues concerning Scope 3 emissions, many respondents only used Scope 1 and 2 emissions data in

28 ECB and ESRB (2022). *The macroprudential challenge of climate change.*

their exercises.[29] Some respondents also used other sector-specific and firm-specific information to supplement their analysis. For instance, the European Central Bank used information relating to energy performance certificates for properties, while the Bank of England used car price data for internal combustion engine vehicles, hybrid vehicles and electric vehicles, as well as statistics relating to the composition of new vehicle sales and new vehicles on the road. These data were used by participating financial institutions to inform their bottom-up financial projections (e.g. for corporate exposures secured by real estate, or retail exposures for car loans). Banca d'Italia considered granular firm-level data in its analysis, including on firms' balance sheets, number of employees and sectoral energy demand to estimate the firms' energy mix with the purpose of assessing their financial vulnerability.[30]

Survey respondents also used projections of macroeconomic variables (e.g. GDP growth) as well as energy variables (e.g. energy demand, energy price and energy mix) to inform their analysis of sectors and counterparties. Many tapped on the NGFS climate scenarios to obtain such projections, while some of them used data from other sources (e.g. national authorities).

For the analysis of physical risk, some exercises used forward-looking risk indicators for physical hazards. Around one-third of exercises used risk indicators for flooding, while a few exercises also used risk indicators for drought, wildfire, hurricanes/typhoons, or sea level rise. Data used for physical risk assessments tended to be at a more aggregated local or regional level. For instance, the European Central Bank used estimated damage rates for commercial and residential buildings for different flood depth levels, obtained from the European Commission's Joint Research Centre, as well as estimated impacts of heat stress on labour productivity as estimated by the International Labour Organization. Meanwhile, Banque de France used forward-looking indicators for health risk (e.g. mortality rates) due to vector-borne diseases and air pollution at a national and regional level. The South Africa Reserve Bank used rainfall data from its national weather service to design a historically consistent drought scenario.

As for financial data, more than half of the exercises used banking asset exposures by sector of borrower/counterparty, while about one-quarter used the amount outstanding of residential mortgages. In addition to the above exposures data, respondents also used a range of other information such as the extent of insurance coverage, projected dividend pathways and IMF World Economic Outlook forecasts. In the case of physical risk, around one-quarter of exercises examined banks' exposures by the geographical asset location of their borrowers or counterparties. For the insurance sector, data relating to the location, properties, and policy terms and conditions for insurance underwriting contracts were used in the analysis of insurers' liabilities.

Bridging data gaps is essential to increase the robustness and accuracy of climate scenario analysis exercises, and most respondents have been taking steps in this direction (see section 4.1).

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29 Scope 1 refers to all direct GHG emissions. Scope 2 refers to indirect GHG emissions from consumption of purchased electricity, heat or steam. Scope 3 refers to other indirect emissions not covered in Scope 2 that occur in the value chain of the reporting company, including both upstream and downstream emissions. Scope 3 emissions could include: the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities (e.g. transmission and distribution losses), outsourced activities, and waste disposal.

30 In its second ongoing exercise, Banca d'Italia is also employing data on non-financial corporations' transition plans to estimate the impact of alternative scenarios on the value of its own (non-monetary-policy) portfolios.

2.4. Metrics developed to assess climate-related risks

As part of their climate scenario analysis exercises, many financial authorities and financial institutions have developed or adapted metrics to assess climate-related risks (see Annex 3, for a list of data and metrics). These metrics have been used for a number of climate-related assessments, and broadly fall into two categories, namely exposure metrics and risk metrics. While work in developing such metrics remains at an early stage, this sub-section provides a broad overview of exploratory approaches adopted by respondents in this area.

2.4.1. Overview of exposure metrics

Exposure metrics often combine financial exposures with climate-related considerations or variables. This includes financial institutions' exposures to firms/sectors or regions vulnerable to climate-related shocks, as well as measurements of the alignment of a given portfolio with specific climate goals.

For transition risk, one example is the ECB's use of two climate-related exposure metrics, namely the emission-to-allowance gap and the loan-weighted emission intensity. The emission-to-allowance gap captures the difference between firm-level emissions and free allowances in the European Union Emissions Trading System (EU ETS), and serves as an indication of firms' exposure to potential changes in carbon prices. Meanwhile, the loan-weighted emission intensity measures the carbon intensity of bank lending to economic sectors, and serves as an indication of potential vulnerabilities arising from stresses in these sectors.

For physical risk, the exposure metrics most frequently utilized were in relation to flooding, primarily due to the prevalence of banks' mortgage exposures to properties in locations vulnerable to flooding. Beyond bank exposures, a few exercises also considered insurers' assets exposures and insurance liabilities associated with such physical shocks.

2.4.2. Overview of risk metrics

Risk metrics go beyond exposure amounts and incorporate additional considerations on the economic and financial impacts of climate-related risks. Such metrics are typically estimated through the use of forward-looking climate scenarios, and provide an indication of potential losses or damages.

Given that the majority of scenario analysis exercises focused on either credit or market risk, the most common risk metrics used by respondents pertained to credit quality and changes in market valuations. Examples of such metrics include the probability of default (PD) or loss given default (LGD) for credit exposures to given geographical regions or sectors, as well as losses on investment portfolios.

These risk metrics can also be further customised to capture more holistically the impact of physical or transition risks. For instance, the ECB developed two intensity metrics, namely transition-to-credit risk intensity (TCI) and physical-to-credit risk intensity (PCI), to assess the climate-related vulnerabilities of euro area banks' loan exposures.[31] Both metrics were constructed partly using banks' loan exposures and borrower-level PDs; the TCI combines them with borrower-level emissions data, while the PCI combines them with borrower-level physical risk scores. By blending conventional financial data with climate-specific metrics, the ECB was able to better account for the interaction of climate risks with existing financial conditions.

2.4.3. Considerations relevant for identifying and designing metrics

Data availability and comparability are the primary considerations of most financial authorities in choosing relevant metrics at this juncture. Given existing climate-related data gaps, many respondents preferred to use readily available data and leverage on existing modelling frameworks to generate metrics, so as to simplify the analysis and facilitate easier interpretation of results. Many respondents opted to focus primarily on metrics used in conventional (i.e. not climate-related) stress tests or scenario analyses as a start, especially given the exploratory nature of their climate scenario analysis exercises.

Other common considerations among financial authorities are relevance and materiality. Many respondents cited the importance of choosing metrics that reflect the most material climate-related impacts in their own jurisdiction's context. Others, like the Japan Financial Services Agency, suggested that metrics relating to transition plans, such as companies' targets and the progress made in achieving them, could be an important input for risk assessments as they provide a forward looking perspective and could cast some light into the execution of a transformational strategy.

As the use of metrics remains at an early and exploratory stage, there is much room for new metrics to be developed, especially as data gaps are addressed over time. To support the development of new metrics, it is important for authorities and regulated firms to collectively address data gaps, as more consistent, granular and reliable data (e.g. regulated firms' disclosures relating to emission reduction targets or net zero commitments/plans, corporate counterparties' physical asset locations) will in turn improve the quality of forward-looking risk metrics.

3. Relevant findings of scenario analyses

3.1. Vulnerabilities to climate change and the transition

3.1.1. Exposure to climate-related risks

The key outcome of many of these exercises is a first assessment of the climate-related exposures and vulnerabilities of a jurisdiction's financial institutions or system. As discussed previously in the report, different exposure metrics have been used (see Annex 3). For physical risks, the exposure is mostly determined by the total amount or share of assets or collaterals in specific locations identified at risk. Similarly, exposure to transition risks is measured mainly by

[31] ECB/ESRB (2022). *The macroprudential challenge of climate change*.

the amount or share of assets or collaterals exposed to greenhouse gas intensive (or dependent) economies, sectors or firms.

The diversity in design and scope of the exercises leads to different outcomes in terms of exposure and vulnerabilities detected (Table 1), making it difficult to disentangle the effects of differences in approaches from the effects of differences in exposures. Given the recognised uncertainties and limitations in methodologies, financial authorities' survey responses often pointed to qualitative results from the climate scenario analysis undertaken, rather than quantitative estimates of exposure.

Regarding physical risks, estimates range from "limited" to "high". These jurisdictions' assessments of the magnitude of the losses are difficult to compare directly given the differences in the analysis carried out and the limited range of climate hazards considered (often on a stand-alone basis). In its assessment of flooding risks, the Bank of Finland estimated that the value of housing loans for dwellings located in areas at risk would amount to about 1.3% of all corporate loans, concluding that this would not be "severe enough to become a major threat for financial stability". Using a climate hazard index and property data, the Reserve Bank of Australia found that 1.5% of properties could see house prices fall by 10% or more by 2050, though some properties could see very large falls and risks are concentrated in small geographical areas. Other responses point however to material exposures to physical risks, such as "sizeable loan exposures" in Norway or "high share of exposures" in Denmark. For instance, the share of the Norwegian real estate situated in the "200-year zone" – i.e. the zone where storm surge statistically occur once every 200 years – is expected to increase from 1.8% today to approximately 5.5% with the expected rise in the sea level by 2090. In the EU, natural hazards could impact up to 30% of Euro area bank corporate exposures (ECB, 2021a).

Similarly for transition risks, outcomes on exposure vary across exercises. The People's Bank of China observed a relatively low proportion of loans to "industries that would face a weakened capacity to service debts under the stress scenarios"; while other jurisdictions find "moderate" to "significant" exposures to transition risks. Focusing on large banks, the Bank of Norway estimated that 15% of loans are issued to firms that account for 80% of GHG emissions, with more precisely 20% of these loans to transition-sensitive industries. Similarly, the Deutsche Bundesbank concluded that the share of loans issued to transition-sensitive sectors would amount to 19%, with stocks and non-financial bonds reaching up to 33% and 45%, respectively, of banks' securities portfolios.[32] Banque de France/ACPR estimated that around 10% of banks' credit books were exposed, a proportion that is estimated not to exceed 3.5% in Spain (and only for the most significant institutions with international exposure). At the EU level, exposure to high-emitting firms amounts to 14% of Euro area banking sector balance sheets, with 25 banks comprising 70% of these credit exposures (ECB, 2021a).

Heterogeneities in exposures to climate risks were also observed for individual banks, due to different concentrations to transition-sensitive industries. This is the case for Colombian banks, which had quite different exposures, ranging from 1% and 26% of their credit portfolio. Similarly, Korea found that exposure and impacts could differ significantly across banks, with specialised banks more impacted. However, these exercises highlight that impacts in certain sectors and

32 Note some differences across countries as to the classification of transition-sensitive sectors but all refer to or account for GHG emission intensity by sector.

geographical areas can be considerable. In the case of France, the cost of risk for loans to the seven most sensitive sectors could triple. A few other exercises find “meaningful” exposures of loans and investment portfolios to climate-policy-relevant sectors (such as the New York State Department of Financial Services).

Table 1 - Examples of estimates on financial exposure to climate risks (by type of risk)

Transition risks	**Bank of Norway**:
	• Banks: 20% of loans to transition-sensitive sectors.
	Deutsche Bundesbank:
	• Banks: 19% of loans to transition-sensitive sectors; 33% of stocks to transition-sensitive sectors; 45% of non-financial bonds to transition-sensitive sectors.
	• Insurers: 9% of stocks to transition-sensitive sectors; 8% of non-financial bonds to transition-sensitive sectors.
	• Investment funds: 15% of stocks to transition-sensitive sectors; 36% of non-financial bonds to transition-sensitive sectors.
	Banco de España:
	• Banks: From 1,5% to 3,5% of loans to transition-sensitive sectors.
	ECB (2021a):
	• Banks: 14% of loans to transition-sensitive sectors.
	Banque de France/ACPR:
	• Banks: 10% of loans to transition-sensitive sectors.
	Superintendencia Financiera de Colombia:
	• Banks: From 1 to 26% of loans to transition-sensitive sectors.
	Bank of England:
	• Banks: 12% of corporate banking loans to transition risk-vulnerable sectors • Insurers: 21% of assets to transition risk-vulnerable sectors
Physical risks	**ECB (2021a)**:
	• Banks: 30% of corporate exposures.
	Bank of Norway:
	• Real estate: 5.5% of property impacted by 2090.
	Reserve Bank of Australia:
	• Real estate: 1.5% of properties see house prices fall by 10% by 2050.
	Bank of Finland:
	• Real estate: Value at risk amounts to 1.3% of corporate loans. **Bank of England:**

- Banks: 11% of corporate banking loans to physical risk-vulnerable sectors
- Insurers: 17% of assets to physical risk-vulnerable sectors

3.1.2. Financial vulnerability assessment

Regarding financial vulnerability, it stands out that economic modelling is central in all exercises to translate climate-specific information into financial impacts. In terms of impacts, it is still too early to draw conclusions, given the large heterogeneity in methodologies, metrics used and results across exercises.

For physical risks, while metrics might be divergent depending on the specific physical risk being analysed, their translation in risk metrics combine climate physical information with associated economic damages. The combination of flood hazard with economic exposure data at the municipal level in the exercise conducted by the Superintendencia Financiera de Colombia (SFC) estimated the distribution of the expected economic damages (translated into loan losses provisions) for each scenario and found that loan losses for individual banks could increase by 0.2% of total assets for the least vulnerable bank, to 2.2% for the most vulnerable one in the scenario where a severe flood occurs in 2080 (SFC, 2021). The ECB top-down exercise estimated that banks' probabilities of default (PD) deteriorate most by 2050 under a no-transition scenario, increasing overall by 6% relative to an orderly transition, precisely because of increased economic damage from natural disasters in the long run. This degradation in PDs would translate into a relative increase in expected losses of 8% by 2050 under a no-transition scenario relative to an orderly transition (ECB, 2021b).

When it comes to transition risks, financial impacts can vary significantly by sector. Building on scenarios of a sharp rise in global carbon prices and a quick uptake of renewables, De Nederlandsche Bank estimated that banks' losses could reach up to 3% of total assets over a five-year horizon. The Bank of Canada/OSFI estimated that the refined petroleum sector could see its PDs increase by up to 550% by 2050 (relative to a current policies baseline) in the case of a delayed transition scenario. The energy sector, however, benefits from the transition overall, and sees close to no change in PD. Similarly, Banque de France/ACPR concluded that PDs could be multiplied by a factor of 6 for the petroleum sector over the same horizon in its most adverse transition scenario relative to an orderly transition baseline. The UK CBES exercise show that, for life and general insurers, the "No additional actions" scenario would be likely to have a more significant impact than either of the transition scenarios, even within the 30-year window of the exercise. For life insurers, this was because forward-looking asset price impacts are greatest at the end of that scenario with an overall impact worth just over 15% of total market value. Such falls in asset prices would of course affect all holders of assets and participants in these markets. For general insurers, the primary way that losses materialised was via a build-up in physical risks, which resulted in higher claims for perils such as flood and wind-related damage.[33]

[33] UK and international general insurers, respectively, projected a rise in average annualised losses of around 50% and 70% by the end of the NAA scenario. Staff analysis on UK insurance losses suggests increases could be as much as four times higher than firms submitted.

The ultimate objective of climate scenario analysis generally is translating exposure and real economy impacts into financial vulnerabilities, and usually conventional financial risk metrics are used to this end. The People's Bank of China computed final financial impacts on the Capital Adequacy Ratio (CAR) of the banks participating in its exercise. On aggregate, it estimated that the banks' CAR met regulatory requirements under all its stress scenarios, varying between 14.3 and 14.6% by 2030, primarily because of a low loan exposure to transition-sensitive firms. Regarding market risks, a few exercises look at changes in asset prices and ratings (Banque de France/ACPR, Deutsche Bundesbank, De Nederlandsche Bank, Bank of Canada/OSFI, Superintendencia Financiera de Colombia). In Germany, aggregate losses reached 2% in the securities portfolios (comparing between "Net Zero 2050" and "Current Policies") for banks and up to 7% for investment funds. In terms of volume of losses, the ECB bottom-up stress test reveals that credit and market losses could amount to around €70 billion on aggregate for 41 EU significant banks in the short-term disorderly transition and the two physical risk scenarios (flood risk and drought and heat risk) taken together (ECB, 2022a). For Canada, under its transition scenarios the largest impacts were in the fossil-fuel sectors – coal and oil & gas – where asset values were 80 to 100% below the current policies baseline in 2050. Superintendencia Financiera de Colombia found a 113% increase in domestic bank's losses in sovereign bond holdings, under a full market value-based approach applied in a flood scenario. The UK CBES exercise found that banks' projected credit losses were 30% higher in the Late Action (LA) scenario than the Early Action (EA) scenario. Loss rates in the LA scenario were projected to more than double as a result of climate risks – equivalent to an extra c.£110 billion of losses for participating banks over the period, with around 40% of these losses realised during the first five years of transition. One key driver was the large increase in carbon prices, which led to large corporate loan losses across energy users and energy producers. Furthermore, the sharp adjustment process caused an economy-wide recession, including a rise in unemployment and fall in house prices, resulting in significant mortgage impairments.

Many jurisdictions highlight that these measures of exposure and vulnerability are likely understated. Respondent authorities, such as the Central Bank of Brazil, point out that "ideally, the metrics should capture second-round effects, potential climate non-linearities, and adaptation measures taken by financial and non-financial firms". The scarcity of available data and modelling limitations and uncertainties are other key reasons alluded to by respondents to suggest that these preliminary results might significantly understate the actual climate-related risks. This would call for further development of the climate-economy-finance nexus to better account for the dynamic adjustments between economic sectors, the climate and macro-financial feedback loops, as well as interconnectedness within the financial system.

It is also difficult to discern any systematic pattern in the outcomes of those exercises which took into account firms' dynamic responses from those who did not. It was expected from jurisdictions assuming a dynamic balance sheet that firms would rebalance their exposures, and adjust their risk management strategy accordingly, leading to more muted impacts. However, this was not the case, potentially reflecting that some firms found it challenging to account for adjustments in their behaviour, resulting in limited changes despite being allowed to do so. For instance, the Banque de France/ACPR reported that some of the participants did not proceed to undertake corrective actions, such as exiting from impacted sectors, while others followed more closely the longer-term structural changes simulated in the scenarios or remain aligned with their published transition plans. A number of authorities stated that they would aim to better account for firms' transition plans going forward.

3.1.3. Macroeconomic and sectoral impacts

Many exercises report more significant GDP and financial losses for disorderly transition scenarios compared to an orderly transition, as well as more significant economic losses in case of a no transition with physical risks. For instance, the latest ESRB exercise (ECB, 2022b) estimated that the expected losses for the banking sector would be 27% and 15% lower in the case of, respectively, an orderly and a delayed transition compared to the current policies scenario by 2050, highlighting the benefits of a timely transition mitigating future physical risks. Insurers and investment funds would even benefit from an orderly transition as soon as from 2025, for a sharp reduction in market risk losses due to the favourable revaluation of their asset holdings. The earlier EU economy-wide exercise had also pointed to the benefits of acting early, with the early adoption of climate policies bringing benefits in terms of investing in and rolling out more efficient technologies (ECB, 2021b).

However, while keeping in mind the caveats such as modelling uncertainty and data limitations, many exercises to date do not find severe macroeconomic and financial impacts.[34] The Bank of Japan/ Japan Financial Services Agency argues that the transition shocks to GDP growth, unemployment and inflation may not be so severe under the scenarios, in particular due to modelling limitations. The Financial Supervisory Authority of Norway (Finanstilsynet) estimated that Norway's GDP can decline by up to 4.4% over two years in the case of a sudden and steep rise in the global carbon price in 2025, which is probably one of the strongest estimated impacts across the exercises. Nevertheless, it still concludes that the financial implications are "manageable" for Norwegian banks. Most respondents however have highlighted the large uncertainties regarding the results.

In line with the common finding of concentrated impacts in a limited number of sectors, the range of impacts might vary across countries depending on the sectoral composition of their economy. For instance, commodity-exporting countries like Canada are likely to be more impacted. Most respondents highlight the importance of taking into account sectoral linkages and the channels through which shocks propagate through the economy. In transition scenarios, the largest impacts are on carbon-intensive sectors, including oil, gas and coal extraction, as well as fossil-fuel dependent industries and electricity generation. Furthermore, assumptions about technology matter. As the Bank of Korea exercise highlights, while there can be a negative near-term impact on the energy generation sector, this sector can recover as it is able to replace fossil fuels with renewable energy sources. On the other hand, for some manufacturing industries where emissions mitigation technologies have yet to be developed, output losses are large and persistent in transition scenarios.

Similarly, in adverse physical risk scenarios, more severe and frequent natural disasters can have a significant impact on sectors like agriculture, mining or construction, or geographical areas that are more vulnerable to weather events. For example, Danmarks Nationalbank found that some credit institutions have a high share of exposures at risk of flooding that are concentrated in the same geographical area. Similarly, De Nederlandsche Bank's 2021 exercise on acute physical climate risk shows that severe floods in densely-populated western parts of the Netherlands could cause swift bank capital depletion, in particular as it is not always possible

[34] Note that some macroeconomic impacts in CSA can be features of the scenarios rather than results from the analysis.

to insure against flood events in the Netherlands. The ECB bottom-up exercise also finds a substantial increase in loan losses in high and medium flood risk area and for regions and activities more vulnerable to higher temperatures. The Financial Superintendency of Colombia (SFC) assessment found that some Colombian banks are about two to three times more vulnerable to flood hazards than most others because of high exposures in more rural areas.

In summary, those institutions whose portfolios are more heavily weighted towards carbon intensive (or carbon dependent) sectors could see a greater proportion of impairments than those that have a relatively low proportion of their books in these sectors. More regionally concentrated lenders or insurers may find themselves particularly exposed to physical risks compared with more diversified firms. This in turn could have knock-on impacts on sector divestments and hence financial stability if financial firms suddenly decide to transition away from these sectors or locations.

3.2. Financial stability implications and authorities' response

3.2.1. Financial stability implications of climate change

While it is difficult to meaningfully compare results, the preliminary findings of these initial exercises for financial stability is that, at least at this current juncture, while the impacts of climate risks are not small, they seem to be concentrated in some sectors and overall, at least for now, contained from the perspective of domestic financial systems. As highlighted in the previous section, the macroeconomic impacts of these first transition scenario exercises are moderate for most jurisdictions. However, the tail risks associated with climate change may not be as manageable, while these exercises remain largely exploratory in nature and are therefore not comparable to traditional stress tests that assess resilience to tail risks.

While climate risks might be material for some vulnerable firms, possibly leading to individual insolvencies, no jurisdiction pointed to clear system-wide financial stability implications at this stage from the initial round of exercises. In particular, some firms' geographical exposures are diversified across different jurisdictions, limiting the potential spillover effects to the domestic financial system. The range of estimates for this first round of exercises suggests that losses could be sizeable, but also manageable at a system's level, albeit subject to the caveats mentioned above regarding the potentially underestimated exposure and risk metrics and the need to account for the concentration of these risks. Overall, aggregate total solvency of credit institutions would not fall below regulatory minimum in many jurisdictions.

Some respondents emphasize nevertheless that unless an orderly and fast-paced transition process is implemented, climate-related risks will end up representing a major source of systemic risks in the future, and hence need to be monitored closely. If poorly anticipated or ill-designed, climate policy may also give rise to concentration of risks, which could translate into losses for some financial institutions and the potential build-up of systemic risk in the financial system. While the effects are still comparatively small and manageable from an aggregate financial stability perspective in many exercises, second-round effects have not been accounted for. Given the risks of common exposures, the interconnectedness across financial actors and the interdependencies across sectors within the real economy, further analysis is required to enhance the understanding and assessment of systemic risks. It is worth noting that financial stability risks ultimately depend on the scale and timing of policy actions, with delayed transition possibly causing ripple effects in financial markets, while immediate and well-communicated action would smooth the impact over time.[35] Many exercises also did not consider other potentially large sources of risk, such as those stemming from an abrupt correction in asset prices when transition shocks result in fire sales of assets. The FSB is undertaking analytical work on climate-related vulnerabilities in order to integrate climate risks into broader financial stability surveillance, including developing appropriate, decision useful risk metrics, as well as developing an understanding of transmission channels that can determine a disorderly transition's impact on the financial system.

3.2.2. Possible policy responses

Many jurisdictions highlight the uncertainties and methodological limitations around climate-economy modelling, with results being highly dependent on initial assumptions. Climate-related risks are characterised by deep uncertainty and nonlinearity, and the possibility of extreme values (e.g. tail risk) cannot be ruled out. Methodologies also face a number of limitations. These initial climate scenario analyses exercises, which could underestimate real impacts of transition and physical risks, stand out primarily as learning opportunities.

Despite significant progress, a number of technical hurdles and methodological challenges are still hindering the comprehensive and robust assessment of climate risks to reliably inform policy and supervisory actions. Data consistency and methodologies to translate exposures into risk metrics relevant to macroprudential policy remain key challenges. The assessment tools and analysis need to be further refined and repeated to address the inherent uncertainties associated with climate change.

While the exploratory objectives of many of these initial assessments and their preliminary nature will not motivate macroprudential or micro-prudential responses at this stage, there is a consensus among respondents on the need for further monitoring, as climate change can represent a major source of systemic risk. While their findings feed into the discussions in the respective financial stability committees, their implications in terms of micro or macro prudential responses are still limited at this stage and mostly qualitative. There is a consensus that improvements in the assessments of potential losses for firms and in aggregate are necessary to gauge the financial stability implications of climate risks and inform decisions. At the same time, most respondents concluded from their initial assessments that financial institutions should be developing their capacities to assess, monitor and manage climate-related risks.

The survey results reveal that most exercises were undertaken to improve the understanding of the risks and capabilities of financial institutions, without any expectation with regards to policy or supervisory follow-up actions. A large majority of the jurisdictions stated explicitly that they do not intend to use the results of their assessment for revising their macroprudential policy recommendations, such as requiring additional capital or add-ons. The outcomes of these exercises may however steer discussions on supervisory expectations. One respondent highlighted that findings might also be used to prepare guidance for financial institutions on best practices in the area of climate stress testing. Outcomes will be used to encourage financial

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[35] It should be noted that a certain amount of physical risk is already built-in given historical emissions, which may result in elevated financial stability risks. It is possible that such risks may not be fully preventable, even with drastic policy actions.

institutions to pre-emptively respond to climate risks. More specifically, some jurisdictions have pointed towards some specific sectors or climate events that have drawn their attention, such as flooding risk, which financial institutions might be explicitly asked to consider in some countries.

3.3. Comparability of outcomes and opportunities for future approaches

While most jurisdictions emphasise the importance of ensuring comparability between different exercises at international level, many also reiterated the need to tailor the analysis to their specific context and objectives.

3.3.1. Cross-border cooperation as a necessary way forward

Many respondents highlighted the differences in objectives, methodologies, underlying data, results and outcomes. While many noted that perfect comparability would not be realistically feasible, most highlighted the need for a common baseline approach for climate scenario analysis. This approach would include a series of key characteristics, chiefly:

- the use of common energy-climate and relevant macroeconomic scenarios (especially the ones published and updated by the NGFS, the Intergovernmental Panel on Climate Change or the International Energy Agency), associated with greater sectoral and jurisdictional granularity;
- shared methodologies for macroeconomic modelling, as well as harmonized sectoral breakdown in macroeconomic forecasts; and
- an enhancement of the climate information architecture, including corporates' and financial institutions' climate-related disclosures and taxonomies.

More specifically, respondents have emphasized the important role that greater transparency could play in deepening comparability, notably regarding modelling approaches, but also macroeconomic and policy-related assumptions, and data points.

In addition, pooling resources – primarily for modelling and data collection purposes – may be helpful, especially given the constraints in resources that some organisations or jurisdictions may face.

3.3.2. The way forward involves overcoming some limitations

While members emphasized the need for structured reporting on assumptions, methodologies and results, they also pointed out the limitations in conducting top-down macroeconomic climate scenario analyses at an international level.

Even though the benefits of increased comparability are clearly recognised, a number of jurisdictions also emphasised the need to tailor climate scenario analysis exercises to account for a series of specificities, including (i) jurisdictions' objectives for such exercises; (ii) their physical vulnerabilities to climate change (e.g. geographical location, vulnerability scores, etc.) as well as those vulnerabilities that are transition-related (e.g. financial and banking sector model and maturity, cross-border exposures, stage in the transition to a low-carbon economy, etc.);

and (iii) the sectoral composition of their economy and specific transmission channels. More specifically, in the context of physical risks, the feasibility of conducting a global exercise is hindered by the need to tailor the analysis to local conditions at a sufficient spatial granularity. As for transition risks, an important obstacle remains the currently limited availability of reliable data on greenhouse gas emissions at company (Scope 1 and 2 and, at least in some cases, Scope 3) and at household level.

Respondents reiterated the need not to overlook the specificities of emerging market and developing economies – notably as those economies are the most exposed to acute physical risks and the ones with the poorest coverage in data and in insurance penetration; and are typically more exposed to concurrent hazards (e.g. typhoon, hurricane and storm surge in tropical-storm-prone countries or coastal inland flooding). The joint modelling of hazards might be particularly relevant for those economies, calling for greater support from global organizations. In addition, other social consequences of climate change (e.g. famine and/or mass migration) are more likely to materialize in emerging market and developing economies, also requiring specific modelling (e.g. impact on the labour force, productivity, pension systems).

Nonetheless, there are advantages to foster global approaches, including (i) greater quality in climate scenario analysis; (ii) more jurisdictions conducting such exercises would ultimately allow authorities to gather more climate and financial data to analyse cross-border exposures and compounded risks across value chains; as well as (iii) the possibility to gather greater physical risk data in order to assess the impact of climate-related hazards.

Additional limitations that should be taken closely into consideration involve difficulties in integrating both the conventional and longer-term horizons (i.e. the realization of long-term costs feeding back into shorter-term horizons via a reassessment of market valuation, as underlined by the IMF[36]). The inherent uncertainties, notably those related to long time horizons and the evolution of policy and socio-economic factors, as well as to the climate models, remain another key challenge that will hinder comparison across exercises.

Finally, data continues to be an important limitation, especially as granular and forward-looking data is needed more for climate risk analysis than for standard stress testing, given the sectoral and geographical specificity of climate risks.

4. Focus on data gaps

4.1. Main data gaps identified

Data gaps remain a key challenge for respondents' own scenario analysis efforts. Respondents cited limitations in data availability and consistency/comparability. Data accessibility across jurisdictions is also an important consideration for a proper analysis of cross-border transmission of climate shocks.

[36] Adrian et al. 2022. "Approaches to Climate Risk Analysis in FSAPs." IMF Staff Climate Note 2022/005, International Monetary Fund, Washington, DC.

In terms of data availability, respondents highlighted the lack of sufficiently comprehensive, granular climate-related information on counterparties as a major hurdle for their analyses. For example, the Banque de France noted that while sectoral-level GHG emissions data was available (from sources such as the World Input-Output Database), counterparty-level data on GHG emissions was difficult to obtain. Some respondents highlighted that entity-specific data such as GHG emissions and energy mix was not readily available, especially for smaller and non-listed corporate counterparties. Meanwhile, the Bank of England noted that for its bottom-up analysis, financial institutions experienced challenges in collecting detailed information from individual counterparties for their counterparty-level analysis.

In addition, geographical location data is identified as one of the key data gaps, which limits the ability to assess the vulnerability of assets or liabilities from physical risks. For example, granular geolocation information was generally available for firms' headquarters and main subsidiaries, but not their facilities and other physical assets, meaning that in some cases in-house models had to be used or simplifying assumptions had to be adopted (e.g. that economic activity is spread equally across different regions).[37] In terms of physical risk, while the NGFS Climate Impact Explorer provides aggregated country/region-level estimates for selected climate parameters, respondents indicated that it may not be sufficient to adequately capture the effect of some physical risk drivers.

Similarly, respondents highlighted limitations in forward-looking information. In particular, forward-looking information about entities' transition plans was not readily available. The lack of available data in this area meant that financial institutions were unable to fully understand their counterparties' and customers' transition plans, particularly with regards to verifying the credibility of third party transition plans. Some institutions also highlighted the need for more detailed forward-looking data.

Respondents also cited challenges with regard to the use of existing industry classification codes for climate-related analysis, with some noting that they did not allow for the categorisation of economic activities at a sufficiently meaningful level of detail. For example, the Bundesbank noted that when analysing the energy sector, it would be desirable to distinguish between renewable energy and energy based on fossil fuels, but industry classification codes did not allow for this. In addition, some respondents remarked that it was difficult to classify companies that have multiple or mixed business lines across various industries. Differences in the classification of these companies could partly explain the variability across institutions, and could drive potential misestimation of risks in some sectors or segments.

Moreover, respondents also noted consistency issues when drawing on climate-related projections across different sources. For example, to address data gaps in the NGFS scenarios, some financial institutions participating in the Bank of Japan / Japan Financial Services Agency's exercise adopted external data sources to obtain information on sectoral economic activities under transition pathways. However, as these data sources are not necessarily consistent with the NGFS scenarios, the use of such external data sources result in unintended differences in

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[37] For instance, the Financial Superintendency of Colombia assumed that economic activity is spread equally across each municipality, as it did not have data on the precise location of assets of Colombian banks. Meanwhile, the Bank of Finland adopted a simplified formula to estimate the use of residential real estate in high-risk areas as collateral for housing loans, as there was a lack of building-level information.

loss projections amongst the different participants in the Bank of Japan / Japan Financial Services Agency exercise. Similarly, Banca d'Italia highlighted that, for some variables, they faced challenges in reconciling historical data points between the NGFS scenarios and other sources.

Finally, there are potential consistency and comparability issues across institutions due to differences in analytical tools, capacity, expert judgment, and assumptions when using data, including criteria for scenario selection. There are two key aspects that make exercises difficult to compare: 1) the design of the scenario; and 2) the severity of the scenario. For example, in terms of design, where data on value chain emissions relating to corporate counterparties (i.e. scope 3 emissions) were able to be sourced, these were not always standardised due to differences in reporting and measurement approaches, in turn limiting their comparability. Another example regarding the varying level of severity across jurisdictions is whether a scenario such as Net Zero 2050 is taken as the transition or best case scenario. Furthermore, the manner in which the data is used can lead to significant divergences in results; this is true not just across different jurisdictions, but also across different financial institutions for bottom-up scenario analysis exercises. For instance, Banque de France noted that divergences in banks' bottom-up estimates of average PD across sectors could potentially be attributed to methodological choices. The Bank of Canada noted that such consistency issues would be further magnified by the long-term horizon typical in many climate scenario analysis exercises.

4.1.1. Impact of data gaps on the accuracy and scope of scenario analysis

Many respondents indicated that the results of their exercise may not provide an accurate assessment of climate risks and may underestimate the impact of climate change. Data gaps clearly limit the accuracy of exercises and results need to be interpreted cautiously since they may underestimate the impact of climate change. For example, Norges Bank reported that a lack of Scopes 2 and 3 GHG emission data meant that they underestimated the risk. However, the assessment of the impact of data gaps on results is a difficult task due to the inherent modelling uncertainty.

The availability and granularity of data impacted the scope of some respondents' exercises. Several respondents designed their exercise around known data gaps or reported that data gaps altered the scope of the exercise. Danmarks Nationalbank and Banco de la Republica opted to conduct an analysis at an industry or sector level, instead of at a counterparty level, or included only companies for which they obtained data. Many respondents acknowledged that further analysis and refinement would be needed in the future. The Bank of England also noted that whilst data gaps exist, the exploratory nature of the scenario exercises meant a greater emphasis was provided on qualitative outcomes than in other regulatory exercises.

4.2. Approaches adopted for addressing data challenges

While many respondents noted that data limitations could not be fully addressed at the moment, some attempted to overcome such issues by undertaking additional modelling work, especially in the area of downscaling. For example, the Financial Superintendency of Colombia downscaled national-level flood risk estimates by the World Resources Institute, using a relative economic flood risk indicator at a municipal level and found that while Scope 1 emissions were more readily available, macroeconomic models helped to address data gap issues pertaining to

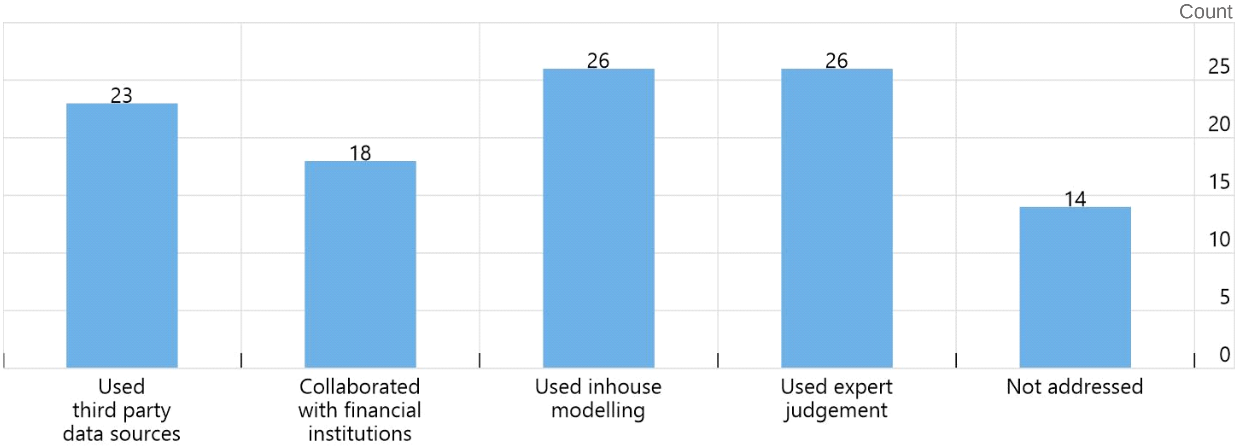
Scope 2 and Scope 3 emissions, on a sectoral level. Meanwhile, the Banque de France relied on a suite-of-models approach to downscale model outputs from the NGFS climate scenarios to sector-level and firm-level estimates.

Some respondents also relied on additional assumptions based on expert judgement. For instance, to address the challenge of inconsistent industry code classifications, the Bank of Canada and OSFI developed a mapping based on several industrial classification systems, to ensure greater consistency across different financial institutions. As another example of adaptation, in the Bundesbank's scenario analysis exercise, a firm in the coal industry which did not disclose the revenue share from its coal extraction or coal-fired power plants was assumed to have its entire revenues to be derived from coal-based activities.

More than a third of respondents also used third-party data sources to inform their analysis. For instance, the European Central Bank mapped physical risk indicators/scores to firms' assets at address-level. For sovereign credit ratings, the Financial Superintendency of Colombia referenced data from a rating agency that estimated the relationship between losses from natural disasters and credit ratings from a global sample of countries. Some respondents, such as the Bank of Portugal, used both reported and estimated firm-level emissions data from a data vendor. The Malta Financial Services Authority used financial data together with the NACE classifications obtained from a third party. Finally, beyond commercial data providers, some respondents worked directly with financial institutions through a bottom-up approach, to overcome the inability of relying on historical relationships to establish a credit/climate relationship.

Overall, respondents indicated that collaboration with financial institutions will be required for supplementary data and assumptions – not only those conducting bottom-up analysis. For instance, creating information on the overall share of loans to low or high carbon intensive sectors or company-level emission data. Overall, the responses to the survey indicate that addressing issues would require a consistent data collection effort. Collective global efforts, such as the G20 Data Gaps Initiative will also be useful to help financial institutions address these issues.

How did authorities address data gaps? **Graph 6**



Source: FSB-NGFS Survey

There are many initiatives to close data gaps in the longer term. The NGFS's final report on bridging data gaps mapped available climate data sources to metrics required, including for financial stability monitoring and stress testing. It also provided concrete policy recommendations for policymakers and other stakeholders for improving the availability, quality, and comparability of climate-related data. The FSB is developing its climate-related risk monitoring framework, through its Standing Committee on Assessment of Vulnerabilities, by first identifying key vulnerabilities and associated metrics, then the required data to construct those metrics and fill any data gaps. A number of organisations are also publishing guidance frameworks or standards in relation to disclosures - such as the ISSB climate-related disclosure reporting standards which are being analysed by IOSCO for a potential endorsement - and transition plans. Transition plans will be a valuable source of data where they include information on how companies will achieve pledged targets. For example, the Glasgow Financial Alliance for Net Zero (GFANZ) report on 'Expectations for Real-economy Transition Plans' brings consistency on metrics and data points required by global financial institutions to evaluate the progress and credibility of companies' net zero transition plans.[38] More recently, the initiative just launched through the Climate Data Steering Committee for the development of the open data platform, the Net-Zero Data Public Utility (NZDPU), will contribute to addressing the data gaps and inconsistencies that slow climate action. It will help in consistent disclosure of direct and indirect emissions in CO2 equivalent units, and also enhance transparency on net zero targets and actions to achieve those targets. This should help in establishing emission baselines that financial institutions can refer to in order to set targets and develop accurate transition plans.[39]

5. Conclusions

Climate scenario analyses exercises are at an early stage, given the complexities of scenario analysis and modelling climate risks as well as the lack of necessary data. For now, the findings of the exercises have not translated into micro- or macro-prudential policies. Nevertheless, it is worth noting that most respondents agree that those exercises should be continued, upgraded and updated to track climate risks and inform policy decisions in the future.

International collaboration is needed to share good practices and advance towards a common framework for climate scenario analyses. The NGFS Scenarios have provided a common starting point for many exercises, but heterogeneity in the methodologies, data used (in addition to the NGFS Scenarios) or sectors considered, to name a few, make it difficult to compare rigorously the results across exercises, and draw conclusions regarding global financial stability. A balance should be found between standardisation and local specificities, in particular in emerging and developing economies, as fully standardised exercises may not be able to cover unique circumstances faced by different jurisdictions. To enable more robust and meaningful findings from climate scenario analysis, significant work will also need to be done in the areas of collecting, validating and combining various datasets.

The FSB and the NGFS will continue their work on climate scenario analyses, and will foster international collaboration to advance towards a common and comprehensive framework for

[38] GFANZ (2022), *Expectations for real economy transition plans*, September.

[39] GFANZ (2022), *Development of the Net-Zero Data Public Utility*, September

scenario analyses. The NGFS will continue improving its climate scenarios, in particular with more granular data at the sectoral and geographical levels, as well as with more physical risk data, to make them even more usable off-the-shelf, limiting the additional modelling work needed. It will also work toward providing shorter term scenarios, with some of them displaying more adverse developments. Alongside the development of scenarios, the NGFS will also work on methodological issues pertaining to the use of scenarios. Regarding data gaps, the NGFS is currently working to develop a new website and identify possible long-term solutions for regularly updating its data directory. The FSB, in line with its Roadmap for Addressing Financial Risk from Climate Change, is working on improving the availability and cross-border comparability of climate related data more broadly, in particular to further coordinate the establishment of common metrics for financial risks (e.g. for financial stability analysis and supervisory reporting), including forward-looking metrics anchored in real-world climate targets. On vulnerabilities analysis, the work is continuing to progress along three strands: i) ongoing monitoring using the tools currently available ii) development of conceptual frameworks and iii) further development of scenario analysis. Further experience with building and using climate scenarios can help the monitoring of financial risks to appropriately account for the longer time horizons that climate-related risks may involve.

Annex 1: FSB-NGFS Survey on Climate Scenario Analyses

Overview of climate scenario analyses undertaken by authorities, with a focus on data and models used

Climate Scenario Analysis (CSA) exercise - Status and Timelines

1. Please indicate the current status of your exercise.
   - Concluded
   - In progress
   - Not yet started/planning phase
   - No plan

   If you have published information about the nature of the exercise being undertaken, please provide a link here:

   Alternatively, if you are able to share a non-published document about the design, please do so.

2. If the exercise is not yet concluded, when do you expect to finish? (*Date)*

3. If the exercise is concluded, do you have a plan for the next exercise, if so when? Is there an expected frequency of conducting the exercises?

   If you have a plan, what is the difference from the previous exercise (including any difference in scenarios to be used) and what is the reason for the difference?

4. Have you published / will you publish the results?
   - Yes
   - No

   If you have published results, please provide a link here:

5. How many people (full time equivalent) have been involved / do you estimate will be involved in your exercise?
   - 1-5
   - 6-10
   - 11-15
   - 16-20
   - 21-25
   - 26-30
   - 30+

6. Have you collaborated/ do you plan to collaborate with external parties (e.g. consultants, data providers, etc.) in your exercise?
   - Yes
   - No

   If yes, please provide more details below:

Objectives and scope of analysis

7. What is the main objective of your scenario analysis (tick all that apply):
   - To assess how climate risk could impact financial stability (macropru)
   - To assess how climate risk could impact individual financial institutions (micropru)
   - To assess how climate risk could affect the macroeconomy
   - To develop climate scenario analysis capabilities in financial institutions
   - To develop climate scenario analysis capabilities in your organisation
   - To facilitate dialogue with the industry about climate-related financial vulnerabilities
   - Other (please elaborate below)
8. What do you assess and compare via your scenario analysis?
   - GDP impact of climate change
   - Financial system expected losses accounting for climate change-related risks
   - Different types of transition to a "green" economy
   - Impact of climate-related policy implementation
   - Other (please elaborate below)
9. Which types of climate risks have you explored / will you explore in your scenario analysis? Check all that apply:
   - Transition risk – Policy changes
   - Transition risk – Technological changes, behaviour or social changes
   - Physical risk – Acute
   - Physical risk – Chronic
10. Which types of financial risks were/ will be assessed due to potential effects of physical and transition risk? Check all that apply:
   - Market risk
   - Credit risk
   - Liquidity risk
   - Insurance risk
   - Operational risk

- Reputation risk
- Liability/legal risk
- Other (please explain below)

11. Which financial sectors did/will you include in the exercise? Check all that apply:
    - Banks
    - Insurers
    - Asset managers
    - Pension funds
12. Which real sectors did/will you include in the exercise? Check all that apply:
    - Non-Financial corporations directly
    - Non-Financial corporations indirectly, through financial institutions
    - Households directly
    - Households indirectly, through financial institutions
    - Governmental or public authorities directly
    - Governmental or public authorities indirectly, through financial institutions
13. What potential vulnerabilities did/will the climate scenario analysis aim to assess?

Type of climate risk	Key risk driver	Variable of evaluation
Physical Risk	Please specify (*E.g. Floods, Droughts, Rising sea levels*)	Please specify whether asset, such as credit portfolio, or liability, such as legal contingency, angle
Transition Risk	Please specify	Please specify whether asset, such as credit portfolio, or liability, such as legal contingency, angle

Modelling approaches

14. How many scenarios have you used / are you planning to use in your exercise?
    - 0
    - 1
    - 2
    - 3
    - 4
    - 5+
15. Which NGFS and Non-NGFS scenarios have you used / are you planning on using in your scenario analysis? (tick all that are being used)

- Divergent net zero
- Delayed transition
- Net Zero 2050
- Below 2˚C
- Nationally determined contributions
- Current policies
- Scenario other than NGFS (please elaborate below)

16. In case you used NGFS scenarios in your analysis, were they adapted at a more granular level to be applicable for jurisdictional circumstances?

    - Yes
    - No

    If yes, how did you adapt them? Which were the main changes you made? Which were the main challenges you faced? Please briefly explain below:

17. Which macroeconomic model did/will you use for your scenario analysis (e.g. NIGEM, other)?

18. What is your approach to scenario analysis?

    - Top down
    - Bottom up
    - Hybrid

    What is the rationale behind your choice? Please explain below:

19. What balance sheet assumptions did/will you make?

    - Static
    - Dynamic
    - Both

    What is the rationale behind your choice? Please explain below:

    If a dynamic balance sheet assumption was used, what are the main assumptions on the behaviour of financial institutions over the time horizon?

20. What is the time horizon of your exercise(s) and is it different for physical and transition risk? Check all that apply:

	≤ 5 years	>5 to 10 years	> 10 years to 30 years	> 30 years (please specify)
Physical risk				
Transition risk				

What is the rationale behind your choice? Please explain below:

At what level of granularity is/was the exercise undertaken (e.g. at the counterparty or sectoral level)?

- Macro level
- Sectoral level
- Counterparty level

Please elaborate below if relevant, in particular with more information on the level of sectoral granularity (number of sectors, etc.)

Where applicable, which criteria did/will you use to identify sectors most exposed to physical and transition risk? When considering physical risk, do you take any tipping points into account (e.g. melting permafrost)?

Criteria used for physical/transition risk	Sectors identified as most exposed
[E.g. High Scope 1 and 2 emissions]	*[E.g. Oil and gas, mining]*
[E.g. Vulnerable to drought]	*[E.g. Agriculture]*

21. To what extent is the financial stability angle an explicit objective of the exercise? Did/Will you account for systemic risks – risk transfers, feedback loops/second order effects and interactions between different sectors on a domestic level – either quantitatively or qualitatively?

    - Yes
    - No

    If yes please explain how, including any modelling choice you made. If not, why not?

22. In case you considered cross-sectoral and system-wide aspects in your exercise, which transmission channels are the most important? Please elaborate below:

23. Did/Will you account for international spillovers or the cross-border transmission of climate risks to and from your jurisdiction?

    - Yes
    - No

    If yes please explain how. If not, why not?

Data gaps

24. What data did you use in your most recent climate scenario exercise? Please describe the categories as well as the data items that for each category are key drivers of the CSA exercise results. (Macrofinancial variables, financial exposure, physical risk data, etc)

    i) Non-financial exposures data:

(1) For transition risk

- Taxonomy based on Climate Policy relevant sectors
- Energy performance certificates by property
- Firm/Industry/Sector level GHG emissions (Scope 1,2,3)
- Other (please elaborate below)

(2) For physical risk

- Forward-looking risk indicators for flooding
- Forward-looking risk indicators for drought
- Forward-looking risk indicators for wildfire
- Forward-looking risk indicators for hurricanes/typhoons
- Forward-looking risk indicators for sea level rise
- Forward-looking combined physical risk indicators (i.e. not hazard-specific)
- Other (please elaborate below)

ii) Financial exposures data:

(1) For transition risk

- Banking asset exposures by sector of borrower/counterparty
- Amount outstanding of residential mortgages
- Non-bank financial institutions' (e.g. investment funds) portfolio holdings by sector
- Other (please elaborate below)

(2) For physical risk

- Banking asset exposures by location of borrower/counterparty and financial collateral
- Banks' exposures to real estate by location
- Other (please elaborate below)

iii) External sector

What data, if any, did you use to capture the external sector?

25. Which are the main data gaps that you have identified in your analysis (in terms of granularity, quality or consistency). Please select all that apply:

- Lack of adequate emissions data (e.g. across Scope or across GHG type)
- Lack of comparable data across banks
- Lack of comparable data across non-financial companies
- Lack of physical location data or georeferenced data

- Lack of adequate forward-looking parameters for loss data due to climate events (as historical losses are not a suitable estimate of future losses)
- Lack of adequate forward-looking macrofinancial parameters
- Lack of other forward-looking data
- Other (please elaborate below)

Please describe further the nature of the main data gaps

26. Was there any consistency or granularity problem across institutions? Across sectors of economic activity?
    - Yes
    - No

    Please elaborate below

27. In case you identified any data gaps, which actions did you take to address them? Please select all that apply:
    - Used third party data sources
    - Collaborated with financial institutions
    - Used inhouse modelling
    - Used expert judgement
    - Not addressed

    Please elaborate:

28. To what extent is the reliability of the results from your analysis affected by data gaps? Please explain:

29. Did you take steps contributing to bridging the data gaps in the future? Please explain (e.g. data collection)

Risk metrics

30. What kind of metrics have you used to measure climate-related risk (transition and physical)?

Type of risk	Metric used (*please insert the metric you used. Some non-exhaustive examples are listed below)*
Transition risk	*GHG emissions and sector specific transition pathways*
Physical risk	*Climate-related factors (physical hazards)*
Real economy exposure	*Impact on economic activities of non-financial firms (sectoral- or firm-level)*

Type of risk	Metric used (***please insert the metric you used. Some non-exhaustive examples are listed below)***
Financial system exposure	*Risks to the financial system (via financial exposures to non-financial firms, PDs and LGDs, interdependency across defaulting firms, etc.)*
Propagation of systemic risk	*Potential propagation/amplification in the financial system (common exposures, financial interlinkages, fire-sales, etc.)*
Financial sector transition plans	*Describe*

31. Which financial risk metrics are you using, or would you consider most relevant for the monitoring of climate-related financial stability risk? Please elaborate, distinguishing between physical and transition risk where relevant

Type of financial risk metric	Discussion
[*Metrics related to Physical Risk*]	
[*Metrics related to Transition Risk*]	

32. What considerations were relevant to choose and design the metrics?

Findings

Assessment of vulnerabilities

33. Please provide a short summary of the main findings from your CSA exercise

34. What are the key quantitative measures that express the outcome of the climate scenario analysis exercise?

35. What is the assessed exposure of financial / non-financial firms to climate related risks? How is it measured (e.g. in terms of % of GDP; of regulatory capital; other)?

36. What assumptions were made relating to financial or non-financial firms' response to climate related risks? Please briefly elaborate on assumed transition plans, risk mitigating actions and strategies.

37. What are the conclusions of the CSA exercise on the outcomes and scale of impact of climate related risks on the economy and by sectors of economic activity? Please elaborate

38. Are there any uncertainties in your analysis and if yes, how do you evaluate or take into account the impact of such uncertainties in your results?

39. How do the findings on outcomes inform, at your institution, the following elements?

Type of implication	Discussion
Financial stability monitoring of climate-related risks	
Policy approach: Micro prudential and macroprudential response	

Conclusions on financial stability implications

40. What are the conclusions (if any) from the CSA exercise on the financial stability implications of climate related risk? Please elaborate

Opportunities for future approaches to inform a global perspective

41. Going forward, how can more comparability at the international level be fostered between different jurisdictions' exercises and the outcomes be leveraged?

42. To what extent could the scenario analysis at your institution benefit from international coordination efforts? In which respect?

43. What are the main priorities going forward in terms of data gaps, modelling choices, risk metrics?

Annex 2: Overview of exercises carried out by participating FSB and NGFS member authorities

Legend: Blue indicates "concluded", yellow indicates "in progress" and grey indicates "in planning" or "no plan".

Jurisdiction	Organisation	Expected end date of the exercise	Balance sheet assumption	Approach	Level of granularity	Risk coverage	Link to published results
Argentina	National Superintendency of Insurance (SSN)	tbd	tbd	tbd	tbd	tbd	
Australia	Australian Prudential Regulation Authority (APRA) (1)	Nov 2022	Static, dynamic	Bottom-up	Counterparty, macroeconomic, sector	Physical (acute/chronic), transition	
Australia	Reserve Bank of Australia (2)	End 2022	Static	Top-down	Macroeconomic, sector	Physical (acute/chronic), transition	
Australia	Reserve Bank of Australia (3)	Concluded	Static	Top-down	Counterparty	Physical (acute/chronic)	
Brazil	Central Bank of Brazil	Oct 2022	Static	Top-down	Counterparty, sector	Physical (chronic), transition	Link
Canada	Bank of Canada & Office of the Superintendent of Financial Institutions (OSFI) (1)	Concluded	Static	Hybrid	Counterparty, sector	Transition	Link
Canada	Bank of Canada & OSFI (2)	2023	Static	Top-down	Counterparty	Physical (acute)	
Canada	Bank of Canada & OSFI (3)	2023	Static, dynamic	Top-down	Counterparty, sector	Transition	
Canada	OSFI	End 2024	tbd	tbd	tbd	Physical (acute), transition	
China	People's Bank of China	Concluded	Static	Hybrid	Counterparty	Transition	Link

Jurisdiction	Organisation	Expected end date of the exercise	Balance sheet assumption	Approach	Level of granularity	Risk coverage	Link to published results
Colombia	Banco de la República (1)	Concluded	Dynamic	Top-down	Macroeconomic	Physical (chronic), transition	
Colombia	Banco de la República (2)	Dec 2022	Static	Bottom-up	Counterparty, sector	Physical (chronic)	
Colombia	Financial Superintendency of Colombia (3)	Concluded	Static, dynamic	Top-down	Sector	Physical (acute), transition	Link
Denmark	Danmarks Nationalbank (1)	Concluded	Static	Top-down	Counterparty	Transition	Link
Denmark	Danmarks Nationalbank (2)	Concluded	Static	Top-down	Counterparty	Physical (acute)	Link
Egypt	Central Bank of Egypt	Concluded	Static	Top-down	Sector	Physical (acute), transition	Link
European Union / Euro area	European Central Bank (1)	Concluded	Static	Top-down	Counterparty	Physical (acute/chronic), transition	Link
European Union / Euro area	European Central Bank (2)	Concluded	Static, dynamic	Bottom-up	Counterparty, sector	Physical (acute/chronic), transition	Link
European Union / Euro area	European Central Bank (3)	Concluded	Dynamic	Top-down	Counterparty, sector	Physical (chronic), transition	Link
European Union / Euro area	European Securities and Markets Authority (ESMA)	Concluded	Static	Top-down	Sector	Transition	Link
Finland	Bank of Finland (1)	Concluded	Static	Top-down	Sector	Physical (acute)	Link
Finland	Bank of Finland (2)	Concluded	Static	Top-down	Counterparty	Transition	Link

Jurisdiction	Organisation	Expected end date of the exercise	Balance sheet assumption	Approach	Level of granularity	Risk coverage	Link to published results
France	Banque de France	Concluded	Static, dynamic	Bottom-up	Counterparty, macroeconomic, sector	Physical (acute/chronic), transition	Link
Georgia	National Bank of Georgia	2023	Static	Top-down	Sector	Physical (acute/chronic), transition	
Germany	Deutsche Bundesbank (1)	Concluded	N/A	N/A	Sector	Transition	Link
Germany	Deutsche Bundesbank (2)	Concluded	Static	Top-down	Sector	Transition	Link
Germany	Deutsche Bundesbank (3)	Concluded	N/A	N/A	Macroeconomic, sector	Transition	Link
Germany	Deutsche Bundesbank (4)	Concluded	Static	Bottom-up	Counterparty	Transition	
Germany	Deutsche Bundesbank (5)	Dec 2022	Static	Top-down	Counterparty, sector	Transition	
Germany	Deutsche Bundesbank (6)	End 2022	Dynamic	Bottom-up	Counterparty, sector	Transition	Link
Greece	Bank of Greece	Concluded	N/A	Hybrid	Macroeconomic	Physical (chronic), transition	
Hong Kong	Hong Kong Monetary Authority	Concluded	Static	Bottom-up	Counterparty, sector	Physical (acute/chronic), transition	Link
Hungary	Central Bank of Hungary	Concluded	Static	Top-down	Sector	Physical (acute/chronic), transition	
Iceland	Central Bank of Iceland	Jan 2023	Static	Hybrid	Macroeconomic, sector	Physical (acute/chronic), transition	

Jurisdiction	Organisation	Expected end date of the exercise	Balance sheet assumption	Approach	Level of granularity	Risk coverage	Link to published results
India	Reserve Bank of India	Mar 2023	Static	Bottom-up	Counterparty	Physical (acute), transition	
Indonesia	Bank Indonesia	Dec 2022	Static	Top-down	Macroeconomic, sector	Transition	
Israel	Bank of Israel	Q4 2024	tbd	tbd	tbd	Physical (acute/chronic), transition	
Italy	Banca d'Italia (1)	Concluded	Static	Top-down	Counterparty, sector	Transition	Link (1) Link (2)
Italy	Banca d'Italia (2)	Dec 2023	Static	Top-down	Counterparty	Transition	
Japan	Bank of Japan & Financial Services Agency	Concluded	Static	Bottom-up	Counterparty, sector	Physical (acute), transition	Link
Korea	Bank of Korea	Dec 2023	Static	Top-down	Sector	Physical (acute/chronic), transition	Link
Malaysia	Bank Negara Malaysia	2025	Static	Hybrid	Counterparty, sector	Physical (acute/chronic), transition	
Malta	Central Bank of Malta (1)	Concluded	Static	Top-down	Sector	Transition	Link
Malta	Malta Financial Services Authority (2)	Concluded	Static	Top-down	Sector	Transition	
Mauritius	Bank of Mauritius	Jun 2023	Static	Top-down	Counterparty, macroeconomic, sector	Physical (acute/chronic), transition	

Jurisdiction	Organisation	Expected end date of the exercise	Balance sheet assumption	Approach	Level of granularity	Risk coverage	Link to published results
Netherlands	De Nederlandsche Bank (1)	Concluded	Static	Top-down	Sector	Transition	Link
Netherlands	De Nederlandsche Bank (2)	Concluded	Static	Top-down	Counterparty	Physical (acute)	Link
Netherlands	De Nederlandsche Bank (3)	Concluded	Static	Hybrid	Counterparty	Transition	Link
Norway	Norges Bank	Concluded	Static	Top-down	Counterparty, sector	Physical (acute), transition	Link
Norway	Finanstilsynet	Concluded	Static, dynamic	Top-down	Macroeconomic	Transition	Link
Poland	Polish Financial Supervision Authority	Sep 2022	Static	Hybrid	Counterparty, sector	Physical (acute/chronic), transition	
Portugal	Banco de Portugal	Mar 2023	Static	Top-down	Counterparty,	Physical (chronic), transition	
Singapore	Monetary Authority of Singapore	H2 2022	Static	Bottom-up	Counterparty, macroeconomic, sector	Physical (acute/chronic), transition	
South Africa	South African Reserve Bank (1)	Concluded	Static, dynamic	Hybrid	Sector	Physical (chronic)	Link
South Africa	South African Reserve Bank (2)	2024	Static, dynamic	Hybrid	N/A	Physical (acute/chronic), transition	
Spain	Banco de España (1)	Concluded	Dynamic	Top-down	Sector	Transition	Link
Spain	Banco de España (2)	H2 2022	Dynamic	Top-down	Sector	Physical (acute/chronic)	

Jurisdiction	Organisation	Expected end date of the exercise	Balance sheet assumption	Approach	Level of granularity	Risk coverage	Link to published results
Spain	Banco de España, joint with DGSFP, CNMV and Tesoro - AMCESFI[40] (3)	H1 2023	N/A	Top-down	Sector	Transition Physical (acute/chronic)	Link (see Box 1A)
Switzerland	Swiss National Bank (SNB) & Swiss Financial Market Supervisory Authority (FINMA)	Concluded	Static	Hybrid	Sector	Transition	
Trinidad and Tobago	Central Bank of Trinidad and Tobago	tbd	Static	Top-down	Macroeconomic	Physical (acute), transition	
United Kingdom	Bank of England	Concluded	Static	Bottom-up	Counterparty, macroeconomic, sector	Physical (chronic, acute), transition, litigation	Link
United States	Federal Deposit Insurance Corporation (1)	tbd	tbd	tbd	tbd	Physical (acute/chronic), transition	
United States	Federal Housing Finance Agency (2)	Dec 2023	Static	Hybrid	Counterparty, sector	Physical (acute/chronic), transition	
United States	Federal Reserve Board (3)	End 2023	tbd	Bottom-up	tbd	tbd	
United States	Inter-American Development Bank (4)	2022/2023	Static	Bottom-up	Macroeconomic	tbd	

[40] AMCESFI is the Spanish Macroprudential Authority Financial Stability Council that is preparing its first biennial report to assess the risks to the Spanish financial sector posed by climate change. This report will be prepared jointly every two years by the financial system's three sectoral supervisory authorities (Banco de España, CNMV and the DGSFP).

Jurisdiction	Organisation	Expected end date of the exercise	Balance sheet assumption	Approach	Level of granularity	Risk coverage	Link to published results
United States	New York State Department of Financial Services (5)	Concluded	Static	Hybrid	Counterparty, sector	Transition	Link
United States	Office of the Comptroller of the Currency (OCC) (6)	tbd	tbd	Hybrid	Counterparty, sector	Physical (acute), transition	
International	ASEAN+3 Macroeconomic Research Office (AMRO)	End 2023	Static	Top-down	Macroeconomic, sector	Physical (acute/chronic), transition	
International	European Bank for Reconstruction and Development (EBRD)	Concluded	Static, dynamic	Hybrid	Counterparty	Transition	
International	European Stability Mechanism	End 2023	tbd	tbd	tbd	tbd	

Annex 3: Examples of climate-related data and metrics used by respondents

Category	Sub-category	Examples
Transition Risk	GHG Emissions	Aggregate, sector- [most], and/or firm-specific [ECB, Bundesbank] GHG emissions; differentiation b/w nonfinancial and financial GHG emissions [ECB]
	Transition pathways	Net income components (direct emissions costs, indirect input costs, capital expenditures, revenue) [Canada]
	Carbon taxes/prices	Carbon price pathways [several]; impact of alternative carbon taxes on firms' and households' energy demand/cost [BdI]
	Energy mix and costs	Energy demand by type, commodity prices, energy prices for buildings [BoE, BoG, ECB]
	Other	Mix (internal combustion/electric/hybrid) of new and/or used vehicle registrations and prices [BoE, BoG]
Physical Risk	Physical hazard indicators	Indicators for flooding, wildfires, sea level rise, subsidence, cyclonic storms, health risk, air temp., precipitation, humidity, cloud cover, wind speed [BdF, BoG, MAS, and BoE, ECB, BoJ/JFSA, Norway]
Real Economy Exposure	Impact on NFCs	Sector- or firm-specific impact of climate risks on economic activities of NFCs [most]
	Macroeconomic and financial indicators	Potential propagation/amplification of climate-related shocks through macrofinancial feedback loop effects [Canada]
	Other	Impact of varying carbon tax levels on firms' EBITDA and households' income [BdI]
Financial System Exposure	PD and LGD	Impact on loan PD and LGD [most]
	Other	Type/amount of loan collateral [Bank of Finland, Danmarks Nationalbank]; exposures of funds to high-emissions sectors and economies [ESMA]; losses from bond repricing [ECB]
Propagation of Systemic Risk	Interdependencies and interlinkages	Amplification or propagation throughout financial system via interlinkages [most]; aggregation of metrics for transition risk, physical risk, real economy exposure [BoE], repricing of assets and impact on unemployment rate and housing prices [FHFA]
Financial Sector Transition Plans	Qualitative Evaluations	Having financial institutions to assess and review their counterparties' and customers' transition plans [BoE] and consider "adaptation" plans of large counterparties and explain strategies for exposure reallocation [ECB], information on potential management actions of banks and insurers [MAS]
	Dynamic Balance Sheets	Evolution of sector-specific exposures on balance sheets [BdF, APRA]