Network for Greening the Financial System

Guide to climate scenario analysis for central banks and supervisors – Update

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NGFS
Central Banks and Supervisors
Network for Greening the Financial System

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Notice to readers on physical risk estimates in Phase V of NGFS long-term scenarios

The NGFS long-term climate scenarios are a set of forward-looking pathways designed to explore how the global economy and financial system might evolve under different levels of climate policy ambition and physical climate impacts over the rest of the 21st century. They were developed by the Network for Greening the Financial System (NGFS) to provide a consistent analytical basis for assessing climate-related financial risks and opportunities. The academic paper underpinning the physical risk estimates in Phase V of NGFS long-term scenarios (released in November 2024), Kotz *et al.* (2024), has received academic critiques (see first and second Matters Arising) as part of the post-publication review process at Nature.

Therefore, users should be aware of this academic debate pertaining specifically to the Phase V physical risk methodology when interpreting and applying Phase V results, alongside the broader limitations of physical risk estimates already detailed in NGFS documentation.

It should be noted that the long-term scenarios outputs which do not incorporate physical loss estimates from Kotz *et al.* (2024) remain unaffected.[1] Also, the outputs of NGFS short-term scenarios are not impacted, as they do not rely on the Kotz *et al.* (2024) paper.

It cannot be excluded that the economic effects of climate change might turn out to be more severe than anticipated in the NGFS scenarios, for instance, if certain tipping points are reached. Thus, users should also take into account the tail risks of climate change, along with other risks such as nature-related ones, which are not necessarily captured by these scenarios.

The NGFS is constantly working to further improve the scenarios, including with regard to physical risks. Users are reminded that neither the NGFS, nor its member institutions, nor any person acting on their behalf, is responsible or liable for any reliance on, or for any use of the NGFS scenarios and/or supplementary documentation. This also applies to the use of the data produced under the scenarios – see section 5 in https://data.ene.iiasa.ac.at/ngfs/#/license. Thus, while the NGFS climate scenarios are certainly a helpful tool, they do not alleviate the responsibility of users, including banks and other (financial) organisations, to design and implement their own risk management frameworks.

1 The affected variables are those reflecting physical loss estimates from Kotz *et al.* (2024) in Phase V of NGFS long-term scenarios. This includes: all outputs of "Integrated Physical Damages" scenarios by REMIND-MAgPIE, all "physical" and "combined" (*i.e.* combined physical and transition damages) outputs by NiGEM, as well as post-processed or downscaled outputs for GDP damages from the damage function (*i.e.* GDP change and Net GDP variables referring to "Kotz-Wenz"). All other variables from Phase V, the physical risk estimates as presented in the Climate Impact Explorer, as well as outputs from previous phases of NGFS long-term scenarios, remain unaffected.

Joint foreword by Sabine Mauderer and Livio Stracca

Sabine Mauderer
Chair of the NGFS
(Deutsche Bundesbank)

Livio Stracca
Chair of the Workstream
on Scenario Design and Analysis

Since the publication of the first NGFS Guide in 2020, we have seen significant progress on climate scenario analysis. What was once an emerging topic has become a critical tool for risk management, strategic planning, and policy design. Around the world, financial institutions, central banks, and supervisors are integrating climate-related risks into their risk frameworks with increasing depth and sophistication. This progress reflects not only the growing need to address climate change but also the growing maturity of the tools and methodologies available to understand and respond to it.

In this context, the NGFS has played a pivotal role in advancing climate scenario analysis. Through successive updates of the NGFS climate scenarios and the growing experience across its members, the NGFS has helped to develop more nuanced, granular, and policy-relevant assessments of both physical and transition risks. This updated Guide builds on those advancements, offering practical insights, improved methodologies, and new use cases that reflect how far we have come and how much work still remains.

Despite these strides, climate scenario analysis remains a complex task. It requires grappling with deep uncertainty, long time horizons, and the interplay between climate dynamics, economic behavior, and financial system responses in the short-term. The goal of this Guide is to help practitioners address these challenges by providing robust frameworks that enable better-informed decisions in the face of uncertainty.

This update draws on the collective expertise of NGFS members and partners around the world. It also underscores the importance of transparency, collaboration, and continuous learning as we refine our approaches. The NGFS remains committed to supporting the development of high-quality, policy-relevant climate scenarios and providing analytical guidance. We hope this updated Guide will continue to serve as a valuable resource for central banks, supervisors, financial institutions, and all those working to ensure that financial systems are resilient in the face of climate-related risks. The challenge is great, but so is our collective capacity for innovation, cooperation, and action.

Executive summary

The members of the Network for Greening the Financial System (NGFS) acknowledge that financial systems and financial institutions are exposed to significant impacts from climate change. They encourage central banks and supervisors to lead by example and integrate climate risks into financial stability monitoring and supervision. Climate risks include physical risks, related to the physical impacts from climate change, and transition risks, related to the adjustment to a net-zero emission economy.

Since the publication of the first edition of the NGFS Guide on Climate Scenario Analysis, the field has matured substantially. When it was first released in 2020, the Guide represented a pioneering effort to establish a structured and practical framework for central banks, supervisors, and financial institutions to begin exploring climate-related risks through scenario analysis. That original Guide emphasized the novelty of the exercise and the practical challenges involved in adapting existing risk assessment tools to the forward-looking and uncertain nature of climate change.

This updated Guide builds on the original foundation, incorporating the lessons learned from the past years of innovation and application by NGFS members and the broader community. The first edition was published at a time when most central banks and supervisors were still at the early stages of applying climate scenario analysis. Since then, climate scenario work has become a central feature of supervisory climate stress tests, macroprudential risk assessments, and the risk management frameworks of financial institutions. NGFS scenarios have been widely adopted as international reference points, and their successive vintages have steadily improved in terms of granularity, sectoral detail, regional coverage, and integration of physical and transition risks. This new Guide reflects the rapid progress made in methodologies, data availability, modelling approaches, and supervisory practice.

The four-step process introduced in the first Guide remains a useful organizing principle, but the updated Guide expands each step with new insights, methodologies, and examples.

Four step process

Step 1: Identify objectives and scope. Climate scenario analysis can serve diverse objectives, from system-wide financial stability assessments to supervisory stress testing, to risk management of central bank portfolios. Experience has shown that clarity of purpose is critical to determine the level of detail of the analysis. A materiality assessment can be useful at the outset to help determine the risk drivers that will be in or out of scope. A targeted exercise would focus on the impact of these risks on a small number of economic indicators, sectors, financial asset classes and/or financial firms, while a system-wide risk assessment would be more expansive.

Step 2: Choose climate scenarios. The NGFS long-term scenarios remain a cornerstone for international comparability and consistency. Since the first Guide, successive vintages have expanded their granularity, with greater sectoral detail, improved representation of physical risks, and updated macroeconomic pathways aligned with international climate targets. The NGFS has also published its first vintage of short-term scenarios, which are increasingly relevant for assessing near-term risks tied to policy, technology shocks, or extreme weather events. Considerations on short-term scenarios and the selection of the proper time horizon are also reflected in this Guide.

Each user will need to make a number of additional design choices to tailor the scenarios to the specific exercise. The updated Guide discusses how to tailor these reference scenarios for specific purposes, including adjusting sectoral and regional assumptions, expanding scenario narratives, and integrating tail risks.

Step 3: Assess economic and financial impacts: Considerable progress has been made in tools that translate climate developments into economic and financial outcomes. The Guide discusses a wide range of approaches, including Integrated Assessment Models (IAMs) used in the NGFS long-term scenarios that link climate, energy use, and the economy in one framework, giving a broad and consistent picture but without much financial detail, as well as Computable General Equilibrium (CGE) models used in the NGFS short-term scenarios that provide additional detail on sectoral impacts and a bottom-up modelling of the energy sector and technologies. Stress-testing tools used by supervisors go deeper into banks' balance sheets and portfolios, but they rely on scenario inputs from the broader climate-economy models.

For practical application, the Guide points to the scenarios already developed by the NGFS. The NGFS long-term scenarios provide information on climate-related developments, energy transitions, and expected macroeconomic impacts, which can be complemented with additional detail on sectors or financial risks where needed. The more recent NGFS short-term scenarios go further by directly including sectoral and financial impacts, reducing the amount of work required from users. Together, these scenario sets offer a foundation that can be adapted and expanded with additional modelling tools depending on user needs.

Step 4: Communicating and using results. Scenario analysis is increasingly being used not only as a diagnostic tool but also as a foundation for strategic decision-making, guiding supervisory dialogue, and shaping financial institutions' risk management practices. Communicating the results, and the key assumptions underpinning them, will help improve awareness. The scenario analysis exercise may lead to further analysis of specific pockets of risk and monitoring of key risk indicators. It can also inform whether existing regulatory policies (e.g. capital treatment) and approaches (e.g. economic forecasting) are fit for purpose.

Looking forward

This second edition marks an important milestone in advancing climate scenario analysis within central banking and supervision. While major progress has been made, important challenges remain, such as limitations in climate and financial data, the difficulty of calibrating tail risks, and the need to reconcile short-term market dynamics with long-term structural changes. It is intended as both a practical manual and a living reference, evolving as methodologies mature and as collective experience grows.

The NGFS provides detailed technical documentation *via* the Scenario Explorer and website, and users can contact the NGFS (sec.ngfs@banque-france.fr) or raise questions *via* the NGFS Q&A form for additional guidance. This can help ensure that modifications remain aligned with the underlying modelling framework and that scenario outputs retain comparability across exercises.

1. Introduction

The NGFS's goal is to share best practices and equip central banks and supervisors, as well as private institutions, with the tools to identify, assess and mitigate climate risks in the financial system. Since it was founded, the NGFS has steadily advanced this agenda, with the first edition of the User Guide on Climate Scenario Analysis representing a landmark step in this process. This updated edition builds on that foundation, reflecting the considerable progress made in recent years, both by NGFS members and the wider community, in developing and applying scenario analysis.

Climate risks continue to challenge conventional approaches to risk assessment. Their long time horizons, uncertainty around future socio-economic, policy and climate developments, and global scope set them apart from traditional financial risks. Standard approaches, which often rely on historical data, are not sufficient to capture the uncertain and forward-looking nature of climate risks.

Scenario analysis has therefore become an indispensable tool to overcome these challenges. By providing a structured, "what-if" framework, scenarios allow users to explore how climate-related risks may evolve across different pathways and what implications they hold for the economy and the financial system. In recent years, experience has shown the value of these exercises for shaping supervisory expectations, informing monetary and financial stability assessments, and guiding risk management strategies.

Since the publication of the first Guide, significant methodological advancements have been made. The integration of physical and transition risk channels has deepened, with greater sectoral and regional granularity. Modelling capabilities have broadened, blending climate-economy models, macroeconomic tools, and stress testing frameworks. Importantly, the first vintage of NGFS **short-term scenarios** has been published to capture near-term climate-related shocks, complementing the longer-term pathways.

The NGFS continues to collaborate with the academic community to publish standardised sets of scenarios that can be used for macro-financial analysis in an open-source platform. This includes both short- and long-term scenarios with structured sets of transition risk, physical risk, and macroeconomic variables and the key assumptions that they rest on.

This updated Guide incorporates the advances made and translates them into practical advice for central banks, supervisors, and financial institutions. It is informed by the lessons learned from climate stress tests and applications of scenario analysis conducted globally by central banks, supervisors, as well as the private sector since the first edition.

Scenario analysis involves four broad steps: identifying objectives and exposures, choosing scenarios, assessing impacts and communicating results. The guide is set out as follows:

- Chapter 2: Identifying objectives, material risks and stakeholders;
- Chapter 3: Choosing relevant scenarios;
- Chapter 4: Using the scenarios to assess economic impacts;
- Chapter 5: Using the scenarios to assess financial risks;
- Chapter 6: Communicating the results and next steps.

Figure 1 **Overview of the scenario analysis process**

1 Identify objectives, material risks and stakeholders

Central banks and supervisors should ensure the scope of the exercise is focused on key exposures. This involves identifying the institution's objectives, the most material risks and the key stakeholders to involve.

Possible objectives:

- A. Assessing financial firm-specific risks
- B. Assessing financial system-wide risks
- C. Assessing macroeconomic impacts
- D. Assessing risks to central bank's own balance sheet

Identify most material risks

- Assess materiality

Identify target audience

- Map key stakeholders

Define appropriate time horizon

shorter time horizon — ↓ uncertainty | better capture of long-term effects — *longer time horizon*

Depending on scenario analysis objective and financial instruments being analysed

2 Design scenarios

Central banks and supervisors should choose scenarios that are relevant to the risks they want to explore.

Based on

- Expected scenario outcomes
- Relevance to local context
- Severity of scenario
- Time horizon of scenario

determined by

- Assumptions on:
  - Socioeconomic context
  - Climate policies
  - Technological evolution
- Type of risk to be analysed (i.e. physical vs transition)

Define appropriate number of scenarios

fewer scenarios — ↑ ease of implementation, ↑ ease of communication | ↑ Scope of results — *more scenarios*

Depending on scenario analysis objective

3 Assess impacts

Central banks and supervisors should select the methods and tools needed to assess the potential macroeconomic and financial impacts.

- ***Assess economic impacts***

Specifics:

- What key variables?
- What level of granularity?
- What tools and how to use them?
- How to refine outputs?
- What are the key assumptions and sensitivities?

Level of granularity

	Economic resolution	*Spatial resolution*	*Temporal resolution*
Low *Medium* *High*	↑ Macro to firms & households	↑ Global to sub-national	↑ Decade, annual, quarter, etc.

- ***Assess financial risks***

Specifics:

- Which type of exercise?
- Which method?
- Which data?
- How to recalibrate scenarios?
- What are the key assumptions and sensitivities?

Type of exercise

Top-down exercise — ↑ ease of implementation | ↑ granularity of outputs — *Bottom-up exercise*

Depending on granularity of the analysis

4 Communicate and use results

Central banks and supervisors should consider the information to disclose in order to improve firms' risk-mitigation practices and foster further research.

Communication
E.g. awareness, stimulate research and discussions

Policy actions
E.g. micro/macro-prudential, monetary, economic, fiscal

2. Identifying objectives, material risks and stakeholders

This Chapter sets out the preparatory work that institutions should do to ensure the scope of the exercise is focused on key exposures. This involves determining how the exercise relates to the institution's objectives, assessing the materiality of climate risks to these objectives and identifying the key stakeholders.

Objectives

Scenario users should first consider how the exercise will relate to their objectives. Generally, climate scenario analysis can support decision-making by providing forward-looking insights under conditions of uncertainty. At a high level, scenario analysis can serve broader strategic and analytical objectives, including:

A. Cost-benefit analysis: evaluating the trade-offs of the costs of potential transition pathways or climate policies versus the costs from climate change impacts in the case of unmitigated temperature rises.
B. Impact and resilience assessment: testing the resilience and capacity of firms, sectors, or the financial system to adverse climate-related shocks, and understanding vulnerabilities such as across sectors and regions.
C. Strategy development: informing the strategic responses of financial institutions, central banks, and supervisors (e.g. risk management, portfolio alignment, transition planning).
D. Capacity building: developing internal expertise, data infrastructure, and analytical tools to deal with forward-looking uncertainty.

Defining the objective of the exercise will help determine the type of assessment and thereby breadth of analysis undertaken. Scenario analysis can be applied at different levels:

- *Assessing specific risks to financial firms*, including the impact on firm balance sheets, profitability, capital and / or business models. See also the *NGFS Guide for Supervisors on Integrating climate-related and environmental risks in prudential supervision*;
- *Assessing financial system-wide risks*, including their aggregate size, distribution and systemic nature;
- *Assessing macroeconomic impacts*, including the short and long-run effects on growth, employment, inflation and terms-of-trade;
- *Assessing risks to a central bank's own balance sheet*, including arising from their market operations and other portfolios they manage (e.g. on behalf of government).

Central banks, supervisors, and financial institutions should also consider how to integrate scenario analysis into existing risk assessment processes. For example, by incorporating climate scenarios into a financial system stress test or a macroeconomic forecast. Table 1 below sets out some further examples. These exercises can be quantitative or qualitative.

Table 1 **Examples of how central banks and supervisors assess different risks**

	Objective	Types of assessments	Useful for
A	Cost-benefit analysis	Assess macro-economic and -financial impacts	Macroeconomic forecasting, research on structural changes, Monetary policy and Financial stability
B	Impact & resilience assessment	Assess financial firm specific risks and system-wide risks, challenging firm capital adequacy assessments, research on individual transmission channels	Stress testing, Microprudential policy: Identifying risks to safety and soundness Macroprudential policy: Identifying systemic risks and macroeconomic impacts Assess risks to own balance sheet
C	Strategy development	Risk assessments factoring in changes in strategic decisions (e.g. portfolio reallocation)	Managing risks to own operations TCFD disclosures, Transition planning Assess risks to own balance sheet
D	Capacity building	Developing data, tools, and methodologies through any of the above assessments	Enhancing institutional preparedness; Building expertise; Improving modelling capacity

Box 1

Bank of England: Assessing climate-related risks of the central bank balance sheet and monetary policy operations

Central banks are affected by risks stemming from climate change as they engage in collateralised lending to eligible counterparties or purchase financial assets as part of their monetary policy operations. Hence, their financial assets may be exposed to climate-related risks in the same way as those held by private financial institutions (NGFS, 2024a). Therefore, scenario analysis can be a useful tool for central banks when evaluating climate risks associated with their balance sheet. For instance, the Bank of England (BoE) has conducted several climate scenario analyses, utilising NGFS scenarios, to assess the exposures of its balance sheet to both physical and transition risks (see Bank of England, 2024).

Sovereign bonds are an important asset class when it comes to central banks' balance sheet and monetary policy operations. The market for them is highly liquid, they are widely accepted as collateral, and they are often used as a benchmark for the pricing of other financial assets. Using the NGFS scenarios, the BoE has estimated climate-related financial risks related to its sovereign bond portfolio, specifically, its exposure to interest rate risk and credit risk.

One key challenge of the exercise was to translate the projections of macroeconomic variables of the climate scenarios to more granular bond-level projections. For interest rate risk, the BoE approach started by taking the projections for short-term and 10-year interest rates from the NGFS scenarios and extended them to obtain projections across the whole yield curve. By compounding these interest rates projections bond yields of different maturities were derived for each scenario, assuming that investors have perfect foresight.

For credit risk, the risk premia associated with sovereign bonds were estimated based on their empirical relationship with the debt-to-GDP ratio and sovereign credit ratings.[2] The projections of debt-to-GDP ratio were obtained by bottom-up estimates of the evolution of the numerator, i.e. sovereign debt, using data on several contributing variables, including GDP, carbon tax revenues, green investment and fuel taxation – some of which are directly available from the NGFS scenarios. To obtain projections of sovereign credit ratings, a random-forest machine learning model was employed which projected credit ratings as a function of debt-to-GDP ratio, GDP growth, GDP per capita, GDP growth volatility, current account balance (as percentage of GDP), as well as the location of the issuer[3]. The projections were then used to project the changes in sovereign risk premia for each scenario *via* the sensitivity of sovereign risk premia to debt-to-GDP ratio and credit ratings, estimated with historical data.[4]

The projected risk premia were then combined with interest rate shocks from the NGFS scenarios to obtain the total yield curve shock. Finally, the shocked yield curves were combined with standard methods from fixed income mathematics to estimate the financial losses from BoE's sovereign asset holdings in each scenario. Sovereign bond portfolio analysis is just one illustration of how the NGFS climate scenarios can be utilized by central banks to assess climate-related risks of their monetary policy operations. The BoE has also considered climate risks related to corporate bonds and residential mortgages held in their balance sheet.

2 For the sake of the analysis, it is assumed that sovereign bond yields are the sum of the risk-free rate and the credit risk margin.

3 i.e. whether the issuer is from an EU member state or from Japan.

4 The scenario horizon spanned until 2050, but an instant repricing of the existing stock of sovereign bonds in the first scenario year was assumed to reflect those future risks out to 2050 being priced in today.

Assessing material risks

Scenario analysis should aim to assess the most material risks to the institution's objectives. A materiality assessment can help identify the climate drivers that are likely to have the most significant impacts. This will help identify relevant scenarios and prioritise analysis, given that it would be impractical to explore all potential risks at the outset. It is very important to be clear about the risk drivers that are in or out of scope. These judgments should be revisited after the conclusion of the exercise to ensure the scenario analysis is focused on the most relevant risks.

Users should first gather all relevant information that is available, bearing in mind that there will likely be information gaps. Good starting points include the publication documents of the NGFS short- and long-term scenarios[5], as well as the IIASA-NGFS scenarios explorer portal.[6] These set out climate risk drivers and their possible impacts on the financial system and economy. This will likely need to be supplemented with jurisdiction-specific research on climate risks from the financial sector, government, industry and academia, including climate scientists.

Users should then identify the types of risks that will be included in the assessment. Transition risks relate to action taken to reduce emissions to reach net zero greenhouse gas emissions. Physical risks relate to the effects of global warming on physical capital, human health and productivity and agriculture. Macro-financial risks refer to the standard financial risk categories (e.g. credit, market, operational) and economic indicators (e.g. output, unemployment, inflation). While these three categories are often presented separately for analytical clarity, they are inherently interlinked. Transition and physical risks both give rise to macro-financial consequences. For example, a disorderly transition may lead to stranded assets and higher credit risk, while intensified physical hazards can disrupt production, reduce productivity, and increase inflationary pressures. Macro-financial risks therefore represent the aggregate economic and financial transmission of underlying physical and transition shocks.

Table 2 **Research questions to identify potential risks and assess materiality**

Type of risk		Research question	Source of information
Climate	Physical risk drivers	• What are the most material domestic physical hazards from extreme events (e.g. flooding, extreme temperature changes, windstorms) and from gradual changes in climate (e.g. changes in agricultural yields or water availability, sea level rise, heating and cooling requirements)? • What effects could there be on real estate and infrastructure, business continuity, people and food systems? • Are there any significant international transmission channels (e.g. import/export of food, supply chains)? • What kind of adaptation measures are being implemented (e.g. shift in crop types, water regulations, coastal protection measures)? • Are there any compounding, non-linear effects from co-occurring natural hazards (e.g. the combination of droughts and floods)?	• NGFS publications • Government reports • Academic research (including IPCC reports) • Financial industry reports on climate risks • Public data sets (e.g. physical hazards, energy efficiency, emissions)
	Transition risk drivers	• What type of government policies are being considered/implemented (e.g. carbon tax, direct regulation, subsidies)? • Which technological trends could play a key role in the coming decades (e.g. renewable energy, carbon capture and storage, electrification of motor vehicles)? • Are there any significant changes in consumer preference (e.g. transport demand, diets, energy efficient housing, energy efficient appliances)? • Which sectors of the economy are particularly at risk of policy or technological disruption (e.g. energy sector, agriculture, construction, industry, mobility and freight transport)?	

5 See the publication documents of Phase V long-term scenarios here, and Phase I short-term scenarios here.

6 See Long-Term Scenarios Explorer Portal here and Short-Term Scenarios Explorer Portal here.

Macro-financial	Financial	• What are the largest exposures of banks by type of asset (e.g. retail credit, wholesale credit, trading book)? • What are the largest insurance underwriting exposures? • What are the largest exposures for capital markets (equities, corporate bonds, derivatives, structured products)? • What is the geographical distribution of these exposures? For corporate exposures, this should take into account both jurisdiction and operating locations • What is the distribution across economic sectors for these exposures?	• Financial regulatory data • Central bank statistical information • Review of relevant variables in internal financial and macroeconomic models • Academic research
	Macroeconomic	• What are the most material drivers of changes to macroeconomic conditions (e.g. GDP and potential growth, unemployment, interest rates, inflation)? • What is the current sectoral composition of the economy and how is this changing?	

Climate risks are complex and there are many dimensions to consider. These include: the extent to which the risks vary depending on the time horizon (e.g. short-term, medium term, long-term risks), the risk distribution (e.g. average losses, losses from worst-case low-probability events) and how much we know about the potential impacts from events where we have little historical experience.

Stakeholders

Users should consider how their stakeholders will be involved in the scenario analysis. These stakeholders could be included explicitly, as part of the exercise (e.g. in a firm-based stress test); and/or part of the target audience for the results (refer to Chapter 6 for more details on communication). There are five main groups:

- **Financial institutions** (including banks, insurers, asset owners and asset managers) are developing their own scenario analysis expertise. Credit rating agencies are also looking at scenarios to refine and develop their ratings methodologies. These efforts can both inform, and learn from, scenario analysis undertaken by central banks and supervisors. Supervised entities may also participate directly in the exercise.
- **Financial standard setters** may find the results of scenario analysis useful in developing domestic and international standards for financial institutions.
- The **general public** is an important stakeholder given the role of central banks and supervisors as public institutions. Scenario analysis may inform, and be informed by, the public discourse around risks and responses to climate change, for instance, when deciding on scenario narratives.
- **Governments and international bodies.** National mitigation and adaptation plans, and international coordination on these issues, will be a key input into the scenario analysis. Information on the transmission channels and macro-financial impacts of the exercise may in turn inform government policy.
- The **academic community** engages in research on the impacts of climate change. Central banks and supervisors have a role to play in fostering and learning from research on the role played by the economy and financial system.

3. Scenario design

Climate scenarios explore different possible climate change futures and pathways towards achieving long-term climate goals. This Chapter sets out the main assumptions underpinning climate scenarios and some further scenario design choices to be made. It finishes by providing an overview of the NGFS scenarios.

Choice of the scenario horizon

The appropriate time horizon for the chosen scenarios will depend on the objective of the specific exercise. Short-term scenarios are more suitable to analyse near-term adverse shocks and tail risks, such as sudden climate policies and extreme weather events. Hence, shorter time horizons are useful to analyse that could crystallise within business planning horizons and to assess the financial resilience and impact on regulatory capital more precisely. EIOPA (2019), Norges Bank (2019) and De Nederlandsche Bank (2018) used a 5-year scenario length in their analyses of climate-related risk. Longer time horizons are useful to assess the impacts of structural changes, such as changes in technology or chronic weather patterns, on the economy and financial system and to consider how the strategic decisions and business models of financial firms could affect the risks. Banque de France/ACPR (2020), Bank of England (2021) and Danmarks Nationalbank (2019) consider timelines of up to 2050, 2080 and 2100, respectively.

Short-term scenarios can help convey a greater sense of urgency, and are perhaps easier to conceptualise, but provide a relatively limited view of how the risks unfold relative to long-term scenarios. This, however, comes with an important caveat that the longer the scenario, the greater the uncertainty band around the results. This increases the importance of choosing an initial set of starting assumptions that reflect the risks that will be explored. Table 3 lists the pros and cons of short versus long-term scenario horizons in more detail.

Table 3 **Opportunities and challenges in the choice of the scenario horizon**

	Short-term horizon	Long-term horizon
Opportunities	• Better fit to assess impacts on solvency • More in line with the decision-making horizon of policy makers and industry • Closer to standard, non-climate stress testing **NGFS resources: NGFS short-term climate scenarios**	• Accounts for structural evolutions in climate and physical risks • Allows to test the resilience of business models to structural changes • Allows to get insights into the strategic decision making of institutions under dynamic balance sheet assumptions (see next subchapter) **NGFS resources: NGFS long-term climate scenarios**
Challenges	• Cannot capture the long-term consequences of the short-term climate assumptions (e.g. the frequency and severity of climate impacts under a given short-term emission trajectory)	• High uncertainty of projections in the long-term • Challenges associated with dynamic balance sheets in long term horizons (see next subchapter)

Box 2

Alternative short-term scenarios used by other authorities DNB and the ESRB/ECB

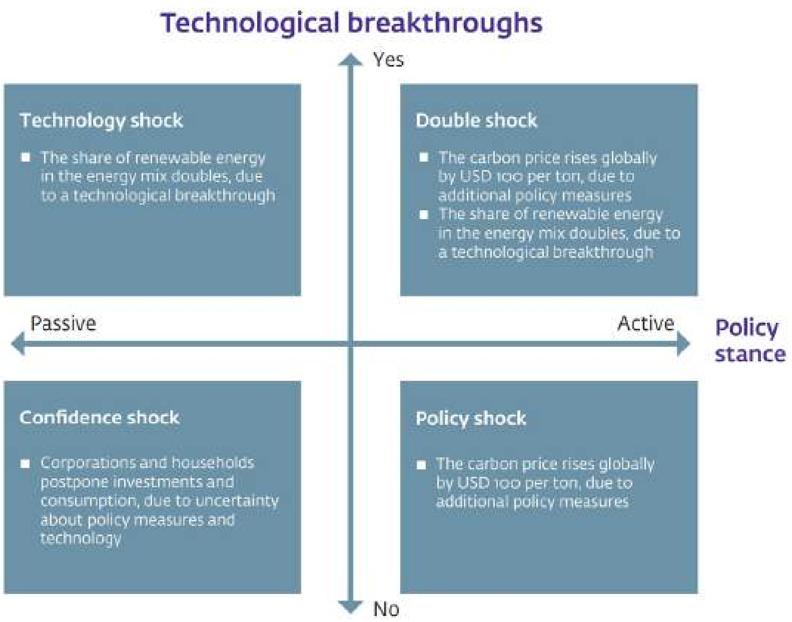
In its transition risk stress test, DNB explores four short-term disruptive energy transition scenarios (see Vermeulen *et al.*, 2018). In line with common stress testing practice (cf. BCBS, 2018), the four stress scenarios were chosen to be 'severe but plausible,' thus capturing tail risks. To determine scenario narratives that would qualify as severe but plausible for the short term, DNB tested the scenario assumptions with external experts.

Unlike the NGFS scenarios, the DNB scenarios are not explicitly tied to a temperature outcome and focus on transition risk. This approach has the advantage of creating scenarios that are more or less independent of climate science. The guiding assumption is that the energy transition is ultimately a socio-political and technological phenomenon, which can occur under varying conditions of climate change. A drawback of this approach, however, is that there is no direct link between the DNB scenarios and the well-known IPCC scenarios. In addition, the DNB approach is mainly effective for short time horizons where it is safe to ignore the interplay between the energy transition and climate change, but may be less suitable for exercises that focus on a longer time horizon. The DNB scenarios cover a five-year time period.

DNB calibrated its scenarios along two axes, which each reflect a key driver of the energy transition: policy and technology (figure 8). This resulted in one scenario with a delayed policy response ("policy shock"), one scenario

…/…

Figure 2 **DNB scenarios**[7]



7 In the "Policy shock" scenario, policies aiming at achieving the goals set by the Paris Agreement are initially deferred. As a result, policies reducing CO_2 emissions and limiting the increase in global temperature to below 2 degrees Celsius above pre-industrial levels are ultimately introduced in a disorderly manner. The late implementation of policies necessitates abrupt adjustments leaving the private sector, and subsequently the financial sector, with little time to accommodate changes.

The asymmetric "Technology shock" scenario considers a positive breakthrough in energy storage technology. Because the breakthrough is unforeseen, it becomes a source of disruption for the economy and the financial sector. This results in a precipitous redistribution of resources across sectors, defaults and write-offs of carbon intensive assets.

In the "confidence shock" scenario, it is assumed that policy uncertainty triggers a sudden drop in confidence, such that consumers delay their purchases, producers invest more cautiously and investors demand higher risk premiums. As a result, there is a setback in GDP, stock prices fall and lower inflation leads to lower interest rates.

with an asymmetric "technology shock" and one scenario in which both disruptions occur simultaneously ("double shock"). In the case where neither disruption occurs, it is assumed that the lack of an energy transition triggers a drop in confidence for consumers, businesses and investors ("confidence shock"). The first two scenarios, i.e. a delayed policy response and an asymmetric technology shock, were also considered in the pilot stress test developed by the joint ESRB/ATC and ECB/FSC project team.

The scenarios are derived within the multi-country model NiGEM that provides detailed information about the evolution of macro-financial variables at a country level. In the delayed policy response it is assumed that an abrupt policy change aiming at mitigating climate change translates into a sudden and sharp increase in the carbon price by US$ 100 per ton at the global level. An abrupt increase in energy prices leads to sharp devaluation of trading assets, reflected in the drop of stock and bond prices, and the deterioration of economic conditions for the entire 5-year horizon. In case of a technological innovation shock, the technological breakthrough would allow the share of renewable energy to double over a five-year period. The asymmetric technology shock leads to a temporary economic slowdown because of frictions associated with the switch from the old to the new technology, but the new technology ultimately supports economic growth. The double shock resembles the technology shock pattern, but with a steeper initial setback of economic growth due to the increase in the carbon price. The confidence shock scenario is modelled as a drop in consumption and an increase in the cost of capital of firms and the risk premia of investors, which together lead to a broad economic slowdown.

In the ESRB/ATC-ECB/FSC exercise, both scenarios (policy and asymmetric technology shocks) are considered against the baseline accommodating current policies.[8] In the DNB exercise a baseline was not explicitly defined, given that it is unclear what a short-term "business-as-usual" scenario might look like in the context of climate change. Indeed, if business-as-usual is interpreted as a scenario in which no additional climate change mitigation policies are implemented, this would be a scenario in which physical risks will likely increase significantly in the long run. In the short run, this may well result in a confidence shock as depicted in the bottom-left corner of figure (Figure 8).

Overview of the NGFS Scenarios

Since 2020, the NGFS has published multiple sets of climate scenarios that can be used to explore the economic impacts and financial risks from climate change. In 2024, it published its fifth vintage of long-term scenarios that span until 2100. Since the first vintage, the NGFS has continuously updated the long-term scenarios by using the latest economic and climate data available, as well as accounting for the most recent climate commitments of jurisdictions. Since the third vintage, the NGFS long-term scenarios also provide estimates for acute physical risk.

Moreover, in 2025 the NGFS published its first vintage of short-term scenarios with a time horizon until 2030. The short-term scenarios fill a key gap in the NGFS toolkit, as they provide insights on potential developments of climate-related tail risks within a policy-relevant time horizon and at a more granular and comprehensive level.

The long- and short-term scenarios have been developed with different time horizons and analytical objectives in mind. The long-term scenarios provide guidance on long-term trends and offer a smoothed depiction of the structural changes associated with reaching climate goals and with inaction, focusing on macroeconomic and financial system impacts up to 2100. By contrast, the short-term scenarios are tailored for near-term macro-financial assessments and display greater year-on-year volatility. They are best suited for stress testing and short-horizon financial stability analysis, up until 2030.

The NGFS Scenarios are not forecasts, but rather explore risks in a range of future states of the world. In line with the NGFS Scenario Matrix, scenarios were selected to explore moderate (1.5-2 °C) and high (3+ °C) levels of warming by the end of the century. They were also selected to show a variety of different transition pathways for reaching a given

8 Beyond the three year horizon of the ECB forecast, the European economies are assumed to gradually converge to their long-run average growth and inflation rates.

warming outcome. Section 3 provides an overview of the modelling framework and the narratives of the long- and short-term scenarios, respectively. Considerations on the comparability and alignment of the long- and short-term scenarios are also laid out in Section 3.

NGFS long-term scenarios

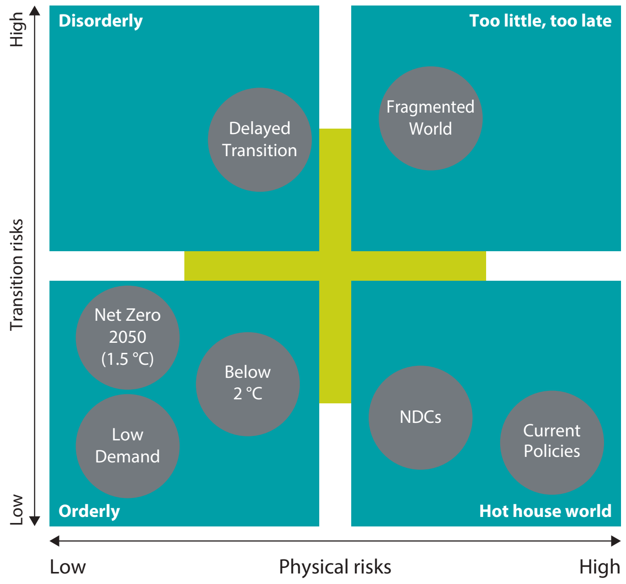
Since 2020, the NGFS published a set of reference scenarios that can be used to explore the long-term economic impacts and financial risks from climate change. The scenarios are positioned along two main dimensions, transition and physical risk, as shown in the NGFS Scenarios Matrix in Figure 4. They can be grouped in four main categories: *Orderly transition*, *Disorderly transition*, *Hot House World*, and *Too little, too late*.

Multiple models were used to produce the scenarios to capture a range of uncertainty in the results. The transition pathways were generated by three different integrated assessment models (GCAM, REMIND-MAgPIE, and MESSAGEix-GLOBIOM) to provide different views of how the economy responds to mitigation policy. The climate model MAGICC[9] was also used to simulate the temperature response to the NGFS scenarios and provide an uncertainty band to a change in emissions.

The scenarios were produced jointly with a consortium of leading research institutions building on the existing transition scenario database for the IPCC Special Report on 1.5 °C Warming[10] and relevant physical risk impact data. The first iteration focused on bringing together relevant physical and transition pathways from the existing literature in a coherent way. All selected scenarios build on the same background socio-economic assumptions, namely the SSP 2 "Middle of the road", where the world follows a path in which social, economic and technological trends do not shift markedly from historical patterns.

The long-term scenarios vary according to how policy action is assumed to evolve in the future. Scenarios

Figure 3 **NGFS scenarios framework in Phase V**



Notes: Positioning of scenarios is approximate, based on an assessment of physical and transition risks up to 2100.

that assume currently implemented policies (NPi) or planned policies as stated in the Nationally Determined Contributions (NDC) under the Paris Agreement result in high levels of warming by the end of the century.[11] Orderly scenarios assume that an optimal emissions price is introduced immediately to limit the rise in temperatures to 'well-below' 2 degrees (66% likelihood) by the end of the century. Most of the disorderly scenarios assume that such an emission price is only introduced after 2030. In any case, emission price trajectories are provided for all scenarios so that the marginal costs of mitigating emissions in each one can be compared.

The scenarios also make a range of assumptions about how technology evolves. The availability of Carbon Dioxide Removal (CDR) technologies is a key driver in particular. If the availability of these CDR technologies is assumed to be limited, much sharper increases in emissions prices are required. In addition, a diverse set of technology assumptions is embedded in each scenario, related to the costs and quantities of fossil resources, the availability

9 The climate model MAGICC was used to estimate the temperature outcomes of emissions pathways in the IPCC Special Report on 1.5 °C Warming (SR15). It emulates historic warming, climate sensitivity and the warming projections of Earth System Models.

10 Huppman *et al.*, 2018.

11 National Policies implemented (NPi) scenarios describe energy, climate and economic projections based on currently implemented national policies. Nationally Determined Contribution (NDC) scenarios consider policies additional to those represented in the NPi scenarios, assuming that all countries fully implement their pledged contributions.

of solar, wind and geothermal resources, land, geological storage, etc. See the Technical Documentation for more details. Furthermore, deep-dives into the scenario narratives and assumptions can be found in the dedicated NGFS notes on narratives and key assumptions of the NGFS long-term scenarios (NGFS 2025a, NGFS 2025b).

1. An orderly transition

The representative scenario for an **orderly transition** assumes immediate action is taken to reduce emissions consistent with the Paris Agreement. It assumes the introduction of an emissions price in 2020 which increases gradually per year and is calibrated to keep global warming well below 2 °C. It also assumes the full availability of CDR technologies. This corresponds to reaching net zero CO_2 emissions between 2050 and 2070. Since policy measures are introduced early and increasing progressively, physical as well as transition risks are assumed to remain low over the period. Note that the availability of CDR technologies at scale is still uncertain as there has not been much deployment yet.

In addition, two other alternate scenarios are included in this category. The first, **Low demand**, assumes that reduced energy demand mitigates the pressure on the economic system to reach global net zero CO_2 emissions around 2050, thereby limiting the costs of transitioning. The second, **Below 2 °C**, assumes only a gradual increase in the stringency of climate policies, giving a 67% chance of limiting global warming to below 2 °C.

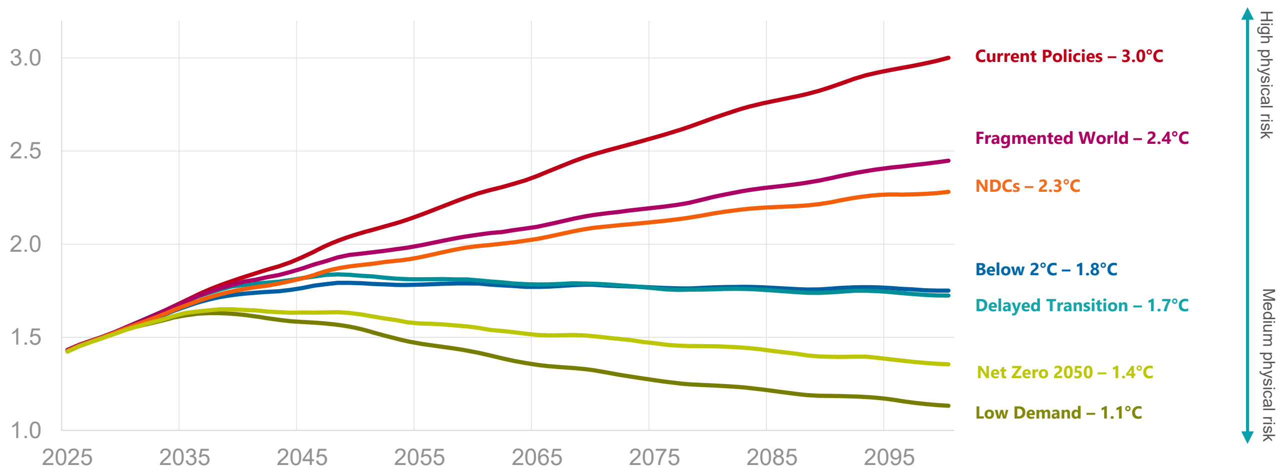
2. A disorderly transition

The representative scenario for a **disorderly transition** shows a much more challenging pathway to meeting the Paris Agreement targets. In this scenario, climate policy follows current policies until 2030. Acknowledging that these efforts will not be enough to meet commitments, the emissions price is revised substantially upward after 2030. The scenario further assumes that there will be only limited CDR technologies available. The period of delay means that net zero CO_2 emissions must be reached more abruptly and costly. Correspondingly the increase in emissions prices is much steeper per year.

3. "Hot house world" scenarios

The representative scenario for a "Hot house world" assumes that only **current policies** are implemented. As a result, the climate goals set out in the Paris Agreement are not met, leading to substantial physical risks over the medium and long term. It is an extrapolation of what would happen if no additional measures were taken. The change in emissions price is therefore assumed to be negligible. This scenario would result in severe physical risks, with an estimated median temperature rise of over 3 °C by 2050.

Figure 4 **°C global mean surface temperature increase/year**



Source: IIASA NGFS Climate Scenarios Database, MAGICC model (with REMIND emissions inputs). MAGICC provides a range of temperature increase compared to the pre-industrial levels. The temperature paths displayed here follow the 50th percentile.

An alternate scenario, labelled **Nationally Determined Contributions (NDCs)**, is included, taking into consideration all pledged but not yet legislated policy measures. The estimated physical risks would be slightly lower than in the Current Policies case, but still well above the Paris target, with a median temperature rise of over 2.3 °C by 2050. The estimated transition risks would still be quite limited compared to the orderly and disorderly scenarios.

4. A "Too little, too late" scenario

The "Too little, too late" scenario is called **Fragmented World** sets out a delayed and divergent climate policy response among countries, globally. This scenario is the most adverse in that it entails both high physical and high transition risks. CDR technologies are assumed to the available at a low to medium extent, with high regional variation. Due to the fragmented and insufficient global policy reaction and slow technological change, global warming would reach up to 2.4 °C by 2050.

NGFS short-term scenarios

The NGFS published its first vintage of short-term scenarios in 2025. This followed the publication of the NGFS Conceptual Note on short-term scenarios the year before (NGFS, 2024b). The scenarios fill a key gap in climate scenario analysis by offering a comprehensive toolkit to assess short-term climate risks within a policy-relevant time horizon spanning from 2024 to 2030. They comprise two transition risk scenarios that are net-zero aligned and two physical risk scenarios, and cover a wide range of granular climate, economic and financial data.

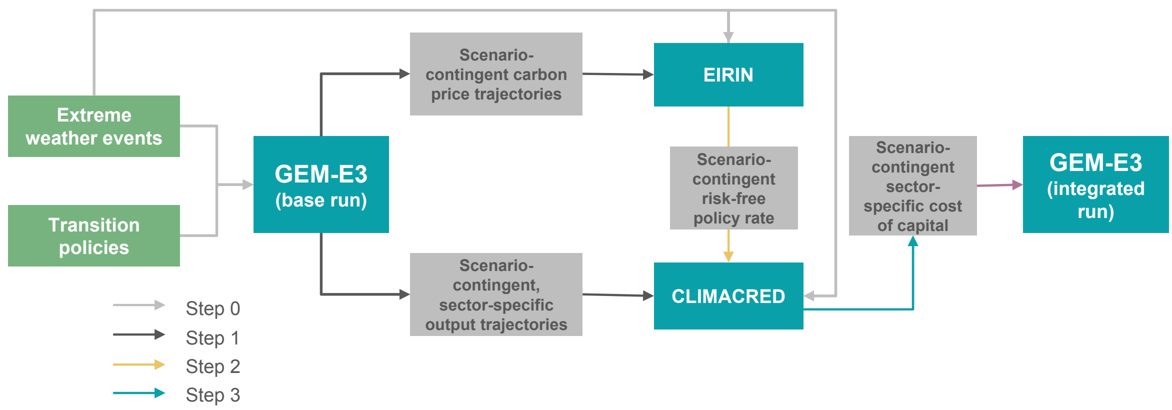
The short-term baseline scenario differs from the long-term baseline in that it already incorporates transition risks proportional to all national climate policies pledged as of January 2023 (i.e. NDCs). The incorporate physical risks in form of compounding extreme weather events that were implemented *via* a storyline approach.

The short-term scenarios were developed *via* an integrated modelling framework, as illustrated in Figure 5. GEM-E3 models macroeconomic and sectoral developments which are fed into EIRIN to model inflation and monetary policy response projections. The policy rate from EIRIN together with the sectoral output trajectories from GEM-E3 are added as inputs into CLIMACRED, which models the financial sector response *via* projections of financial risk variables, broken down by country and sector. In the last step, sector-level capital costs from CLIMACRED are used inside GEM-E3 to for a final, integrated run of the macroeconomic module that accounts for the impact of financial second-round effects on the real economy. More details can be found in the Technical Documentation of the NGFS short-term scenarios.

1. Highway to Paris

The Highway to Paris scenario assumes a gradual implementation of a globally coordinated net-zero transition. The transition is technology driven and mainly financed *via* recycled carbon revenues in form of green subsidies and investments. While carbon prices lead to an increase in energy prices and inflation, the green investments offer an economic boost and offset the impact from the carbon supply shock. Demand for goods

Figure 5 **Modelling framework of the first vintage of the NGFS short-term scenarios**



and services from high-polluting sectors increasingly fall because consumers favour green products, which leads to higher premia and capital costs for high-polluting sectors.

2. Sudden Wake-Up Call

This scenario assumes baseline developments at the start of the scenario horizon, but in 2027 a sudden shift in the perception of climate change and policy preferences occurs. The sudden increase in transition efforts leads to an abrupt and sharp increase in carbon prices, triggering a supply shock. This scenario assumes a less efficient recycling of carbon revenues into green subsidies, which puts cost pressures onto the economy. Consumer and investor preferences shift abruptly towards green sectors, which leads to a wave of financial instability and asset price adjustments.

3. Disasters and Policy Stagnation

This scenario follows a business-as-usual pathway over the scenario horizon and additionally assumes a sequence of region-specific compounding natural hazards occurring in 2026 and 2027 in form of dry and wet events. These extreme weather events lead to capital destruction, reduced productivity and production, and creates cascading economic impacts. Trade and financial linkages spread the negative impacts across the world, amplifying financial and economic instability.

4. Diverging Realities

This scenario assumes the development of a fragmented world where advanced economies pursue a net-zero transition in line with the Highway to Paris scenario, while the rest of the world is hit by a sequence of extreme weather events. The effects of regional natural hazards propagate globally *via* trade linkages. Particularly, supply chain disruptions in critical raw materials create spillover effects for advanced economies and increase their cost of transition to a low-carbon economy.

Comparability of NGFS long- and short-term scenarios

NGFS short- and long-term scenarios provide complementary perspectives on climate-related risks. They should be compared with caution as they explore different narratives and employ different modelling frameworks. Long-term scenarios offer a structured, stylised picture of systemic risks over the coming decades. Short-term scenarios enable detailed, dynamic assessments of near-term shocks, including feedback mechanisms. Table 4 presents the key attributes of both long- and short-term scenarios along key categories. Users should not directly compare variables across the scenario sets without recognising these foundational differences in purpose, structure, and assumptions.

Table 4 **Key attributes of NGFS long- and short-term scenarios**

	Long-term scenarios (vintage V)	Short-term scenarios (Vintage I)
Coverage	Downscaled data available for over 180 countries (physical risk) and 50+ countries (macroeconomic indicators), though with less sectoral depth	Detailed outputs across 46 regions and 50+ sectors, with financial risk metrics such as cost of capital and default probabilities
Modelling suite	Built around three Integrated Assessment Models (IAMs): REMIND-MAgPIE, GCAM, and MESSAGEix-GLOBIOM[12]. These independently derive the impacts of different policy ambitions on the energy and transition-relevant sectors, emissions, and land use. Physical risk models include acute and chronic physical risk models, which generate GDP impacts. The macro-financial impacts are then assessed ex-post using the NiGEM model, with no feedback from macro-outcomes to the IAMs	Coupled model framework involving GEM-E3 (for macro-sectoral impacts), EIRIN (for inflation and monetary policy impacts), and CLIMACRED (for financial risk impacts). These models are sequentially linked and include a feedback loop to the integrated macro-variables in GEM-E3 that allows macro-financial dynamics – such as changes in cost of capital and monetary policy responses – to influence investment decisions and sectoral output. This key modelling distinction – one-way coupling versus feedback-inclusive – contributes to significant differences in scenario dynamics and realism over the short horizon, yet is less crucial for long-term horizons

12 For further details on the underlying modelling concept of IAMs compared to other models.

Baseline assumptions	• The baseline in NiGEM is a hypothetical forecast base without climate policies and climate change, rather than an actual and plausible scenario • Calibrated using Shared Socioeconomic Pathways (SSP2), IMF World Economic Outlook projections, and NIESR data	• The baseline scenario incorporates climate policies until 2030, pledged as of January 2023, and is more comparable to the NGFS long-term Nationally Determined Contributions (NDCs) scenario • Calibrated on a baseline based on the IMF's October 2023 WEO
Carbon price assumptions	**Both scenario sets use (shadow) carbon prices to act as a proxy for climate policy stringency, by representing the marginal cost of abating the emissions until reaching the emission target.** In both sets, the carbon price is generated endogenously, yet they differ in scope and application, as well as assumptions about the recycling of carbon revenues	
Physical risk modelling	• Chronic physical risk is estimated via damage functions applied ex post • Acute damages are also applied ex post via bottom-up acute risk indicators (droughts, heatwaves, floods and cyclones), with GDP impacts available at a range of severities (percentiles) • Currently, chronic and acute damages are treated separately (not additive, yet with a degree of overlap) • All long-term scenarios include physical risk estimates	• Storyline approach to simulate compound acute physical shocks (e.g., heatwave-drought-wildfire and storm-flood events) affecting each continent individually with pre-defined severities (return periods) • Both the types of events (individual types and the compounding), and the severities of these acute disasters are not aligned with the long-term scenarios • Only two short-term scenarios feature explicit physical risk storylines

Climate scenario assumptions

Climate scenarios are the core input into assessing the macro-financial impacts from climate change. It is important that users consider the assumptions being made, and choose scenarios that are relevant to the risks they want to explore. The key model assumptions and design choices relate to emissions and climate outcomes, the socioeconomic context, climate policy, technology and consumer preferences. This section gives an overview on the assumptions applied in the NGFS long-term scenarios. Further information and details can be found in the dedicated NGFS note on key assumptions of the NGFS long-term scenarios (NGFS, 2025b).

The transition pathways of NGFS scenarios are quantified with Integrated Assessment Models. In order to reflect the structural uncertainty of IAMs, the NGFS framework includes and compared three IAMs (REMIND-MAgPIE, MESSAGEix-GLOBIOM, GCAM). Key foundational differences between the three IAMs participating in the NGFS scenarios are the anticipation of future developments and targets (perfect foresight or limited short-term foresight) and the decision-making mechanism or objective function (maximizing welfare or minimizing system cost).

Socioeconomic context

The socioeconomic backdrop of the scenarios helps to contextualise the setting in which the climate scenario occurs. A world in which consumption patterns become more sustainable could have a marked reduction on emissions, whereas a world in which fossil-fuel development continues will either increase emissions or reinforce the pathway we are currently on.

The Shared Socioeconomic Pathways (SSPs) have also been standardised by the research community to help coordinate climate scenario modelling. They can be used to estimate how different levels of climate change mitigation (under the RCPs) could be achieved under a possible socio-economic pathway. They are based on quantitative projections of three variables – GDP, population, and urbanization rate – as well as detailed narratives describing technological advancement, international cooperation or resource use, foreseen for a wide range of countries and regions, up to 2100.[13]

In the NGFS long-term scenarios, economic developments and population is aligned with the latest release of SSP2 (middle-of-the-road scenario). This specific pathway bases near-term economic trends on the latest versions of the OECD Economic Outlook and the IMF World Economic Outlook[14], and in the long-term it assumes medium global

13 Riahi *et al.*, 2017.

14 For vintage V of the NGFS long-term scenarios, it is based on OECD Economic Outlook as of 2023 and the IMF World Economic Outlook as of 2023.

GDP growth, moderate convergence between rich and poor countries, moderate changes in global inequality, and medium fertility and gaining trends for the population

Technological evolution

Climate scenarios define the technology pathways that lead to a reduction in emissions. This varies from model to model but typically includes increasing energy efficiency, decarbonisation of power supply (*via* phase-out of fossil generation and increasing low-carbon technologies like renewables), increasing electrification, more efficient land use and some direct carbon dioxide removal from the atmosphere through bioenergy with carbon capture and storage and/or land-related sequestration (e.g. afforestation). Scenarios make assumptions about how these technologies progress over time, to project how levels of investment and deployment rates develop in the future.

The primary driver of technological changes in the NGFS long-term scenarios is the change in the relative costs of technologies. Technology uptake and growth is influenced by factors such as investments costs, operational costs, fuel and emission costs, efficiencies and lifetimes. For high-polluting technologies, carbon prices are an additional driver. Carbon prices lead to higher operational costs which lead to an endogenous shift towards cheaper clean technologies and reduces usage of polluting technologies.

Land use

Land use concerns changes in deforestation, reforestation, bioenergy production, and agricultural land expansion. In the NGFS long-term scenarios, changes in land use and biomass production are driven by carbon prices and therefore differ by scenario. Assumptions on land use potential, i.e. the share of land available for biomass energy production, follows the SSP2 assumptions and is of moderate availability.

The land-use modules of the IAMs deployed for the NGFS long-term scenarios also model agricultural demand which is driven by GDP, population, dietary patterns, and food waste. This demand is met primarily through increases in land productivity as well as through cropland expansion or relocation (e.g., *via* trade). Land-based GHG emissions (CO_2 from land-use change and CH_4 and nitrogen-related emissions from agricultural practices, such as fertilizer use) and biomass potentials are also target to carbon pricing which limits deforestation and promotes afforestation or natural vegetation regrowth.

Climate policies

Climate scenarios also make either implicit or explicit assumptions about how climate policies may evolve. The key policy assumptions generally relate to:

- *Timing:* whether action is taken sooner or later, which has a significant impact on the rate of required emissions reductions;
- *Policy mechanism:* including the policy mix (e.g. taxation, cap-and-trade carbon pricing, subsidies, emissions restrictions, industry regulations), who pays (governments, companies and/or households) and how government revenues (if any) are redistributed;
- *Policy certainty:* whether policy implementation is relatively gradual and predictable, or unanticipated and abrupt. This could for example take place in the context of a delayed policy response, with a sudden implementation of new regulations (e.g. ban on coal, imposition of carbon taxes) rather than a smooth phase-in period;
- *Policy coordination:* the degree of coordination across countries in tackling climate change.

Climate-economy models set out the types of technology changes needed to transition but are not always explicit on the policy mechanisms to get there. Global climate transition pathways are derived from the integrated assessment models (IAMs) that model the interaction between energy, land, economy and climate systems.

The NGFS long-term scenarios account for (i) currently implemented policies, (ii) Nationally Determined Contributions for 2030, and (iii) Net Zero targets. These policies differ across the NGFS scenario narratives. For current policies, legislated policies are incorporated based on a bottom-up assessment of the required emission reductions and the implied carbon price to achieve the target. For NDCs by 2030, country-level targets published by the UNFCC are aggregated to IAM regions and imposed similarly as for current policies. Net Zero targets are assumed to meet their targets around the target year. In the NGFS transition scenarios (those who achieve net zero), the regional net zero targets may be exceeded because of a global net zero target.

Carbon price

Carbon prices in both NGFS long- and short-term scenarios are **shadow prices** and differ from actual market prices. Shadow carbon prices are model-derived and signal the stringency of climate policy in a scenario, reflecting the abatement costs needed to achieve the imposed emissions reduction targets. These values are different from the observed market prices, which are driven by market supply, demand, and regulatory factors.

Consumer preferences

Climate scenarios make a number of assumptions about how consumer preferences evolve. In their simplest form climate-economy models assume that the transition is primarily led by the supply side of the economy (i.e. new technologies allow for the provision of existing goods and services at a lower emissions intensity). However, there is increasing academic research and policy attention on how much shifts in consumer preferences for certain goods and services could contribute to achieving climate goals. Examples include demand for different forms of transport, agricultural land and dietary preferences. In the NGFS long-term scenarios, behavioural changes are determined by the SSP scenario (see above) and assumed to be moderate. The green transition is rather led by climate policies and innovation, however, in the case of the Low Demand scenario, the role of behavioural changes in energy production and consumption is assumed to play an important role. Additionally, the transport sector relies on assumptions on mobility behaviour, which affects the demand of fuel, fleet and infrastructure.

Physical climate impacts

Climate scenarios provide information on how temperature and other biophysical processes are changing. The underlying climate and hazard models provide a range of projections depending on differences in the input assumptions used and methodology. It is therefore important to understand how summary statistics (e.g. temperature outcome in 2100) have been derived and compare to the wider distribution of results.

Climate scenarios also provide information on how these changes in climate will affect people's health and productivity, physical capital and food systems. This requires making an additional number of assumptions about the level of adaptation and how economic activity will be affected. These assumptions are further explored in Chapter 4.

In the NGFS long-term scenarios, the emission pathways from the IAMs are translated into Global Mean Temperature (GMT) projections *via* the MAGICC model and in the next step physical risk impacts evolving from temperatures are estimated. Physical risks are assumed to be independent from socio-economic factors (e.g. population growth, urbanization), even though it is important to note that future exposure and vulnerability to physical risks will heavily depend on these factors. Four key extreme weather events are captured *via* the physical risk indicators of the NGFS scenarios with the following key methodological assumptions:

- **Extreme droughts:** Crop losses due to extreme long-term drought are estimated, taking both rainfall and evaporation into account. As a consequence, shortages in crop productivity and supply lead to a fall in export volumes and an increase in prices, causing reduction in demand.
- **Heat extremes:** The impact of the exposure of the population to extreme humid heat and the impact on labour supply and demand is modelled.
- **Tropical cyclones (hurricanes and typhoons):** The focus lies on assets damages from extreme winds, Damages from heavy rainfall are not included, and storm surge damages are included only implicitly through wind driven waves.
- **Floods:** The focus lies on asset damages from river floods. The modelling assumes a fixed flood protection standard and no further adaptation effort in the scenarios.

Comparability of NGFS scenarios with other scenarios

Interconnection between IPCC and NGFS scenarios

The Intergovernmental Panel on Climate Change (IPCC) collates and assesses physical and transition scenarios that are continuously developed by the climate research community. The IPCC is the main body responsible for globally coordinating and publishing assessments on climate change for policymakers. In 2011, the research community has collectively chosen four Representative Concentration Pathways (RCPs[15]) that set out pathways for the

15 For further discussion of RCPs see van Vuuren *et al.* (2011).

emissions of greenhouse gases, their future atmospheric concentrations, and projections for consequent climate impacts, to help standardise and improve comparability of climate change analysis. The RCP scenarios are no longer in use in the long-term NGFS scenarios. Instead, the new SSP framework[16] has been in use to provide emission scenarios under socio-economic assumptions, for mitigation and adaptation policy analysis (see sub-chapter on scenario assumptions).

The NGFS scientific consortium is an important contributor to the IPCC process and assessment reports. In particular, IAMs used in NGFS are also informing IPCC analyses. Both IPCC and NGFS processes contribute to the continuous improvements of IAMs. This makes NGFS scenarios strongly consistent and comparable with other scenarios in the IPCC framework.

Scenarios of the International Energy Agency

The NGFS long-term scenarios share many commonalities with the scenarios developed by the International Energy Agency (IEA), although there are also important differences, in terms of mandate and use cases, modelling approaches and outputs available. Assumptions and narratives of the IEA and NGFS scenarios differ, and therefore, they cannot be perfectly matched. Nevertheless, some commonalities can be identified between some of the scenarios based on their policy assumptions and the implied temperature rise. The Annex provides a comparison of the objectives, modelling framework and key outputs between NGFS and IEA scenarios, as well as a matching of the scenarios of the NGFS and IEA based on their policy assumptions and implied temperature increase.

Mapping of sectors from NGFS scenarios to other industry classifications

Financial institutions typically classify their assets using standard economic activity classifications, NACE (Nomenclature of Economic Activities) and GICS (Global Industry Classification Standard), whereas climate scenarios based on IAMs describe activities in terms of physical energy and material flows. To bridge these two perspectives, Battiston *et al*. (2022) developed a two-step mapping that translate IAM-based scenarios into economic classifications. First, the mapping identifies Climate Policy Relevant Sectors (CPRS), a subset of NACE sectors impacted by climate policies. Second, these CPRS sectors were mapped to the IAM variables to serve as proxies to shock an economic model defined in the NACE/CPRS sectors. This mapping has since been refined to more granular sub-sectors and extended to other classification systems (GICS and the IEA World Energy Outlook variables). Sectors are matched either directly or via proxy, depending on the degree of overlap between the activity levels of the IAM variable with those of the economic classification. The full mapping of IAM sectors to NACE, GICS, and IEA sectors can be found in the Long-term Scenarios Explorer Portal here.

Extension of NGFS scenario narratives

As user needs are different, the assumptions of the scenario narratives can be adapted to gain a better understanding of the impact of climate policies on an organization or the economy in general. Each NGFS scenario explores a different set of assumptions regarding the assessment of climate policy, emissions, physical risk impacts, and transition temperatures, which may be adapted. For instance, the adoption of new technologies for decarbonizing the energy mix may not be as abrupt as some climate scenarios suggest. Instead, one could assume that decarbonization takes longer than proposed in the NGFS scenarios because the transition to different energy sources will require a long-term paradigm shift, as illustrated in the use case in Box 3 by the Bank of Japan.

Users may also wish to adjust shock intensities to tailor scenarios to local conditions and specific questions. This can be done, for instance, to test the implications of a more severe extreme weather events than what is reflected in a scenario, or to explore the consequences of a more abrupt and disruptive climate policy than assumed in a given transition pathway. There are different ways to implement such adjustments. A straightforward option is to rescale key variables provided in the scenarios, such as hazard intensity, GDP losses, or carbon price trajectories. Alternatively, users may complement scenario outputs with internal data sources or models, for instance, by overlaying a national catastrophe model to increase the damage severity in certain regions (see Chapter 5 for more

16 For more information on the SSP scenario framework see IPCC WG3 Annex III (A.III.II.1.3.1 and 1.3.2).

examples of such models). When doing so, users should be transparent in the method chosen and the assumptions taken, as altering shock intensity without recalibration may reduce internal consistency across variables.

New scenarios could be created to assess types of transition and physical risk based on but slightly different to those in the NGFS scenarios. For example, one could explore retaliation consequences if a country were not to cooperate in the global green transition. The Bank of Mexico explores this case by changing the socioeconomic and carbon tax assumptions of NGFS scenarios, illustrated in Box 4.

Box 3

Bank of Japan and Financial Services Agency: Enhancing Transition Risk Modelling in Scenario Design

In 2025, the Bank of Japan (BOJ) and the Financial Services Agency (FSA) conducted their second pilot climate scenario analysis. The exercise focused on the **Current Policies** and **Net Zero 2050** scenarios from vintage IV of the NGFS scenarios.

As part of their exercise, the BOJ and FSA introduced modifications to the Net Zero 2050 scenario to better capture the transmission channels of transition risks which are not explicitly reflected in the NGFS scenarios. Specifically, they incorporated two main adjustments: (i) macroeconomic shocks driven by transition dynamics and (ii) an imperfect pass-through of carbon prices to end-consumers. These adjustments were informed by insights from the first pilot exercise, in which scenarios tended to assume no major macroeconomic disruptions. This may have contributed to relatively modest projected credit losses. In addition, the financial performance of high-emitting sectors appeared only mildly affected – partly due to the assumption that carbon costs could be passed through to product prices quickly and fully.

To make the macroeconomic transmission of transition risks more plausible, the revised scenario introduced lower elasticity of substitution across energy sources, assuming that it will take firms a longer time (three years) to adjust their allocation of resources in response to carbon price increases, compared to that of Net Zero 2050. These changes made the scenario more realistic and allowed for a better assessment of vulnerabilities under adverse transition pathways.

Table 5 **Changes in the scenario design of the BoJ and FSA 2025 exercise**

	Analysis with Net Zero 2050 (original)	Analysis with Net Zero 2050 (adjusted)
Opportunities	• In 2024, the GDP growth rate declines due to the increase in carbon prices • From 2025 onwards, the economy expands as green investments and fiscal stimulus promote economic growth. The GDP growth rate remains position until 2030	• In 2024, the GDP growth rate declines due to the increase in carbon prices • In 2025 and 2026, economic recovery is sluggish due to the delay of firms and households in their response to carbon prices. In 2027, economic growth recovers (returning to baseline levels) • Other macro financial variables are adjusted in line with the above pathway of GDP growth
Pass-through rate of carbon price	• Participating banks assume a relatively high pass-through rate of carbon prices to product prices	• The pass-through rate is assumed to decrease by 30% in the first year, 20% in the second year, 10% in the third year, and 10% in the fourth year compared to the pathway of the pass-through rates in participating banks' models

Box 4

Bank of Mexico: Change of NGFS scenario narratives

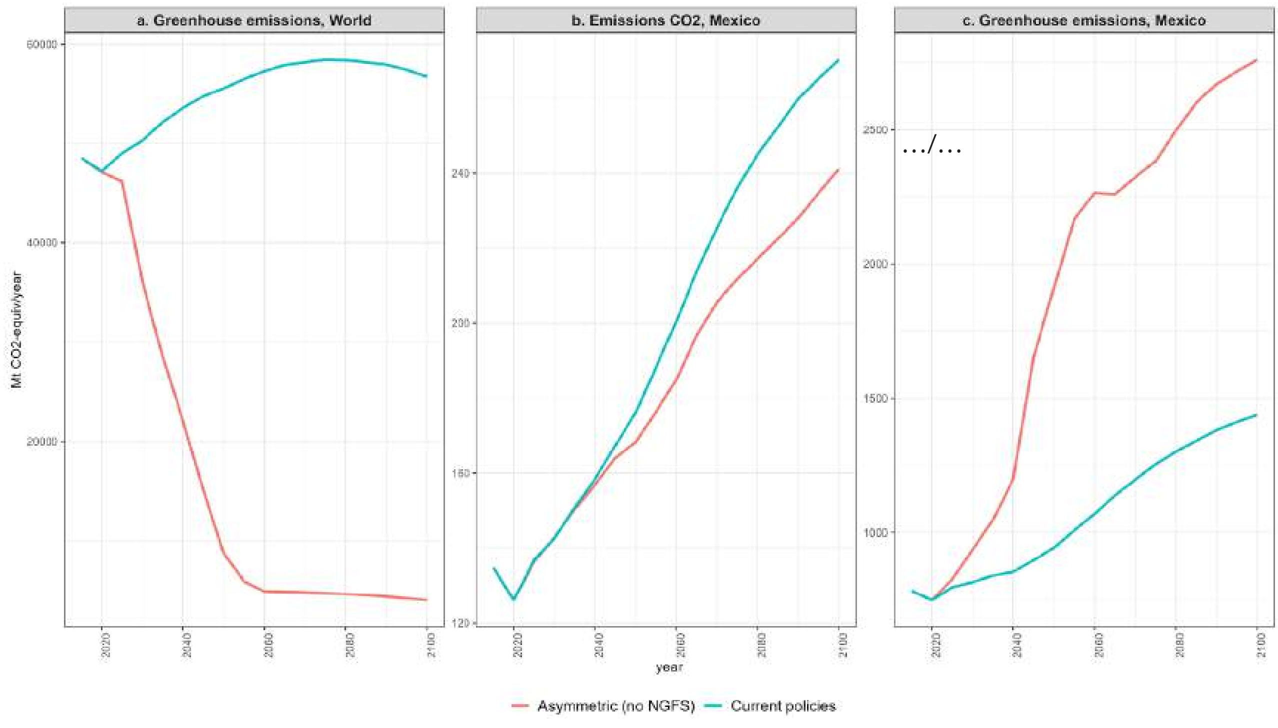
The Bank of Mexico is conducting a pilot climate scenario analysis that considers four different narratives. Three are aligned with the NGFS Phase IV scenarios, namely the Current Policies, Net Zero 2050, and the Delayed Transition scenarios[17]. The fourth scenario was developed specifically for this exercise and is named "Asymmetric scenario". It is not based on NGFS scenarios and explores the consequences of regional misalignment in climate policies[18].

The Asymmetric scenario assesses the implications for Mexico of not aligning with global decarbonisation efforts aimed at limiting warming to 1.5 °C. Specifically, it is assumed that Mexico does not adopt net-zero policies, while the rest of the world pursues a greenhouse gas (GHG) emission pathway aligned with limiting warming to below 1.5 °C (Figure 6.a). The aim is twofold: to assess the implications of a single country deviating from global targets, and to evaluate the potential consequences of this divergence – such as economic penalties through mechanisms like carbon border adjustment tariffs.

The new scenario was implemented using the GCAM model. Emission constraints were removed for Mexico, while global emissions followed a net-zero pathway compatible with 1.5 °C by 2100. Preliminary results offer two key insights. First, Mexico's CO_2 emissions under this

…/…

Figure 6 **GHG emissions in million tonnes of CO_2**



Source: Bank of Mexico calculations, based on GCAM model and NGFS scenarios.

17 Population, GDP and carbon market trajectories in the original NGFS scenarios were adjusted. In the NGFS scenarios, GDP was considered too optimistic. Regarding the carbon market, Mexico was included with the rest of the world. To modify only Mexico's trajectory in the asymmetric scenario, its own market was created. The population projection was adjusted to the World Population Prospects 2024 (United Nations, Department of Economic and Social Affairs, Population Division) and the assumptions of GDP growth were adjusted to the short-term and long-term projections from the OECD (2023) that reach up to 2060.

18 The net-zero scenarios of the NGFS consider regional differences in emissions reductions according to the current policy targets of the countries. Some countries have 2050 as their net-zero target year, others have 2060, and others have not defined targets as of 2021.

scenario follow a similar trajectory to the Current Policies scenario (Figure 6.b). However, when considering total GHG (i.e. CO_2 as well as non-CO_2-related) emissions, the Asymmetric Scenario shows even higher emissions than Current Policies (Figure 6.c). This is largely due to a projected increase in methane emissions. The model assumes that, under global net-zero policies, other countries implement taxes on specific GHGs. This can induce an increase in methane emissions in non-aligned countries, such as Mexico, through increased acivity of high-polluting sectors. In the case of Mexico, the production of dairy and cattle-related activities account for the largest increase in methane emissions.

The regional divergence in the evolution of GHG emissions and macroeconomic outcomes makes the Asymmetric scenario an interesting case study. Though the pilot exercise has not yet been completed, the new scenario enables to assess the unintended macroeconomic effects of regional policy disparities and uncoordinated policy action.

Capturing non-linear and compounding climate impacts

Climate-related shocks, whether stemming from physical or transition risks, seldom occur in isolation but oftentimes in combination, known as compound risks. This can generate non-linear dynamics across climate, economic, and financial systems. For instance, a severe drought could prompt new policies aimed at water conservation, and these policies might, in turn, disrupt agricultural supply chains, creating a cascading economic effect. A further source of non-linearity emerges when tipping points in the climate system are reached, fundamentally altering environmental conditions and magnifying pre-existing vulnerabilities. The ultimate effect on the financial system is directly tied to its exposure to this confluence of risks and the robustness of its risk management frameworks.

Furthermore, climate-related vulnerabilities are often exacerbated by pre-existing macro-financial vulnerabilities, including trade imbalances or high indebtedness. These co-occurring risks can amplify initial shocks, leading to more widespread and profound financial losses for households, companies, and governments, even as they attempt to adapt through changes in spending and investment.

A primary challenge for climate scenario analysis is the accurate depiction and modelling of these non-linear dynamics. Compound risks inherently produce effects that are greater than the sum of their individual parts. These risk combinations can involve multiple physical risks interacting with each other, or physical risks compounding with a broader spectrum of socio-economic or geopolitical risks. While climate scenario design capturing these non-linear effects is still at an early stage, one can leverage on existing analytical frameworks, such as those detailed by the Financial Stability Board (FSB 2025), to map and quantify these intricate interdependencies.

Box 5

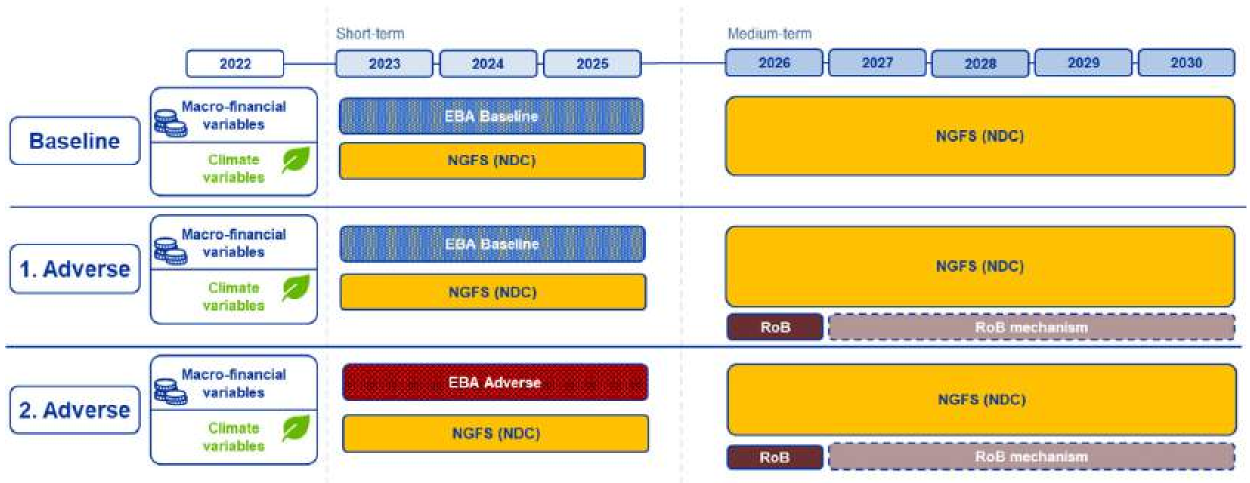
ESRB/European Central Bank: Development of short-term climate scenarios for the Fit-for-55 one-off climate scenario analysis

The Fit-for-55 climate scenario analysis was a one-off exercise, jointly conduced by the ECB, EBA, EIOPA, ESMA, and the ESRB. The exercise assessed the resilience of the financial sector to climate and macro-financial shocks during the implementation of the "Fit-for-55" package[19]. The scenario horizon spanned from 2024 to 2030, for which short-term climate scenarios were constructed based on the scenarios from the NGFS (Phase IV) and the 2023 EU-wide stress test[20]. The exercise considered three scenarios focusing on transition risk:

- The **baseline scenario** reflects a green transition in which the "Fit-for-55" package is implemented as planned and within an economic environment as forecasted based on the baseline scenario of the EU-wide stress test 2023. It includes upfront costs that are needed to avert the impact of climate change in the future.
- A **first adverse scenario** focuses on climate-change related risks that materialize in the near term, in the form of financial constraints on high-polluting sectors triggered by a sudden reassessment of transition risks – called "run-on-brown" (RoB) shock.
- A **second adverse scenario** combines climate-change related risks from the first adverse scenario with non-climate, macroeconomic stress factors, namely the ones included in the adverse scenario of the EU-wide stress test 2023.

The starting points of macroeconomic and financial variables are projected forward following the 2023 EU-wide stress test scenarios in the short term (2023-2025), and following the NGFS scenario in the medium term (2026-2030). Climate-related variables are calibrated based on NGFS for the period from 2023 to 2030, where observed values are projected forward with the year-on-year changes. The NGFS "Nationally Determined Contributions (NDC)" scenario was chosen. This scenario foresees that currently pledged NDCs are implemented fully, even if not yet backed up by effective policies, and respective targets on energy and emissions in 2030 are reached in all countries, meaning that the Fit-for-55 package is assumed to be fully implemented and the target of a 55% reduction in emissions with respect to 1990 levels is met. Figure – provides a schematic overview of the scenario design. …/…

Figure 7 **Schematic overview of the design of the short-term scenarios of the Fit-for-55 climate scenario anlaysis**



Note: More details are available in (ESRB, 2024).

19 The "Fit-for-55" package is a set of legislative proposals aimed at reducing net GHG emissions by at least 55% by 2030, compared to the 1990 levels.

20 The design of the scenarios is in line with the approach used in the scenarios for the ECB's second economy-wide climate stress test exercise (ECB, 2023, Annex A1).

The severity of each scenario differed based on the narrative. In particular, in the Fit-for-55 baseline scenario, the baseline scenario of the 2023 EU-wide stress test is combined with the NDC scenario from NGFS. In the first Fit-for-55 adverse scenario, the first three years are modelled in the same way as the baseline scenario, but in 2026, the "run-on-brown" mechanism is implemented, generating a macroeconomic shock at the beginning of 2026. The second Fit-for-55 adverse scenario is structured in the same way as the first adverse scenario, but the transition happens under global adverse macro-financial conditions until 2025, following the adverse scenario of the 2023 EU-wide stress test. Consistency between the scenarios of the NGFS and the EU-wide stress test is preserved through the following approaches: (i) The macroeconomic projections (e.g. GDP, inflation, long-term interest rates, and gas, oil and electricity prices) from NGFS are applied in form of year-on-year relative changes, and (ii) the values of macro variables at the end of 2025 (i.e. in the last year of the scenarios of the EU-wide stress test) are used as starting points for the projections until 2030 based on NGFS.

Overall, the exercise demonstrated how NGFS scenarios can be blended with scenarios from regulatory stress tests to combine climate- and non-climate-related risks within a short-term horizon.

Further scenario design choices

There are number of further choices related to how the underlying climate scenarios are integrated into the exercise. These relate to the types of risks explored, the number of scenarios, granularity, and calibration.

Considerations on static versus dynamic balance sheets

Together with the choice on the scenario horizon, the assumptions on the change in the balance sheet composition is a strategic design choice that depends on the objectives of the stress test. The static balance sheet approach assumes a constant portfolio composition over the scenario horizon and excludes the possibility of management actions that could change the portfolio. With a dynamic balance sheet approach, portfolios are allowed to change in response to evolving shocks. A dynamic balance sheet approach can allow to gauge the reactions of financial institutions especially under changes in the long-term and to capture second-order contagion effects.

Specific challenges may arise with dynamic balance sheets, especially in long-term horizons. It can be challenging to determine changes in management decisions going beyond usual strategic horizons (typically 3 to 5 years). Exercises with long-term horizons can be informed by transition plans of firms or financial institutions if available. In bottom-up climate stress test exercises, it can be helpful for participating financial institutions to receive a range of available management actions provided by the supervisors. It is also important to define the constraints in the available actions so that results remain insightful. Supervisors should also ensure that at aggregated level, the portfolio reallocation by participating institutions stays realistic under the given narrative and economic projections of the scenarios.

When choosing between static and dynamic balance sheets, users should align their approach with the time horizon and purpose of the analysis. For short-term exercises (typically up to 3-5 years), a static balance sheet assumption is usually appropriate, as it isolates the immediate financial impacts of shocks without introducing behavioural uncertainty. For longer-term scenario horizons (10 years or more), the dynamic balance sheet assumption becomes more relevant to capture structural adjustments, strategic shifts, and changes in the portfolio composition of banks. However, results should be interpreted with caution given higher uncertainty.

Box 6

Using a dynamic balance sheet approach for climate scenario analysis: The application of the ACPR and RBNZ

RBNZ: The use of the static balance sheet approach with qualitative adjustments

In 2023, the Reserve Bank of New Zealand (RBNZ) conducted a bottom-up climate stress test to assess banks' exposure to climate-related risks, enhance their risk management capabilities, and examine the broader implications for financial stability. The time horizon spanned from 2023 to 2050, and the examined scenario was the NGFS "Too Little, Too Late" scenario, which combines intensifying physical risks with disorderly transition risks. A simple base case – excluding climate or economic shocks – served as the counterfactual for comparison.

While the exercise primarily applied a static balance sheet approach, banks were also asked to identify qualitative mitigating actions they might take in response to the scenario. Banks were asked to report the financial impacts of the scenario based on fixed balance sheets with minimal changes to business composition. This enabled the RBNZ to isolate the first-order effects of climate risks on capital, profits, and impairments. While the mitigating actions specified by banks were not quantified, they allowed for the assessment of the potential evolution in banks' lending mix as loans matured.

The hybrid approach of a largely static balance sheet, with limited qualitative mitigation, helped to capture forward-looking behavioural insights while maintaining a conservative modelling baseline. The RBNZ concluded that climate risks could amplify the effects of future economic shocks, underscoring the importance of long-term climate risk management.

ACPR: Comparing static and dynamic balance sheet approaches in climate stress testing

As part of its 2023-2024 climate stress test, the ACPR assessed two sets of scenarios: a set of short-term (until 2027) and long-term (until 2050) scenarios, each based on different balance sheet assumptions. The objective was to explore how insurers' balance sheet would be affected by climate-related risks over different time horizons, with respect to market and underwriting risk. Based on this exercise, the ACPR explored the pros and cons of static versus dynamic balance-sheet assumptions, and drew some lessons from it.

For the short-term scenarios, insurers were required to apply a static balance sheet approach, meaning they could not adjust their portfolios in response to climate shocks. This allowed for a first-order estimate of climate risk impacts in the absence of mitigating management actions. However, in the implementation, insurers interpreted the "static" assumption inconsistently, depending on how their investment strategies were defined. In some cases, maintaining a fixed allocation based on market values led to artificial offsetting effects – where declines in some asset values were automatically compensated by increases in others. Other insurers used strategies based on accounting values or reinvestment flows, which led to diverging outcomes despite the common static assumption.
The ACPR concluded that the term "static balance sheet" may be misleading for multi-year exercises. Instead, it recommends referring to this approach as a "constant asset allocation strategy," recognising that some balance sheet distortions are inevitable over time. For a truly static balance sheet, a one-off instantaneous shock would be more appropriate – but would also limit the scope of insights achievable through a multi-year scenario.

On the liability side, insurers were able to reprice guarantees. However, with respect to property insurance more specifically, ACPR provided premium thresholds which aimed to account for a possible reaction of policyholders to increasing premiums. Thus, the evolution of the number of resigned contracts was thus monitored.

For the long-term scenarios, insurers adopted a dynamic balance sheet approach, allowing for management actions in response to evolving shocks. On the asset side,

…/…

insurers were thus allowed to change the allocation of their assets at a 5-year interval. This made it possible to observe how insurers adapted their strategies – such as shifting away from carbon-intensive assets – in response to transition and physical risks. However, this approach also presented challenges. Without detailed information on asset flows, it was difficult to distinguish the effects of market shocks from those of active management decisions. The ACPR found that in future exercises, it would be beneficial to collect not only end-period balance sheet data, but also investment flow data for each step in the projection. This would provide a clearer picture of how portfolio adjustments interact with climate shocks over time.

Box 7

IMF application of a dynamic balance sheet approach

The 2024 Japan Financial Sector Assessment Program (FSAP) applied a dynamic balance sheet approach to assess climate-related transition risks, marking a significant methodological advancement. Traditional climate risk analysis often relies on the assumption of static balance sheets, which does not adequately reflect the sectoral shifts and evolving credit exposures inherent in the transition to a low-carbon economy. In contrast, the Japan FSAP explicitly modeled the deleveraging and leveraging of industries expected to decline or thrive under the Current Policies and Net Zero 2050 scenarios (NGFS Phase IV).[21]

This approach recognized that shrinking (growing) industries will reduce (increase) credit demand and thus impact banks' interest income. It also incorporated that rising credit spreads, driven by higher probability of defaults (PDs) and loss given defaults (LGDs), are priced into lending rates for industries vulnerable to the transition. Loan growth projections for each industry were calibrated using a rolling multi-year average of sectoral gross value added (GVA) growth, consistent with the transition scenarios.

Considering the dynamic evolution of firm debt was important in climate risk analysis, as it captured shifts in industry size and structure and their potential impact on bank profitability and capital adequacy. For example, the Japan FSAP compared the performance of two sectors: the chemical products and the electricity and gas sectors. The chemical sector, negatively affected by decarbonization, was projected to experience a 0.8 percentage point annual decline in loan growth, while the electricity and gas sector would benefit from the transition, with annual loan growth increasing by 1.2 percentage points per annum until 2040 under the Net Zero 2050 scenario. When the chemical sector shrinks, it would result in lower interest income and less negative loan losses for banks, even though PDs and LGDs rise relative to the Current Policies scenario (Figure 1). Conversely, the growth of electricity and gas sector would translate into higher interest income but also larger loan losses – driven by the increase in exposure volumes, despite reductions in PDs and LGDs relative to the Current Policies scenario. Additionally, sectoral loan growth would also affect risk-weighted assets. More positive loan growth in expanding sectors puts downward pressure on capital ratios, whereas less positive or negative growth exerts upward pressure on these ratios.

Under a dynamic balance sheet, the banking system's capital ratio in the Net-Zero scenario further declines by 0.1 percentage points compared to a static balance sheet where zero gross loan growth is assumed. This decline results from the foregone interest income from shrinking industries outweighing the increasing interest income from growing industries and the reduction in asset riskiness *via* deleveraging within the negatively affected sectors.

…/…

21 For more information, please refer to Japan: Financial Sector Assessment Program-Technical Note on Systemic Risk Analysis and Stress Testing. https://www.imf.org/en/Publications/CR/Issues/2024/05/10/Japan-Financial-Sector-Assessment-Program-Technical-Note-on-Systemic-Risk-Analysis-and-548795.

Figure 8 **Japan FSAP: Effects of Dynamic Balance Sheets under the Net Zero 2050**

With dynamic balance sheets, shifts in industry structure and their resulting effects on bank profitability can be accounted for.

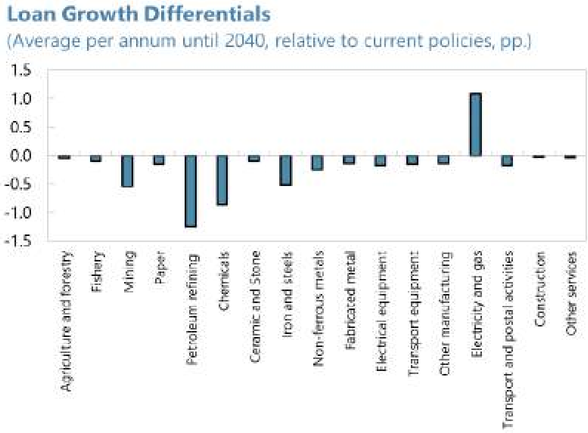
Industry: Chemical
(JPY million, cumulative flows until 2040, Net-Zero minus Current Policies)

	Static	Dynamic
Interest Income	9,623	-218,213
Loan loss	-29,468	21,322
Sum	-19,845	-196,890

Industry: Electricity and Gas
(JPY million, cumulative flows until 2040, Net-Zero minus Current Policies)

	Static	Dynamic
Interest Income	-2,153	598,422
Loan loss	14,963	-348,908
Sum	12,811	249,514

While loans to electricity and gas grow under the Net-Zero 2050 relative to the Current Policies scenario, loans to other sectors decline.



Sources: IMF staff calculations and Japan FASP. Figures are expressed as relative to current policies.

For an extended description of the model, see Gross, M., Yoo, Y., Rojas-Romagosa, H., Barrail, Z., Dehmej, S., and Sheldon, H. 2025. "The ENV-FIBA Model for Climate Risk Analysis – Framework, Model Details, and Guide," forthcoming IMF Working Paper.

Climate risks explored

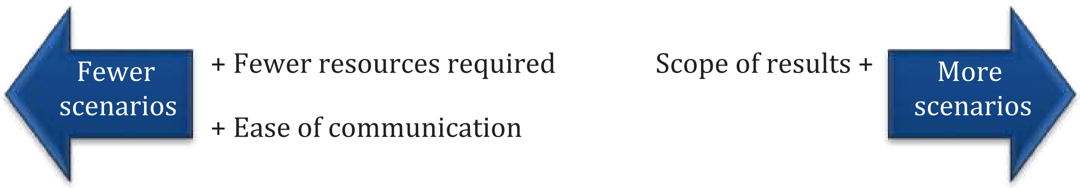
Central banks should consider the types of climate risks they want to explore. Physical and transition risk scenarios are often modelled separately. The NGFS scenarios cover both risks. A full integration would require to simultaneously consider physical impacts and transition policies in the scenario development. The severity and relevance of each risk type, however, depends on the time horizon. Transition risk is more relevant for the short-term because most of the transition impacts, such as mitigation costs and investment efforts, happen at the onset of a green transition. Physical risk, particularly the chronic type, such as changes in extreme temperatures and precipitation, is more severe in the long term as global temperatures continue to increase.

Number of scenarios

Multiple scenarios should be used to explore different plausible scenarios and trade-offs that may exist between them. For example, scenarios with high global emissions can be used to explore physical risks. Scenarios with a reduction in emissions can be used to explore transition risks. This transition can be assumed to occur with coordinated policy, investment in new technologies and gradual capital replacement, or in a disorderly way with late, sudden and/or unanticipated shifts in policy, the economy and financial system.

The number of scenarios that users choose to analyse will depend on the objective of the exercise, the materiality of the macro-financial risks, and resources available.

Figure 9 **Trade-offs of analysing more versus fewer scenarios**



Analysing more scenarios will lead to a more comprehensive and holistic view of the risks. However, the broader scope can constrain how deeply particular details can be explored for a given level of resourcing.

Scenario scope and granularity

Users should determine the level of granularity at which they want to assess the risks. This will have an important bearing on the design of the exercise, choice of scenarios and data required. Possible levels of resolution are set out in Table 6 below.

Different climate-economy models offer different levels of sectoral and geographic coverage. Historically climate-economy models tended to focus more on the energy and land systems, and model world regions at an aggregate level. There are also domestic models run by individual countries that provide a greater level of national resolution. In practice, the scenario will almost always need to be supplemented with additional modelling and data. This is further explained in Chapters 4 and 5.

Scenario analysis focused on individual financial firms and their portfolios will typically need to be undertaken at a high level of granularity. For example, flood risk may impact households on one end of the street and not the other. Similarly, the risks to a fossil fuel company will substantially depend on costs of production and whether the company has plans to broaden out its strategy. While for assessing financial stability risks, aggregation of these granular risks is typically required, it is nonetheless important to identify concentration of certain risks in specific sectors or within regions.

Scenario analysis at a medium or low level of granularity will typically be sufficient for assessing the impact on the macroeconomy. This type of top-down analysis can also be useful to understand the potential feedback loops between the financial sectors and the real economy.

Frequency

Users should consider the desired frequency of analysis. For example, risks could be assessed at an interval of 1 year, 5 years, 10 years, etc. over the duration of the scenario. This is important to consider because climate scenarios often cover long time horizons (out to 2100) with model time steps of 5 years or more.

Annual changes can be derived from longer-term periods if more frequent scenario outputs are not available. However, it will often be necessary to reconsider the scenario assumptions and consider other short-term effects that could arise, including unexpected events that happened around the starting point of the scenarios. For example, this could include assumptions around the extent to which the economy diverges from equilibria and whether there is market volatility or credit tightening within the financial system.

Calibration

Users may approach scenario analysis with different questions in mind, and should calibrate the scenarios accordingly. For example, they may be interested in mapping out a required adjustment path for the financial sector under plausible climate change scenarios, or they may be interested in exploring potential losses under worst-case scenarios.

At a high level, the scenario calibration can be conducted in at least two ways. First, one can select climate scenarios that are more or less severe in terms of physical and transition risks. Second, for variables for which a probability distribution is available (e.g. probability of reaching a particular climate outcome, probability of a physical hazard occurring), one can decide to focus more on mean or median ranges, or on tail risk. However, it is important to consider that climate scenarios per se do not reflect *more or less probable* outcomes, but rather a range of *plausible* outcomes.

Table 6 **Possible levels of granularity**

		Economic resolution	Geographical resolution
Level of granularity	Low	• Macroeconomy	• Global
	Medium	• Sectoral level	• Country to regional
	High	• Firm/Household level	• Postcode down to individual property location

4. Assessing economic impacts

This Chapter sets out some information on the process of using scenarios to assess economic impacts. This includes identifying the macroeconomic impacts assessed, relevant transmission channels, the method of assessment, any key assumptions and sensitivities and refining the results.

Economic impacts assessed

For many types of climate scenario analysis, a key aspect of the climate scenario will be the types of economic impacts from the climate risks to be assessed. In the short- to medium-term this could include impacts on the level of GDP, unemployment and inflation. Over long-term horizons this could also include the cumulative impact on the long-run determinants of growth (e.g. capital, labour and total factor productivity) and changes in demand (e.g. consumption, investment, government expenditure and terms of trade). Climate scenarios may also provide some insight on structural questions such as:

- *Economic structure:* What are the structural shifts between sectors (e.g. from energy-intensive to less energy-intensive)? Are there lasting changes from lowering energy intensity, for example a shift in the share of GDP from goods to services? This may also have knock-on impacts for international trade and policy settings.
- *International competitiveness and trade flows:* How is international trade affected by physical or transition risks materialising? For example, the shift in preferences away from carbon-intensive products can have a significant impact on terms of trade for oil producers. Physical risks may similarly have an impact on terms of trade, for example for food production. What is the relative impact between regions and countries? What is the effect on exchange rates?
- *Policy settings:* How will monetary policy adapt to climate change? What would be the impact on natural interest rates? Related to the fiscal stance, what would be the impact on borrowing and debt, what impact does this have on financial variables like sovereign bond yields?

Transmission channels

Transition risk

Macroeconomic impacts from transition risks arise from a fundamental shift in energy and land use that will affect every sector of the economy. At a high-level, this could lead to some of the existing capital stock being 'stranded' and labour market frictions as the economy shifts towards lower, and ultimately, net zero emissions activities. The size of the impacts will depend on how gradually and predictably, or abruptly and disorderly, this transition takes place, and how investment in new technologies affects productivity.

These impacts are likely to affect economies in different ways depending on economic structure, institutional settings and the specific climate policies pursued. These policies could include fiscal policy (e.g. carbon pricing; public investment or subsidies), structural policy (competition policy or labour market policy to help facilitate the transition, impacting wage and price dynamics) and regulation and standards (e.g. setting emissions standards or targets for certain sectors).

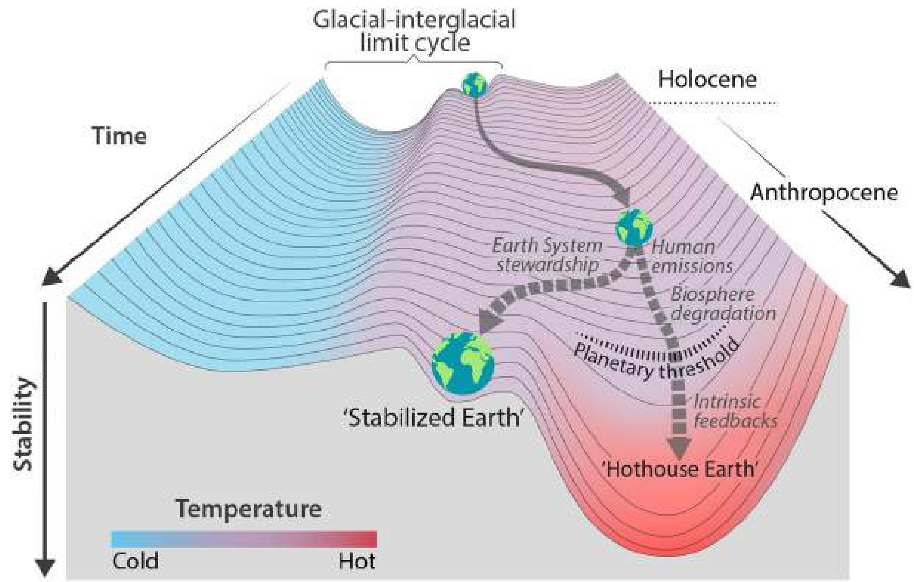
Physical risk

Macroeconomic impacts from physical risk could arise from both an increase in the frequency and severity of severe weather events, and gradual climate change. These risks may have wide-ranging direct economic impacts on:

- *People:* including labour productivity, mortality and morbidity (e.g. from changes in temperature extremes) and leisure;
- *Physical capital:* due to destruction of property and infrastructure (e.g. from floods, windstorms) and diversion of resources and investment into reconstruction and replacement;
- *Natural capital:* due to disruption to agriculture (e.g. from crop failure) and other ecosystem services (e.g. from shifts in the productivity and distribution of fish stocks).

This could lead to significant knock-on impacts on the economy depending on the nature of the threat, the level of resilience and level of local adaptation.

Figure 10 **Planetary thresholds and risks of a hot house earth pathway**



Source: Steffen et al. (2018). Figure 4 shows the pathway of the Earth system out of the previous glacial-interglacial limit cycle to its present position in the hotter anthropocene. Currently, the Earth System is on a Hothouse Earth pathway driven by human emissions of greenhouse gases and biosphere degradation toward a planetary threshold at ~2 °C, beyond which the system follows an essentially irreversible pathway driven by intrinsic biogeophysical feedbacks. The other pathway leads to Stabilized Earth, a pathway of Earth System stewardship guided by human-created feedbacks to a quasi-stable, human-maintained basin of attraction. "Stability" (vertical axis) is defined here as the inverse of the potential energy of the system. Systems in a highly stable state (deep valley) have low potential energy, and considerable energy is required to move them out of this stable state. Systems in an unstable state (top of a hill) have high potential energy, and they require only a little additional energy to push them off the hill and down toward a valley of lower potential energy.

These physical risk impacts could be much larger, and occur much sooner, than anticipated. The distribution of events is shifting such that our historical analysis of both the climate and economic impacts underestimate the size of the risks. The earth is currently on a trajectory towards a 'Hothouse Earth' state with potentially irreversible impacts (shown in Figure 10 above). This could be further accelerated by tipping points such as loss of ice sheets, rainforest cover and permafrost.

These factors make it very difficult to accurately assess macro-financial impacts once global warming passes a certain threshold such as 2 °C of warming compared to pre-industrial levels. For this reason, in addition to the methods set out below, central banks should consider decision-making frameworks for dealing with deep uncertainty, such as those produced by the World Bank.[22]

Methods

Central banks have a range of models for making economic forecasts. These models provide a central organising framework, which can be deployed to study a wide range of economic mechanisms and effects. These macroeconomic models can be easily modified to assess even some channels of climate risk, such as a change in commodity prices or weather shocks that affect supply. However, economic models typically used by central banks have a number of limitations. They usually have a limited representation of energy and agricultural systems, and their modelling horizons often do not extend much further than the business cycle.

There are bespoke models that have been developed to study interactions between physical and transition risks and the economy. These models have primarily been developed for academic research and/or advice for policymakers. However, while broad in scope, they also have a number of limitations. At the less complex end, only a simple growth model is used or the costs (associated with mitigation policies and/or climate damages). While more complex models have now also been developed, they still cannot capture all transmission channels. The NGFS Scenarios are working to address some of these challenges.

22 https://blogs.worldbank.org/ppps/embracing-uncertainty-better-decision-making.

In the interim it is likely that central banks will have to deploy a combination of approaches to understand the macroeconomic impacts. For example, climate-economy models can be used to develop coherent scenarios, and traditional macro models can be used to expand the number of economic variables for assessing risks. Table 7 below sets out the main types of models that exist and how they can be used. They have been split by their lineage as either climate-economy models or adapted macroeconomic models. Also, see Box 2 for more information on the work of Bank of Canada to estimate macroeconomic effects using a CGE model.

Table 7 **Types of economic models to assess climate risks**

Lineage	Model type	Description	Example
Integrated climate-economy models[23]	Cost-benefit IAMs	Highly aggregated model that optimises welfare by determining emissions abatement at each step	DICE, DSICE (Cai *et al.*, 2012, Barrage, 2020)
	IAMs with detailed energy system and land use	Detailed partial (PE) or general equilibrium (GE) models of the energy system and land use. General equilibrium types are linked to a simple growth model	PE: GCAM, IMAGE GE: MESSAGE, REMIND-MAgPIE, WITCH[24]
	Computable General Equilibrium (CGE) IAMs	Multi-sector and region equilibrium models based on optimising behaviour assumptions	G-CUBED, AIM, MIT-EPPA, GTAP, GEM-E3
	Macro-econometric IAMs	Multi-sector and region model similar to CGE but econometrically calibrated	E3ME, Mercure *et al.*, 2018
	Stock-flow consistent IAMs	Highly aggregated model of climate change and the monetary economy that is stock-flow consistent	Bovari *et al.*, 2018
Other climate-economy models	Input-output (IO) models	Model that tracks interdependencies between different sectors to more fully assess impacts	Ju and Chen, 2010 Koks & Thissen, 2016
	Econometric studies	Studies assessing impact of physical risks on macroeconomic variables (e.g. GDP, labour productivity) based on historical relationships	Khan *et al.*, 2019 Burke *et al.*, 2015 Dell *et al.*, 2012
	Natural catastrophe models and micro-empirical studies	Spatially granular models and studies assessing bottom-up damages from physical risks	SEAGLASS (e.g. Hsiang *et al.*, 2017)
Modified standard macroeconomic models	DSGE models	Dynamic equilibrium models based on optimal decision rules of rational economic agents	Golosov *et al.*, 2014 Cantelmo *et al.*, 2019
	E-DSGE	Slightly modified standard frameworks (that allow for negative production externalities)	Heutel, 2012
	Large-scale econometric models	Models with dynamic equations to represent demand and supply, coefficients based on regressions	NiGEM (e.g. Vermeulen *et al.*, 2018)

23 IAM taxonomy adapted from Nikas *et al.*, 2019.

24 Model documentation available at www.iamcdocumentation.eu/index.php/IAMC_wiki.

Box 8

Using CGE models to estimate macroeconomic effects – lessons from the Bank of Canada

The Bank of Canada released a study that adapted climate-economy models to better understand potential sources of economic and financial risks.[25] In it, the authors set out examples of the types of scenarios that could generate economic and financial risks; they do this by varying assumptions on key variables, like climate policy, in plausible ways. They assess the risks around these scenarios using a computable general equilibrium (CGE) model that provides extensive sector-level detail on the potentail impacts of each scenario. An IAM model is used to inform a discussion of the economic costs and risks associated with higher temperatures. The scenarios have a long horizon, focussing on effects until 2050, but show that the impacts could be material much sooner and over a short period of time.

The results provide insights on the distribution of risks for the global economy and financial system, highlighting significant economic risks surrounding climate change and the transition to a low carbon economy. The timing and magnitude of global and sectoral GDP impacts, among other outcomes, look considerably different across the mix of scenarios. The results also suggest that while transition risks can be avoided through inaction, this comes at a significant economic cost through higher physical damages and risks. Action that comes late (as proxied by the introduction of carbon taxes) must be more abrupt to keep temperature increases in check, which raises transition risks. Earlier action also allows more time for new technologies to enter the market in response to price signals, leading to a larger green energy sector and lower transition costs.

Expanding the scenario by modelling additional variables

When assessing the economic impacts of climate scenarios, users may wish to extend the analysis beyond the standard macroeconomic aggregates. User might want to incorporate, for instance, **sectoral output variables**, which shed light on heterogeneous impacts across industries. For example, energy-intensive sectors may experience sharper contractions under a disorderly transition, while service-oriented industries may remain relatively unaffected. Another instance concerns **price and wage dynamics**. Climate shocks can generate both cost-push inflation and demand-side effects. Explicit modelling of producer prices, real wages, or terms of trade provides a richer understanding of the inflationary and distributional consequences of climate scenarios, which is highly relevant for central banks. Expanding the set of variables can help capture more granular and sector-specific transmission channels, thereby improving the relevance of the scenario for its respective objective.

There are various methodological options one can pursue to expand the set of variables:

- **Extend existing macroeconomic models through *satellite models or modules:*** For example, a macro model projecting GDP under transition scenarios can be complemented by a **sectoral module** that allocates the aggregate impact across industries according to their carbon intensity. One area where satellite models can provide significant value is the **real estate market**, including both residential and commercial property. While NGFS long-term scenarios account for the impact of climate risks on real estate prices, they do not fully capture the heterogeneity of impacts across regions and property types. Given the importance of real estate for households' wealth, banks' mortgage portfolios, and insurers' exposures, users may consider complementing the NGFS scenarios with dedicated real estate or mortgage modules.

25 Ens and Johnston, 2020.

- **Downscaling techniques:** This approach is particularly useful to disaggregate scenario outputs across regions, sectors, or income groups based on historical relationships, input-output tables, or econometric estimations. It allows the integration of heterogeneity without redesigning the core model, though it introduces additional assumptions that need to be aligned and should be made transparent.
- **Hybrid modelling approaches:** This approach combines outputs from different frameworks. For instance, results from integrated assessment models can be merged with macro-financial models to enrich fiscal or trade-related variables. Such approaches require careful alignment of assumptions, time horizons, and baseline paths to ensure internal consistency.

Box 9

C-TIF: Extension of NGFS scenario variables

The Climate Transition Impact Framework (C-TIF)[26], introduced at COP28 in 2023, provides a structured tool to assess and compare the socioeconomic impacts of different climate scenarios. Developed in collaboration with the NGFS and a broad range of stakeholders, the framework is designed to support policymakers in making informed decisions for the planning of the climate transition.

The C-TIF contains roughly 70 metrics across five key dimensions: Affordable Energy Access, Lived Environment and Health, Investment Requirement, Jobs Impact, and Growth and Competitiveness. Together, these dimensions offer a comprehensive picture of how different climate scenarios could shape national economies.

The 2025 C-TIF report applies the framework to 15 countries, using NGFS Phase IV scenarios – Current Policies and Net Zero 2050 – to demonstrate how the tool can be used to explore climate impacts under consistent global assumptions. This pilot application highlights the framework's flexibility: it can be adapted to various use cases, from global to sub-national climate transition pathways for the assessment and comparison of multiple regions under coherent plausible futures.

To generate the full set of indicators, the C-TIF combines direct outputs from NGFS scenarios (e.g. GDP per capita, energy intensity, electricity prices) with secondary modelling to derive more detailed variables, such as sector-specific investment needs. For example, investment requirements in the cement sector are derived from NGFS-provided energy demand data, combined with assumptions on fuel efficiency and technology lifetimes from external sources.

Investment needs are estimated at the NGFS continent-level, before being downscaled to the country level based on each country's share in continent-level activity. In cases where the NGFS reports a relevant activity-related variable inside their downscaled dataset (e.g., gas electricity generation), it is used to downscale the related aggregate investment variable (e.g., investment in gas power generation). In cases where the activity-related variable is not reported at the country level, a suitable proxy variable is used.

By connecting climate scenarios with socioeconomic outcomes, C-TIF enables a more granular understanding of the costs, risks, and opportunities of climate action.

26 More details on the Climate Transition Impact Framework (C-TIF) can be found under: https://www.mckinsey.com/capabilities/sustainability/our-insights/climate-transition-impact-framework-ctif-planning-for-a-sustainable-and-inclusive-future#/.

Key assumptions and sensitivities

Transition risk assumptions

The climate scenario design will have a significant bearing on the nature and size of the economic impacts. Some of the key transition pathway assumptions include the speed and timing of policy action, the type of policy implemented (taxes, regulations), the progress in technology (both in carbon emission reduction and in carbon capture and storage technology), and shifts in behaviour from companies and consumers.

Models are also sensitive to assumptions made about how the economy and financial sector respond to shocks. This includes assumptions related to:

- *Carbon price transmission:* whether carbon prices lead to a supply- or demand-driven shock, or both;
- *Market clearing:* how much consumer demand will be matched by the supply of goods in the short and/or long run;
- *Investment:* whether the level of investment in the economy is constrained by savings (possibly leading to crowding out effects) or can grow;
- *Role of the financial sector:* whether the financial sector efficiently allocates capital and provides the investment required or not;
- *Monetary policy responses:* how monetary policy responds to shocks to the economy.

These assumptions help to explain why some models suggest the transition will result in decreased growth while others report a positive green growth effect. Equilibrium models, such as CGEs, are generally characterised by market clearing assumptions and are mostly without frictions. In such models, investments are typically constrained by the level of savings and economies always operate at full potential. In non-equilibrium models, investment is not necessarily required to match savings and money may be available to fund investments and innovation. Non-equilibrium models also tend to assume economies operating sub-optimally and hence away from productivity frontiers. When these imperfections (in the baseline) are resolved by climate policy, the result can be improved efficiency and higher growth impacts. The effects of introducing market frictions have also been replicated in some CGE studies.[27]

In the NGFS scenarios, the three primary transition risk factors that drive macroeconomic impacts are carbon price revenues, primary energy consumption, and useful energy. Carbon revenues are allocated to government investments to a different extent in each scenario, while the rest is used for government debt repayment or tax reductions. The recycling strategy of carbon revenues is one of the key drivers in GDP growth.

27 Chateau and Saint Martin (2013) introduce labour market imperfections (restrictions to worker mobility and wage rigidity) into the baseline of a CGE and implemented climate policy that addressed these imperfections by recycling carbon revenues to reduce labour taxes and maintain real wages.

Box 10

Bloomberg: From Scenarios to Corporate Risk and Opportunity with Bloomberg's MARS and TRACT Models[28]

The NGFS scenarios are now widely used in climate financial risk assessments and disclosures. Yet financials continue to face challenges in downscaling scenarios to corporate-, equity- and bond-level impacts. Bloomberg has built a suite of integrated models to quantify business risk and opportunity for investment and lending portfolios, called Multi-Asset Risk System (MARS) Climate and BloombergNEF Transition Risk Assessment Company Tool (TRACT). The Bloomberg MARS Climate model captures four transmission channels to assess credit, equity and bond pricing risk across NGFS scenarios.

For corporate transition risk, most downscaling models leverage a 'cost of carbon' approach in which NGFS shadow carbon prices are applied to a company's greenhouse gas emissions. The resulting cost is assumed to be passed on to consumers *via* company balance sheets. This approach overlooks key aspects of corporate risk in the energy transition. First, carbon prices are not ubiquitous in the real economy, as only a quarter of carbon emissions are currently priced. Second, carbon risk isn't the main transition risk that businesses face – it's product displacement (business risk), such as the displacement of gas-fired power generation by solar, or of internal combustion engine road vehicles by electric vehicles (EVs). The product displacement transition moves at different speeds across sectors and regions.[29] It's currently moving quickly in power and road transport, as renewables and EVs are now cost-competitive. It is much slower in aviation, cement and steelmaking, however, where low-carbon alternatives remain expensive. In other words, while companies in these industries are carbon-intensive, they arguably face less risk than incumbent electric utilities or automakers. Hence, carbon pricing alone can't reflect the full impact of transition risk in the real economy.

In contrast to solutions using the 'cost of carbon' approach, BloombergNEF's TRACT model looks at product displacement risk and opportunities for corporates in the transition, leveraging on companies' current revenue sources, regional footprints and firm-to-firm supply chain links. The regional change in the demand for commodities and products in scenarios drives corporate revenues for directly exposed firms. For example, an oil major is likely to experience lower revenues if the demand for oil and natural gas declines. A copper mining company could see an increase in its income if the demand for electric vehicles and electrical distribution and transmission rises. A software company, with clients in the coal-mining and oil industries, might also indirectly experience lower revenues over time if the core activities of some of its customers are disrupted.

TRACT captures both direct and indirect impacts with a high level of granularity for nearly 80,000 public and private firms, feeding into the microeconomic module of Bloomberg's MARS CLIMATE model, which derives scenario impacts on credit, equity and bond pricing risk. …/…

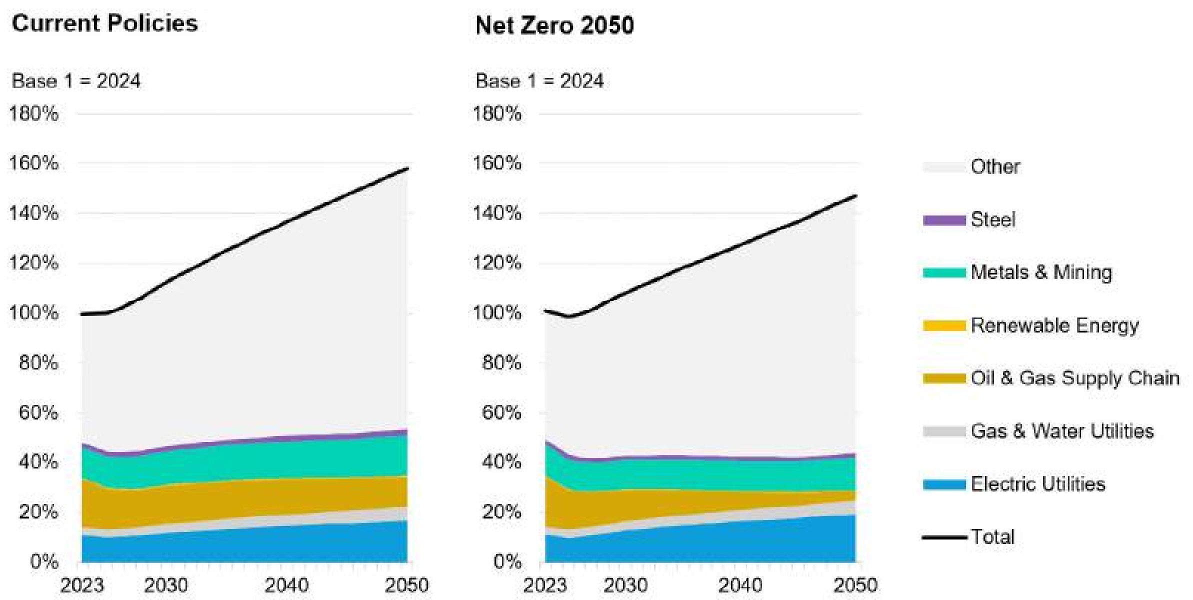
28 Bloomberg Disclaimer: The data included in these materials are for illustrative purposes only. The BLOOMBERG TERMINAL service and data products (the "Services") are owned and distributed by Bloomberg Finance L.P. ("BFLP") except (i) in Argentina, Australia and certain jurisdictions in the Pacific islands, Bermuda, China, India, Japan, Korea and New Zealand, where Bloomberg L.P. ("BLP", together with its affiliates, including BFLP, "Bloomberg") and its subsidiaries distribute these products, and (ii) in Singapore and the jurisdictions serviced by Bloomberg's Singapore office, where a subsidiary of BFLP distributes these products. BLP or one of its subsidiaries provides BFLP and its subsidiaries with global marketing and operational support and service. Certain features, functions, products and services are available only to sophisticated investors and only where permitted. The Services are standard services offered by Bloomberg. Users are responsible for their use of the Services and for assessing whether the Services help meet any regulatory obligations that apply to them. Bloomberg does not guarantee the accuracy of data or other information in the Services. Nothing in the Services shall constitute or be construed as an offering of financial instruments by Bloomberg, or as investment advice or recommendations by Bloomberg of an investment strategy or whether or not to "buy", "sell" or "hold" an investment. Information available *via* the Services should not be considered as information sufficient upon which to base an investment decision. Bloomberg makes no claims or representations, or provides any assurances, about the sustainability characteristics, profile or data points of any underlying issuers, products or services, and users should make their own determination on such issues. The following are trademarks and service marks of BFLP, a Delaware limited partnership, or its subsidiaries: BLOOMBERG, BLOOMBERG ANYWHERE, BLOOMBERG MARKETS, BLOOMBERG NEWS, BLOOMBERG PROFESSIONAL, BLOOMBERG TERMINAL and BLOOMBERG.COM. Absence of any trademark or service mark from this list does not waive Bloomberg's intellectual property rights in that name, mark or logo. All rights reserved. © Bloomberg.

29 See BloombergNEF Energy Transition Investment Trends 2025.

For example, Brazil's top equity index, the Ibovespa, has a high concentration across three industries: oil and gas, electric utilities, and metals and mining. TRACT analysis shows that a Net Zero by 2050 pathway could erode Brazil's oil export revenues as the world switches to electrified mobility (Figure 1). On the flip side, utilities in the country would benefit from the shift to electric end-uses, leading to higher power demand as well as the need to build more renewable power capacity. Similarly, higher global demand for transition metals benefits certain corporates, helping the Ibovespa index mitigate some of the revenue downsides from the oil and gas supply chain. Overall, a net-zero pathway leads to a restructuring – but not a collapse – of the economic value in the Ibovespa when considering both risk and opportunities.

While TRACT offers a microeconomic perspective on transition risks and opportunities, MARS Climate projects firm-level cash flow impacts from the macroeconomic effects of NGFS scenarios. This analysis is informed by the historical sensitivity of corporate earnings to the business cycle. MARS Climate also uses a top-down approach to assess physical risks. This involves downscaling country-level GDP losses – resulting from acute and chronic physical risks as projected in NGFS scenarios – to firm-level cash flow losses. This downscaling is based on Bloomberg's assessment of the relative sensitivity of different sectors, and individual issuers within those sectors, to physical risks.

Figure 11 **Revenue projection for Brazil's main equity index (Ibovespa) across two NGFS scenarios**



Note: Changes derived from real US dollars. Ibovespa contains 84 equities. This projection is broken down by the sectors of companies. BloombergNEF enhanced the NGFS scenarios to capture automotive, metals and mining products granularly.
Source: BloombergNEF TRACT.

Physical risk assumptions

There is a great level of uncertainty around the current estimates of economic damages that result from climate change. Early approaches in cost-benefit IAMs (e.g. in DICE) were estimated using 'enumerative' approaches, using impact assessment and expert judgment to quantify different types of physical risk damages. Variations of these functions are still being used widely but lack a proper empirical foundation and there is wide agreement that they underestimate economic damages.

More recently, CGE approaches have focused on developing an empirical, bottom-up assessment of physical risks within an equilibrium framework. These models have sought to quantify an increasing number of channels (health, tourism, agriculture, sea-level rise) based on updated impact estimates. The size of impacts substantially depends on the channels covered and whether the effects are considered to be temporary (e.g. drop in agricultural production affects short-run GDP growth) or permanent (e.g. increased temperatures reducing labour productivity). Despite a recent growth in empirical studies, high-level approximations of the economic impacts must still often be made. This is due to lack of granular data, uncertainty related to the underlying bio-physical processes and uncertainty related to the future level of adaptation.

There is an increasing amount of macro-econometric research that aims to empirically calibrate top-down damage functions. By linking climate variables such as temperature to aggregate macro outcomes they may capture a wider range of damages than micro-founded approaches. However, they are still subject to a number of limitations. These include:

- **Non-linearities:** studies using historical data make implicit assumptions about future impacts. However, these historical trends may not hold in the future due to socio-economic changes (e.g. migration), or because a particular threshold has been reached (e.g. agricultural yields or labour productivity drop off sharply above a given level of climate change). Some studies have used innovative approaches to account for these potential non-linearities but are still subject to uncertainty about future responses and adaptation.
- **Channel coverage:** macro-econometric approaches may still not capture all relevant transmission channels. This may be due to the spatial and temporal aggregation of data (e.g. average yearly temperatures), or because of a narrow focus on a single macroeconomic indicator (e.g. labour productivity).
- **Feedback effects:** temperature change is typically considered to be exogenous in models. While this might hold true in the short-term, temperatures will likely be affected by economic growth in the long-term.

Further sources of uncertainty are the discount rate applied to future damages and the uncertainties stemming from the modelling of the climate impacts themselves.

The NGFS scenarios model the economic damages from both acute and physical risks. For chronic physical risk, the NGFS scenarios deploy a damage function which captures the changes in GDP from changes in climate patters. Economic damages from acute physical risk are modelled *via* NiGEM and are modelled at the country-hazard-level. Heatwaves affect labour productivity, droughts affect crop yields, and cyclones and floods impact physical assets. The severity of each hazard is driven by the change in global mean temperatures in each scenario.

The broad set of climatic variables integrated in the damage function used in the Phase V of the NGFS long-term scenarios partly overlaps with the types of hazards usually classified as acute (floods, storms, etc.) Users should thus be cautious not to double count impacts when combining chronic and damage functions.

Refining the results

Assessing macroeconomic impacts and vulnerabilities is an iterative process. It may be useful to consider how sensitive the results are to changing some of the key assumptions in either the underlying climate scenario (discussed in Chapter 3) or the macroeconomic modelling (discussed in this Chapter 4). It may also be useful to consider how much the scenario would have to change (e.g. temperatures) to produce a given result (50% reduction in GDP). This process of iterating on the scenario and exploring different outcomes can be just as insightful as the size of the impacts themselves.

5. Assessing financial risk

This Chapter provides information on using climate scenarios to assess financial risks. This includes identifying the scope of financial risks assessed, relevant transmission channels, methods of assessment, key assumptions and sensitivities and refining the results. Often it builds on macroeconomic analysis done as part of the exercise (see Chapter 4).

Financial risks assessed

Users should first consider the financial impacts they wish to measure and the metrics that will be assessed. A targeted exercise may focus on a small number of financial firms, financial asset classes and types of risks – for example, using scenarios to assess the agriculture-related credit risks for a few financial firms. On the other end of the scale, a system-wide stress test could involve both financial and macro channels, multiple sectors and different types of financial firms.

There are at least three dimensions to consider, informed by the results from the initial materiality assessment (see Chapter 2):

- *Firm coverage:* banks, insurers, asset managers, asset owners, CCPs and other financial market infrastructure.
- *Financial risks:* credit, market, operational, liquidity, underwriting.
- *Financial products:* credits (e.g. mortgages, consumer credit, corporate loans and bonds, sovereign bonds), equities, derivatives, insured liabilities.

The depth of the analysis can differ depending on the materiality of the climate risks in the scenario. For example, while some risks (e.g. market risk on listed equities in the energy sector) may require in-depth analysis, it may be sufficient to analyse less material risks (e.g. credit risk on loans to IT services companies) using sectoral or macro-level proxies of risk.

Box 11

ACPR: The use of NGFS scenarios to assess physical risk in the insurance sector

In its 2023–2024 bottom-up climate scenario analysis for the insurance sector, the ACPR assessed both the assets as well as liability side of insurers' balance sheets. For this purpose, they leveraged on NGFS scenarios, described as follows.

Downscaling NGFS estimates to assess physical risk on insurers' assets

In its 2023-2024 bottom-up climate scenario analysis for the insurance sector, the ACPR integrated sector-specific impacts of chronic physical risks by leveraging country-level GDP impact estimates from Phase III of the NGFS long-term climate scenarios. These estimates are derived from a macroeconomic damage function (Kalkuhl & Wenz, 2020), which quantifies broad productivity losses across labor, capital, and total factor productivity based on mean temperature changes.

To translate these national-level impacts into sectoral effects, the ACPR applied Banque de France's sectoral computable general equilibrium (CGE) model (see Box 13). The damage function, which uses average temperature as its sole variable, was conservatively assumed to partially capture the effect of heatwaves on labor productivity. On this basis, the ACPR disaggregated the GDP impacts into two distinct channels:

1. Heat stress on labor productivity, quantified using the *Labour Productivity due to Heat Stress* indicator from Climate Impact Explorer. The sectoral distribution of these losses was guided by findings from the International Labour Organization, which identifies agriculture and construction as particularly vulnerable sectors.
2. Residual productivity shock, applied uniformly across sectors, captured the remaining macroeconomic damage not directly attributable to heat stress.

…/…

At the time of the analysis, the NGFS scenarios did not yet include acute physical risks. Nevertheless, the ACPR's methodology illustrates how NGFS chronic physical risk estimates can be complemented by distinguishing between transmission channels. This approach also highlights the trade-offs involved in scenario design: while it would have been possible to add labor productivity losses on top of the NGFS damage function, the ACPR opted for consistency in macroeconomic variables and avoided potential double counting, even if this choice resulted in a less adverse scenario.

Leveraging Climate Impact Explorer for consistent physical risk assessment of liabilities

To fill data gaps on the physical risk vulnerability of international exposures, the ACPR leveraged on the Climate Impact Explorer. For the liabilities (insured assets) of French insurers, detailed climate projections were available through CCR, the public reinsurance entity. However, for international exposures, similarly granular data was not accessible. To address this gap, the ACPR adopted an approach inspired by the Bank of England (2021) climate scenario exercise. Participating insurers were referred to the NGFS Climate Impact Explorer, which provides harmonized, median projections for key chronic climate variables – such as precipitation and wind speed – based on data from the ISIMIP project. Insurers were instructed to align their non-life loss models for international portfolios with the median trajectories of these variables under RCP 4.5 or RCP 6.0, depending on the availability of relevant data.

This approach aimed to ensure methodological consistency and comparability across participating firms. In cases where hazards did not have standardized reference variables within the Explorer, insurers were encouraged to transparently document their assumptions and modelling choices.

Together, these practices demonstrate a structured and harmonized way to downscale NGFS physical risk estimates and apply them both sectorally and geographically, ensuring comprehensive coverage of insurers' asset and liability exposures to chronic climate risks.

Box 12

FSA: Assessing underwriting risk of non-life insurers

In its second scenario analysis exercise on climate-related risks, the Financial Services Agency (FSA) conducted a climate scenario analysis on non-life insurers' claim payments. The purpose of the analysis was to understand long-term physical risks, hence, two NGFS scenarios were assessed that examine both tails of physical risk, which were the Net Zero 2050 scenario, with low physical risks, and the Current Policies scenario, with high physical risks. The exercise analyzed potential claim payments in 2050 and 2100, focusing on two acute physical risk sources, specifically, the impact of typhoons and floods.

For conducting the analysis, insurers were provided a common risk model from the General Insurance Rating Organization of Japan (GIROJ). The model analyses the impact of typoons and floods on claim payments based on the temperature increase of the scenarios[30]. The provision of a common tool enabled especially small and medium-sized insurers to participate in the exercise. In this way, the FSA was able to increase the number of participating insurers from 3 non-life insurance groups in their first exercises to 19 non-life insurers in their second exercise. At the same time, using the same model across all participating insurers increased transparency and faciliated the comparability of bottom-up results.

30 The average temperature rise of the two scenarios were used.

Transmission channels

Transition risk

Financial impacts could arise from direct exposure to affected companies or households. The scenario therefore needs to be sufficiently granular to assess the costs and opportunities at the required sectoral and regional granularity. Direct impacts could include:

- *Corporate profitability:* companies could face higher operating costs (e.g. on carbon- intensive inputs) or changing demand for certain goods or services.
- *Corporate indebtness:* green investments are required to reduce greenhouse gas emissions. In practice, green investments will be financed through a mix of subsidies, equity and debt financing, the latter increasing companies' debt.
- *Asset stranding:* companies may have to write off capital assets that are no longer economically viable and / or permissible to use. For example, companies may lose value because of changing market expectations on their ability to generate income in the future (e.g. fossil fuel companies with reserves that cannot be utilised).
- *Corporate legal liability:* to shareholders or investors due to mismanagement of the transition. This could lead to higher legal liabilities or directors and officers (D&O) insurance claims.
- *Household income:* due to households bearing some of the costs of the transition, for example from higher taxes (e.g. on fuel) or higher energy or food prices.
- *Property values:* where residential or commercial buildings require significant improvements in energy efficiency or other upgrades to be let or sold under building regulations.

These impacts could be further amplified by changes in the broader macroeconomic environment discussed in Chapter 4. Relevant factors will likely include the level of output, employment, relative prices, interest rates, sovereign debt and exchange rates.

Physical risk

Physical risks could also result in various financial impacts on households and companies. Some of the direct impacts could include:

- *Corporate profitability:* revenues due to direct damage or supply chain disruption. High temperatures not only impact labour productivity, but they can also affect labour supply. Companies could also face higher costs from investing in adaptation.
- *Household income:* due to climate-related disruption of economic activity or impacts on health.
- *Property values:* where real estate or other infrastructure is particularly exposed to a particular hazard (e.g. flooding to coastal real estate). The nature of the financial risks will also depend on the price and availability of insurance.

While only a relatively small number of households or companies may be exposed to the hazard, there may also be knock-on impacts on the broader economy. For insurers, climate disasters can lead to increase in claim payments. On the other hand, the nature and severity of financial risks will also depend on the availability and price of insurance. These indirect effects should be captured by the macroeconomic modelling.

Methods

Top-down and bottom-up exercises

Users should define the extent to which they will perform the analysis themselves, or invite financial firms to participate in the exercise.

- *Top-down exercise:* central banks and supervisors apply their own calculations to financial institutions' reported data. A uniform framework permits greater consistency and comparability of the results. However, granular data as well as qualitative information is required to assess climate risks in a meaningful way.
- *Bottom-up exercise:* the regulator chooses a scenario and calibrates the scenario variables, but then asks financial institutions to perform quantitative and qualitative analysis of how the scenario would affect their balance sheets. Providing more granular scenario variables can help limit the risk of inconsistent interpretations of the scenario. Alternatively, the regulator may in a less structured way encourage an industry-wide initiative by a group of financial institutions or industry associations to proactively choose representative scenarios and share the result of the analysis with central banks and supervisors.

There are advantages to both top-down and bottom-up exercises. Top-down exercises are easier to plan and quicker to execute as they do not require briefing and coordinating with regulated firms. However, bottom-up exercises can permit greater depth of analysis as financial firms often have more data than supervisors, thus allowing for a closer analysis of the underlying risks.

In practice, financial impact assessment often combines both approaches to obtain multiple perspectives on the impact of the scenario. For example, bottom-up exercises will benefit from in-house desk-based analysis to gain some initial insights on the scenario and develop benchmarks that can be used to confirm or challenge firms' individual results (called "constrained bottom-up" approach). On the other side, top-down exercises may benefit from review and/or some independent analysis from firms or other subject matter experts to cross-check the results.

Modelling approaches

Financial risks can be modelled at varying levels of granularity. At an aggregate level, macroeconomic indicators from the climate scenarios (e.g. GDP, unemployment) can be used to estimate the implied impact on financial markets (e.g. yields and equity indices). However, for the reasons explained in Chapter 2 this will not typically be granular enough to meaningfully assess climate risks to a given portfolio.

Sectoral-level modelling approaches have been developed to overcome some of these challenges. This involves downscaling a macroeconomic indicator (e.g. GDP) to sectoral-level (e.g. sector gross value added) using relevant proxies for the underlying climate risks. See Box 13 for examples of how the Banque de France/ACPR and De Nederlandsche Bank increased the sectoral resolution of their climate risk analyses.

Given the complexity of the transmission channels, it will often be insightful to model the risks at an even more granular level, for example on individual companies and households. This requires obtaining data on the location and characteristics (e.g. emissions, energy use) of the underlying borrower or issuer. Micro models (e.g. cash flow models, natural catastrophe models) can then be used to estimate impacts to the relevant indicator such as property values, corporate profitability and/or household wealth. This analysis can also take account of the strategy of the counterparty to respond to the risks where this information is accessible.

Bottom-up quantification can inform, and be informed by, top-down modelling of aggregate effects. See the Bank of England's 2021 Climate Biennial Exploratory Scenario as an example of how top-down and bottom-up approaches can be combined.[31]

Box 13

How Banque de France/ACPR and De Nederlandsche Bank increased the sectoral resolution of their climate risk analyses

Banque de France/ACPR

The Banque de France and ACPR have developed a climate stress test framework focused on transition risks.[32] The economic modelling in the framework consists of several components, including the National Institute Global Econometric Model (NiGEM) model. Since NiGEM produces only aggregate economic outputs, the model is coupled with a static general equilibrium sectoral model developed by Banque de France, which is designed to propagate a tax shock and/or a productivity shock across sectors.[33]

The model relies on input-output data to represent the production in each sector in each country as a process involving non-energy and energy intermediate inputs from all countries, and domestic labour. All these inputs are substitutable to various degrees, and firms optimise their intermediate demands given the relative prices of inputs in a perfectly competitive environment. The model is then closed to form a general equilibrium set-up by adding a representative household in each country, supplying labour inelastically and consuming goods from all countries. …/…

31 Bank of England, 2021.

32 Allen *et al.*, 2020.

33 Devulder and Lisack, 2020.

The shares of inputs in production, the relative sizes of the sectors and the consumption shares are calibrated to match sectoral input-output and final consumption data from the World Input Output Database (WIOD). The substitution elasticities are obtained from the literature. The baseline version of this model assumes perfect risk sharing across countries, imposing that relative consumption responds positively to changes in real exchange rates. For simplicity, the model ignores physical capital, such that production requires only labour and intermediate inputs. The demand side amounts to final consumption from households.

De Nederlandsche Bank

In De Nederlandsche Bank's transition risk stress test[34], four disruptive transition scenarios are simulated with an adapted version of NiGEM to create a set of mutually consistent paths for a set of macroeconomic (e.g. GDP, unemployment, price level) and macro-financial (e.g. interest rates, stock price indices) variables. Since NiGEM produces economic outputs at an aggregate level by geographical region, and not at sector-level, De Nederlandsche Bank developed sector-specific "transition vulnerability factors" (TVFs). The TVFs allowed the NiGEM outputs to be translated to a sectoral level.

The approach can be summarized as follows:

- The TVFs are defined such that the average TVF of the economy (weighted by the value added of each economic sector) is equal to 1. In the stress test scenarios, sectors with a TVF smaller than 1 are affected less than the economy as a whole, while sectors with a TVF larger than 1 are affected more than the economy as a whole.
- The TVF of each sector is defined as the embodied emissions of a sector relative to its value added. Embodied emissions include all emissions created in the production process for a firm's final goods, including all upstream emissions created in other sectors. The emissions and value added data were sourced from EXIOBASE, a global and detailed input-output database that covers a wide range of countries and industries.
- The TVFs are then adjusted in some of the scenarios to more accurately reflect the risk drivers that were in play in each scenario, since embodied emissions alone do not always best capture the risks.
- The TVFs are multiplied by the stock price indices simulated with NiGEM to produce sectoral stock price impacts. The sectoral stock price impacts can be used to calculate losses on equity exposures and also served as input to calculate losses on loans and bonds.

Box 14

Downscaling GDP to sectors *via* emission intensities

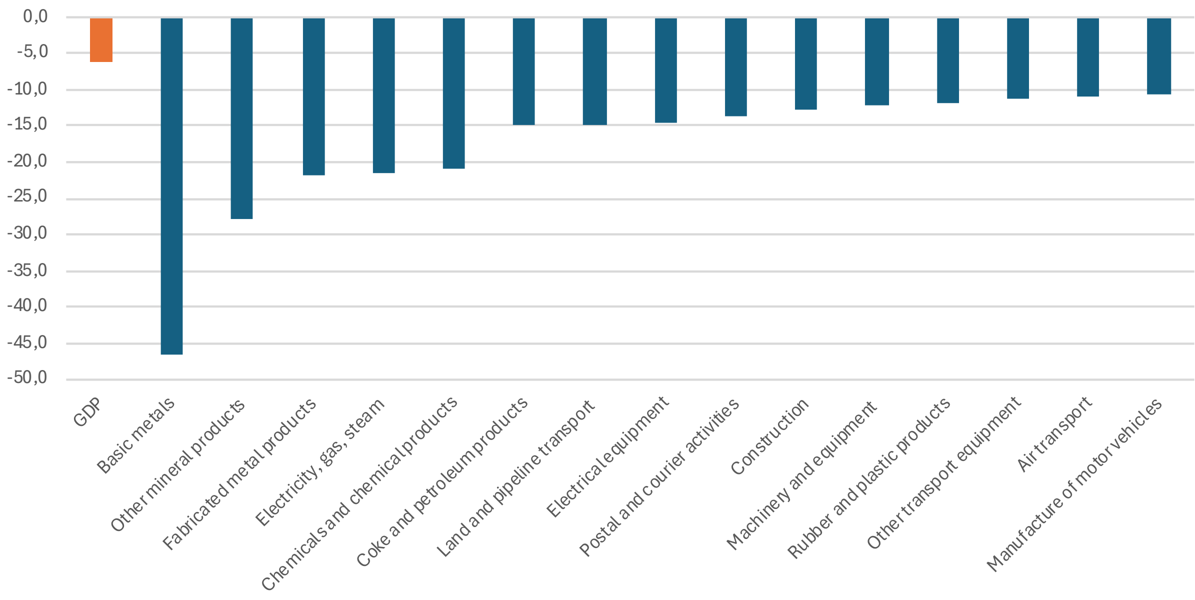
The National Bank of Slovakia (NBS) published its pilot climate stress testing exercise focusing on the impact of transition risk on the credit risk of households and non-financial corporations in 2023. The NBS used two NGFS (Phase II) scenarios focusing on transition risk, namely the Net Zero 2050 and the Divergent Net Zero scenarios, comparing the results to the NiGEM baseline scenario.

The primary macroeconomic driver of corporate credit risk was assumed to be the development of GDP relative to the baseline scenario and its impact on companies' revenues. While the deviation from the baseline under the Net Zero 2050 is relatively minor, the impact is more substantial under the Divergent Net Zero scenario. As the negative impact of the scenarios on GDP is primarily driven by the shock to emission prices, it was assumed that high-emitting companies and sectors will be more affected.

…/…

34 Vermeulen *et al.*, 2018.

Figure 12 **Sector-specific revenue shocks under the Divergent Net Zero scenario**



Notes: The 1st bar refers to the cumulative deviation of the GDP from the Baseline Scenario during the first two years. Other bars refer to the sector-specific revenue shock obtained by adjusting the GDP deviation by the sector-specific TVFs. The figure shows the 15 sectors with the highest TVF.

To incorporate the emission intensity of the respective sectors, the "Transition vulnerability factors" (TVF) for each sector was calculated[35]. The TVF is based on the amount of CO_2 emissions associated with the production of final goods and services in each sector, considering both the sector's own emissions and those of its suppliers, known as "embodied CO_2 emissions". The value-added of final goods produced by each sector is based on the World Input-Output Database (WIOD), while the industry-specific CO_2 emissions are based on the EXIOBASE 2015 database of Eurostat. It was assumed that the sector-spe cific TVFs are identical across countries. The weighted average of TVFs for the global economy is equal to 1, with weights determined by the relative share of value added in each sector.

The final shock to corporates' revenues is then obtained by adjusting the negative shock to GDP relative to the baseline by each sectors' TVF. Figure 12 presents the outcome of the sector-specific revenue shock under the Divergent Net Zero scenario. It can be seen that this approach penalizes more heavily those sectors with substantial CO_2 emissions within the entire value chain, as it considers not only direct emissions, but also emissions from upstream channels.

Expanding the scenario by modelling additional variables

Additional variables may be needed due to the limited number of macro-financial outputs available from the climate model underpinning the scenario. For example, the scenario model may provide some detail on the impact on output and interest rates, but nothing on the yield curve. If, for practical reasons, these additional features cannot be embedded in the underlying model, they may have to be estimated in other ways. Besides the options elaborated in the previous subchapter on expanding economic variables, additional options include:

- *Simulate the missing variables in a separate model.* One could take a model that can produce the desired outputs and then calibrate the model, as closely as possible, on the basis of the chosen scenario. An advantage of this method is that it is model-based, thus providing an economic rationale for the outputs.

35 The TVF is calculated based on the methodology published in Vermeulen *et al.* (2018). *An energy transition risk stress test for the financial system of the Netherlands*. DNB Occasional Studies 16-7.

Another advantage of using a suite of models is that it can capture a broader range of relevant transmission channels, and thereby provide a more comprehensive view of the impacts. A disadvantage of this strategy is that it becomes more difficult to ensure the internal consistency of the scenario since the model used to produce the scenario differs from the models used to produce additional outputs. This can be managed by ensuring a consistent set of assumptions where possible and using the results to recalibrate the scenario.

- *Wider estimates from academic literature.* If the scenario does not provide the required variable it is possible that it has been estimated in other studies (e.g. the potential impact of flooding on supply chain risk).
- *Past trends.* By observing how the variables of interest moved during historical periods, one may form an educated guess about what would happen in the scenario. For example, one could analyse the effects of a previous oil price drop (e.g. following the great financial crisis) or extreme temperature changes (e.g. 2003 European heatwave) on a particular exposure. However, this option should be approached with caution given the likelihood of climate risks resulting in unprecedented, structural changes.

Box 15

SBS Peru: Applying NGFS Scenarios Without NiGEM and Downscaling Physical Risks by Industry and Region

The Superintendencia de Banca, Seguros y AFPs del Perú (SBS) has developed a top-down climate stress test to assess the impact of physical risks on the credit risk of financial institutions in Peru (Romero *et al.*, 2024). The exercise incorporates both microeconomic (direct) and macroeconomic (indirect) channels to evaluate how climate-related hazards – specifically precipitation and sea surface temperature (SST) – affect credit risk in the financial system.

At the microeconomic level, the SBS analyses the impact of acute physical risk i.e. climate hazards on the probability of default (PD) and loss given default (LGD) of borrowers. This is achieved by establishing historical relationships between acute physical risk drivers and district-leve[36] PD (disaggregated by economic sector) as well as region-level LGD, using panel regressions.

The macroeconomic channel captures second-round effects through the impact of chronic physical risk on GDP, which in turn influences credit risk. To estimate these effects, the SBS draws on GDP projections from the NGFS Current Policies (Phase IV) scenario and examines the deviation from the baseline scenarios without any climate risks. Because Peru is not included in the NiGEM macroeconomic model used by NGFS, GDP projections are sourced from the integrated assessment models (IAMs) of the NGFS scenarios, which apply a damage function to reflect the impact of chronic physical risks.

The analysis follows a static balance sheet approach and spans a 30-year time horizon. For micro-level climate data, the SBS incorporates outputs from CMIP6 (SSP5-8.5), specifically 37 precipitation and 30 SST projection models, to enhance regional climate risk assessments. This data is combined with granular debtor-level information, including the location of productive units, sector classification, credit type, and the number of days past due (used to construct default rates[37]), enabling precise geospatial linking of borrowers to climate risk exposure.

…/…

36 Peru has a total of 1,890 districts, which are distributed across 196 provinces. These provinces are part of the 26 regions and 24 departments that make up the political and administrative division of the country.

37 The default rate is the proportion of debt associated with individuals who are more than 90 days overdue after twelve months. This variable is used in the econometric approach of the SBS, which is then predicted to estimate the PD.

The framework supports sectoral and regional downscaling of climate risk impacts. GDP shocks affect PDs differently across sectors, depending on their economic sensitivity. Similarly, the historical regressions differentiate PD and LGD impacts by region and by initial credit quality, allowing for fine-grained risk estimation at the district level.

Overall, the SBS methodology provides an advanced approach to modelling physical climate risks in emerging markets. By combining NGFS macroeconomic data with CMIP6 climate projections and detailed supervisory datasets, Peru's experience illustrates how financial supervisors can bridge data and modelling gaps to implement robust climate risk assessments – even in regions not fully covered by global models.

Time and discounting

Given a scenario and type of exercise, one may face some further methodological questions. Some typical dimensions for which further assumptions may be required include:

- *Balance sheet evolution.* If the scenario plays out over time, as opposed to a point-in-time 'snapshot' scenario, the behaviour of financial institutions might evolve as the scenario unfolds (Table 5). In many stress testing exercises, for example, the simplifying assumption of static balance sheets is made, requiring financial institutions to hold their portfolios constant over time and replace maturing assets with new, similar assets. In contrast, dynamic balance sheets allow for the inclusion of management actions, so that institutions can react to climate regulatory changes, news or different customers' preferences. Over long time-horizons, management actions will be the primary driver of impacts but are very difficult to predict. Box 16 sets out how the Bank of England approached the challenges of long-time horizons in its 2021 Climate Biennial Exploratory Scenario. Further details can be found in Chapter 3.
- *The discount rate.* If the scenario has a relatively long time horizon, the question of whether and how to discount financial values in later periods should be considered. This is relevant in bottom-up exercises where the balance sheets of participating firms are allowed to change over time.

Table 8 **Assumptions of balance sheet evolution**

	Focus	Time dimension
Static analysis	Risk on current balance sheet	Understand current exposure. Less dependent on assumptions
Dynamic analysis	Risks associated with potential changes in balance sheets, also as a consequence of changes in behaviour	Dependent on assumptions about behaviour

Box 16

The Bank of England's modelling framework for the 2021 Climate Biennial Exploratory Scenario on the financial risks from climate change

In its 2021 Climate Biennial Exploratory Scenario (CBES), the Bank of England outlined a detailed exploration of the impact of climate scenarios on banks' and insurers' balance sheets with a time horizon of 2020 to 2050.[38, 39] The CBES was intended to be a learning exercise with the aim to develop capabilities of both the Bank and participants. To make this approach feasible, participating banks and insurers were asked to measure the impact of the scenarios in the following way:

- Participating institutions modeled the impact of the scenarios up to 2050 (i.e. a 30-year time horizon). However, the physical risk variables were calibrated based on physical climate impacts that could materialise in the second half of the century in the absence of further policy action, to explore the impact of these more extreme risks.
- In the first round of the exercise, to make the modelling feasible, participants assumed the nominal size and composition of their end-2020 balance sheets to be fixed over the time horizon of the scenario, as a proxy of their current business models. In practice this meant firms assessed climate-related risks at each point of the time horizon against their current balance sheet.
- In the second round of the exercise, participating firms were asked to identify the management actions they would take to reduce their risks and identify new business opportunities. These were reported as a mix of qualitative responses and quantitative metrics on the adjustments firms planned to make to reduce their exposures.

Data collection

Limited available data and research are a significant challenge. Central banks and supervisors should consider the data they need to assess the risks themselves and in bottom-up exercises the data needed by firms. A typical data collection process could be broken down into the following questions:

- *Which data is readily available?* To minimize administrative burden, the risk assessment should be based as much as possible on readily available data. At the same time, the unique nature of climate-related risks can imply that a proper risk assessment requires data that have not yet been collected. For instance, available climate-related datasets often cover only public companies but more rarely many privately-owned companies, to which financial institutions are exposed. This can pose a significant obstacle to the analysis. Sometimes the purchase of commercial data sources from third parties may be required.
- *Can the required data be constructed on the basis of available datasets?* Often, some data are available but scattered over various datasets, which would need to be combined to create one coherent set. See Box 17 for more information on the DNB's approach to this in their transition stress test. Such sectoral data may still not be granular enough to assess firm-level risks. This may require combining top-down (sectoral statistics) and bottom-up (firm level operating activity) data.
- *Can the required data be requested from financial institutions and/or their counterparties?* This option will be most viable in bottom-up stress testing exercises. This may have an ancillary benefit of promoting more engagement on climate risk management between financial institutions and the real economy. Before conducting such a survey, however, it is useful to check: (a) whether institutions themselves or their clients have access to the desired data, and (b) which format of delivery would be both manageable for the financial institutions and workable for the institution carrying out the analysis.

38 Bank of England, 2021.

39 Physical risks in the No Additional Policy Action Scenario were deliberately calibrated on climate outcomes that could materialise between 2050 and 2080 in the absence of further policy action, to allow the Bank to explore the impact of these more extreme risks within the scenario horizon.

Box 17

Data collected by De Nederlandsche Bank for its transition risk stress test

The transition risk stress test conducted by De Nederlandsche Bank[40] considered the equity, bond and (for banks) corporate loan portfolios of more than 80 banks, insurers and pension funds located in the Netherlands. The data collection process included the following steps:

1) The equity and bond exposures of Dutch financial institutions were gathered from the ECB's Securities Holdings Statistics (SHS) database. Using International Security Identifier Numbers (ISINs) at security-level, the exposures were matched with NACE codes from the Centralized Securities Database (CSDB) to determine to which sector each exposure belonged. If no NACE code could be identified using the CSDB, the ISINs were cross-checked against the Thomson Datastream ratings database. In this way, industry classifications in NACE, NAICS, GICS, TRBC and SP format were collected for all stocks and bonds in the banks', insurers' and pension funds' portfolios. The alternative classification formats were converted to the NACE format through publicly available mappings.
2) An issue that emerged as a result of using NACE codes was that a large amount of securities was classified as NACE code K.64 (finance) while, upon closer inspection, many of these K.64-classified securities were issued by financing vehicles of firms that are active outside of the financial sector. For example, a bond issued by BMW Finance is marked as K.64 (finance), while for the purposes of the stress test it was more appropriate to assign it to C.29 (manufacturing of motor vehicles), i.e. the industry of the parent company. To correct for this, the stock and bond holdings were again checked against the alternative classifications in the Thomson Datastream ratings database; the K.64 code was replaced if one of the other databases listed a different industry classification.
3) To obtain NACE-codes for the corporate loan portfolios of banks, De Nederlandsche Bank conducted a targeted survey among the largest Dutch banks. To ensure simplicity for banks and usability in the stress test models, the survey resembled standard regulatory reporting (i.e. COREP) templates. The survey provided the exposure amounts of banks' IRB- and SA-portfolios disaggregated by sector. For IRB-modelled loans the exposures were further disaggregated by internal risk bucket, probability of default, loss given default and maturity.

Outputs

Users may wish to translate the financial risks into relevant metrics to inform decision-making. Relevant outputs could include: asset impairment, mark-to-market valuation, risk weighted asset ratios, capital buffer depletion, return on equity, and change in business model (portfolio allocation, lending paths, insurance coverage and pricing). The metrics chosen should align with the objectives of the exercise (see also Chapter 3 of the NGFS Guide for Supervisors).

Key assumptions and sensitivities

Transition risks

The types of transition risks that are considered, and the way in which these risks are modelled can have a strong bearing on the results of the exercise. Capturing transition risks is challenging both because it can materialise in complex and varying ways, and because data and model aggregation might make it difficult to accurately pinpoint where the risks materialise. Some examples of the sensitivities in modelling transition risks are:

- *Multiple transmission channels:* there may be revenue drivers (a decline in sales), cost drivers (carbon prices) and asset devaluation (e.g. stranded fossil fuel assets, real estate), with varying degrees of impact.

40 Vermeulen *et al.*, 2018.

- *Business model changes:* there could be shifts in corporate business models in response to climate shocks (e.g. a firm could rebalance away from fuel-intensive production following a new, stringent energy law).
- *Pass through costs:* the reaction of firms and consumers will depend on technological constraints and preferences, respectively, which will affect supply/demand elasticities along the value chains and at final consumption level.
- *Classifying counterparties:* where a standard industrial sector taxonomy is used often balance sheets assets cannot be neatly categorised, particularly for large companies that span multiple activities.
- *Sector classification:* transition risk-relevant sectors might change and evolve over time, particularly for renewable-based sectors a.k.a. "green" sectors for which there is not yet a consistent definition and identification available in most sector classification schemes.

Physical risks

Physical risks can directly affect the value and usability of collateral in the financial system, but also indirectly propagate between financial institutions. Property or land located in areas exposed to floods, wildfires, or sea-level rise may lose value or even become ineligible as collateral, weakening the resilience of lending institutions. Similarly, the availability and affordability of insurance plays a crucial role in mitigating these risks. Rising premiums or the withdrawal of coverage in high-risk regions can exacerbate losses for households, firms, and lenders, potentially amplifying credit risk and reducing financial stability. These dynamics highlight that the transmission of physical risks is not limited to direct damage but is amplified *via* cross-sectoral spillovers among financial institutions.

Financial impacts from physical risks should be understood as having a wide band of uncertainty, particularly further out in the time horizon. The size of the financial risks depends on assumptions about how the economy and financial system will respond to events that have no precedent. While some micro impacts may be based in part on existing channels that are regularly assessed (e.g. impact from flood damage on insurance claims) the probability and / or impact of many other channels has not been robustly estimated (e.g. costs from supply chain disruption). Even where case studies exist, it may not be easy to readily identify the locations of the economic activity and supply chain from the data.

Refining the results

Given the novel nature of climate risks, users will likely learn a lot about the underlying transmission channels and key sensitivities in the first round.

At the end of the exercise, users should consider performing a second round of the exercise, revisiting the scenario assumptions, design and methodology. This can be useful to explore systemic risks (e.g. participating firms all indicate they will exit from a particular sector at the same time) or any other channels that were not identified during the initial materiality assessment.

6. Communicating and using the results

This Chapter sets out the final stage of communicating and using the results of scenario analysis.

Communication of the results

Communicating the results of scenario analysis improves awareness of climate risks. This may encourage firms to improve their risk-management practices and foster further research – particularly where new pockets of risk have been identified.

Information disclosed

Users should consider the information disclosed, given that climate scenario analysis methodologies are still evolving and lack of data remains a significant barrier. This is particularly relevant for scenario-based stress testing exercises where the supervisor has a choice of publishing individual and/or system-wide results (e.g. means and ranges). Details disclosed could include qualitative and quantitative information on the scenario, impact on financial variables (e.g. asset quality, stock prices), regulatory numbers (e.g., capital, leverage and liquidity) as well as impact on macroeconomic variables (e.g. GDP, changes in the capital stock, sectoral shifts).

Since climate-related scenario analysis is a relatively novel activity, there is also significant value in sharing details on the methods, assumptions and key sensitivities. This includes the objectives, the specific scenarios, risk coverage, the rationale for the selections, as well as any limitations of the analysis and how these might affect the results. This communication can help establish market conventions and practices on disclosure. Effective internal communication is also critical for building organisational capacity and integrating the results into supervisory approaches.

Determining the baseline for comparison

An important consideration when communicating the results of climate scenario analysis is the choice of baseline against which outcomes are presented. The baseline defines the counterfactual and frames the interpretation of results, yet its meaning can vary depending on the objective of the exercise. Clear communication of the chosen baseline is therefore essential for ensuring transparency and comparability. Some of the options are as follows:

- **Current policy scenario,** which reflects the likely trajectory of the economy and financial system under policies already in place. Presenting results relative to this path highlights the *incremental risks or benefits* of additional transition measures or of delayed action.
- **No-climate-change baseline,** in which economic projections assume no physical risks and no transition policies. Deviations from this path isolate the impact of climate risks themselves, though such results can appear less realistic for near-term horizons. This framing is particularly insightful for illustrating the "added burden" of climate risks on top of standard macro-financial dynamics.
- **Counterfactual baseline within the scenario set,** such as comparing an "orderly transition" with a "disorderly" or "hot house world" pathway. Presenting results in this way underscores the trade-offs between scenarios and can effectively convey the systemic risks associated with late or insufficient action.
- **Historical baseline,** e.g. the starting point of average conditions over the past decade. This approach enhances accessibility for non-technical audiences, allowing them to anchor outcomes in familiar reference points. However, it is less suitable for policy evaluation as it may not capture structural changes already underway.

Define target audiences

The target audience will be closely tied to the stakeholders identified as part of scoping out the exercise (see Chapter 2). The audience may include financial firms, standard setters, general public, government including international bodies, other central banks and supervisors and the academic community.

Select communication methods

Numerous communication options are available to users looking to share the results of their scenario analysis (see Table 6). Public disclosure can take place on websites, periodic publications (analytical notes, financial

Table 9 **Communication methods**

Communication methods	Target audience	Objectives
Disclosure	Public Government	Raise awareness Provide detailed information Encourage initiatives such as the TCFD Inform government policy action
Conferences	Public Specialists Related parties	Raise awareness Effective and timely communication Two-way dialogue
Bilateral meeting	Government Institutions	Raise awareness Two-way dialogue Share the result of comparative analyses and range of practices Provide feedback to encourage advancement of institution's risk management practices Inform government policy action
Internal communication	Central bankers Supervisors	Raise awareness Receive valuable inputs Consider financial regulatory initiatives Training

stability reports), *via* speeches by senior officials and on social media. Conferences are also an effective way to have direct discussions with specialists and related parties on the analysis. For firm-specific results, bilateral meetings may be more appropriate.

Uses of the results

Scenario analysis should be an ongoing iterative process. The initial results will identify new pockets of risks and key sensitivities of the scenario that were not initially included. These aspects can form the basis of follow-up analysis and research. Possible follow-up actions include:

- *Using the insights as part of supervisory decision-making.* For instance, requesting more detailed information on climate risks from firms, such as exposures, plans for enhancing its risk management framework, and its strategy for climate-related risks. (See NGFS Guide for Supervisors).
- *Identify whether the risks are being sufficiently mitigated by existing processes.* For example, scenario-based stress testing may help identify risks that are under / over capitalised. In addition, the macroeconomic assessment could provide insights on channels that are not yet captured as part of regular economic forecasting.
- *Scenario analysis on own operations may identify how climate change could affect the risk in and effectiveness of central banks' operational policies*, such as its balance sheet investments. Central banks may also include the results in thematic and impact investing considerations, screening criteria for asset purchases, and voting and engagement. Applying climate change scenarios when assessing the value of the central bank's own portfolio can provide an opportunity "to lead by example".[41]
- *Using the results of the exercises to design and calibrate policy instruments*. For instance, supervisors could develop macro- or micro-prudential policies with the aim to mitigate the estimated losses of the climate scenario exercise.
- *Stress testing results can also identify financing needs and design strategies to mobilize private capital.* In this way, stress tests contribute to the mitigation of climate change.

41 Battiston, 2019.

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Annex – Comparison of NGFS and IEA scenarios

Table 10 **Comparison of NGFS long-term climate scenarios with the International Energy Agency (IEA) scenarios in the World Energy Outlook**

		IEA scenarios in the World Energy Outlook	NGFS long-term climate scenarios
Objectives	Mandate	• To **advise governments on energy policy and energy security, affordability and sustainability** • Users are policymakers, financial institutions, non-financial companies	• To assess the (macro)economic and financial implications of different transition pathways or a lack of a green transition • Users are central banks, supervisors, financial institutions, policymakers
	Main use cases	• **Informing energy investments & energy sector planning**	• **Macro-financial risk analysis**
	Data availability	• Publicly available main set of data, documentation and related reports (i.e. World Energy Outlook and Net Zero by 2050 Roadmap) • Regional-level data available by subscription	• Entirely publicly available data at the regional and country-level • Publicly available documentation and reports
Modelling approach	Transition risk	• **General approach: Large-scale technology-rich bottom-up partial-optimisation model aimed at replicating real world energy systems at the country level** – Modelling of energy demand by region and sector (i.e. cooling, EVs, industries' technologies, etc.) and energy supply • **Carbon pricing** is used as a backstop policy, with real-world CO_2 prices helping meet emission reduction targets – Energy sector and climate policies, behavioural changes, etc. (rather than shadow carbon pricing) are the main variables influencing energy investment decisions by governments, companies and individuals – No assumptions on recycling of carbon revenues, because **no macroeconomic feedbacks are modelled** • **Carbon Capture and Storage (CCS) and Carbon Dioxide Removal (CDR):** limited use in NZE Scenarios relative to IPCC scenarios	• **General approach: Optimizing global cost-efficient models centered on shadow carbon prices, which capture the marginal cost of abating carbon emissions** – Granular process-based Integrated Assessments Models (IAMs) covering climate systems, land use, energy systems, water use and macroeconomic impacts – Energy demand based on economic activity; energy supply on carbon pricing • **Shadow carbon price is an endogenous variable driving the use of low-emission energy technology** – Proxy of all climate policies ambitious and effectiveness – The macroeconomic model (NiGEM) linked to the IAMs implements different assumptions on the recycling of carbon revenues • **Carbon Capture and Storage (CCS)** is included but typically represented as a costly option. Availability and costs vary across models and scenarios
	Physical risk	• **The IEA does not model climate economic impacts,** but it uses the MAGICC climate model to estimate the temperature outcomes associated with energy-related emissions pathways • **The impact of heatwaves on cooling demand for buildings is modelled** • Physical risk impacts of cyclones and floods on energy infrastructure (i.e. power plants/grid) risks are analysed but not accounted for in the model	• **The NGFS models the macroeconomic impacts of chronic and acute physical risks.** – It estimates the GDP impact of chronic physical risks, through an econometric damage function – It estimates the GDP impacts of a subset of extreme events (floods, cyclones, heatwaves, droughts) through a set of bottom-up models
	Macroeconomic modelling	• **None.** GDP is exogenous, based on IMF and Oxford Economics data and common across scenarios	• **NiGEM produces the main macro financial variables, using input from** IAMs and acute and chronic physical loss estimates
Key Outputs		• **Energy supply & demand variables** (capacity, usage, investments, prices, trade and production) • **Energy-related emissions pathways** • **Physical outputs** from the economy (e.g. industrial production – cement, steel…) • **Critical minerals supply and demand**	• **Similar energy supply & demand variables as in the IEA scenarios, emissions pathways** (also including AFOLU) and **physical output variables** • **GDP, macro-financial variables and physical damages** (from chronic and acute physical risks) • Shadow carbon price as proxy of all climate policies

Table 11 **Matching of IEA scenarios with NGFS long-term scenarios based on their policy assumptions and the implied temperature rise**

IEA Scenario	Closest NGFS Scenario(s)	Shared Objective	Key Differences
Net Zero Emissions by 2050 (NZE)	**Net Zero 2050 & Low Demand**	Global net zero CO_2 emissions by 2050	In the IEA NZE, the energy sector alone reaches net zero, no reliance on other sectors (e.g., LULUCF). The NGFS Net Zero, instead, includes other sectors, while the NGFS Low Demand adds behavioural changes and demand reduction.
Announced Pledges Scenario (APS)	**Below 2°C**	NDC targets met by 2030	The IEA APS includes long-term net-zero targets, industry commitments, and goals for energy access, making it more stringent than the NGFS NDC.
Stated Policies Scenario (STEPS)	**Current Policies & NDCs**	Current and planned policies	The IEA STEPS includes broader policies than the NGFS Current Policy and private sector investments. These lead to less emissions than the NGFS Current Policies, but more than the NGFS NDCs (which assumes that NDC targets are entirely reached).
Current Policies Scenario (CPS)	**Current Policies**	Written energy policies only	The IEA CPS includes only written policies and does not assume permanence unless legally guaranteed. This makes it more stringent than NGFS Current Policies.

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