Network for Greening the Financial System

Technical document

Guide to climate scenario analysis for central banks and supervisors

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NGFS

Central Banks and Supervisors
Network for Greening the Financial System

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Climate change, and our response to it, will have a significant impact on economic and financial systems. The impacts will be far-reaching in breadth and in magnitude; subject to tipping points and irreversible changes; and are uncertain yet at the same time totally foreseeable. In particular, while we do not know now exactly what physical and transition risks will materialise, we do know for sure that we will face some combination of those risks. And, crucially, we also know that the size and balance of these future financial risks and economic costs will depend on the actions we take today.

If we act now, then we maximise our chances of achieving an orderly transition to a carbon neutral economy. By acting early we minimise transition risks, and by limiting global warming to a range of 1.5˚C to 2.0˚C relative to pre-industrial levels, we simultaneously minimise the extent to which the physical risks from climate change materialise. If instead meaningful adjustment is delayed, then the greater will be its disruption – whether from higher physical risks, or from a more disorderly transition, with markets potentially repricing sharply, and the provision of financial services perhaps disrupted. And of course, if we fail to act at all, that puts us on a path to global warming of 3.0˚C or more, leaving us all exposed to the potentially catastrophic physical risks that arise with an ever hotter planet.

We do not know what state of the world will materialise. But as central banks and supervisors we have a responsibility to prepare for the potential impacts from climate change in a variety of possible future states of the world. Scenario analysis is key to us doing that. It lets us explore impacts and exposures under a range of different potential pathways.

To date, central banks and supervisors that have wanted to do climate scenario analysis have faced a number of obstacles. There is an abundance of climate models to choose from, and it is not immediately clear which ones are most relevant. In addition, the field of climate modelling is technical and difficult to penetrate for non-experts. It is complicated further by the lack of a clear methodological framework for translating climate scenarios into macro-financial analysis.

That is why the NGFS has developed a set of Reference Scenarios, along with this Guide on how to conduct scenario analysis. The NGFS Reference Scenarios provide, for the first time, a harmonised set of high-level climate scenarios, available in a publicly accessible database, in which both transition and physical climate change impacts are included in a consistent way. To allow central banks and supervisors to get the most use from these scenarios, the Guide provides practical advice on using scenario analysis to assess climate risks to the economy and financial system. The NGFS scenarios provide a foundation for decision-useful financial and economic analysis. And they will be useful not only to central banks and supervisors, but also to financial firms and to corporates as they too seek to manage their exposure to these risks.

Challenges and shortcomings remain. Indeed we are close to the start of this intellectual journey not at its end. That is why we will work towards an updated set of scenarios that will be published later in the year. To ensure that those scenarios will be as complete, coherent and useful as possible, we would like to invite everyone, not just central banks and supervisors, to engage with us on this important topic.

We simply cannot afford to be unprepared.

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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.

To this end, the NGFS committed to publishing the first-of-its-kind Guide on climate scenario analysis for central banks and supervisors. The forward-looking nature of climate risks and the inherent uncertainty about future events make it difficult to assess them using standard risk modelling methodologies. Scenario analysis offers a flexible 'what-if' methodological framework that is better suited to exploring the risks that could crystallise in different possible futures.

This Guide provides practical advice on using scenario analysis to assess climate risks to the economy and financial system. It is based on the initial experiences of NGFS members and observers, and also aims to progress discussion on the methodologies used. While mainly aimed at central banks and supervisors, many aspects of the Guide might also prove informative to the wider community.

The Guide provides a four-step process. It recognises that this field is still relatively in its infancy and that there is no universally agreed approach.

Four-step process

Step 1

Identify objectives and exposures. Scenario analysis is relevant to many objectives of central banks and supervisors. It can be used to stress test financial firms and the financial system, explore structural changes to the economy and/or assess risks to central banks' own portfolios.

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. Most publicly available climate scenarios were originally designed for policy evaluation and research, and are therefore not entirely appropriate for central banks and supervisors' purposes. The NGFS has been working with the academic community to publish a set of high-level **reference scenarios** that can be used for scenario analysis in a comparable way across different jurisdictions.

Each central bank and supervisor will need to make a number of additional design choices to tailor the scenarios to the specific exercise. This includes choices related to the risks covered, the number of scenarios, time horizon and the specific outputs that will be needed (the 'scenario variables'). Early consideration should also be given to how detailed the analysis will need to be. This will have an important bearing on the scenario design.

Step 3

Assess economic and financial impacts: Central banks are interested in assessing the impact of climate risks on a wide-ranging set of economic and financial variables (e.g. GDP, inflation, equity and bond prices, loan valuations) etc. This includes risks that arise from different physical and transition outcomes across a wide range of sectors and geographies.

A range of methods is used to model these economic impacts. This includes several types of bespoke climate-economy models such as Integrated Assessment Models (IAMs) and Computable General Equilibrium (CGE) models. Central banks are considering how to combine these approaches with the more traditional economic modelling tools they use with the aim of providing a wider range of outputs and greater detail about individual economic sectors.

A major challenge remains that many macroeconomic models are used to assess divergences from long-run equilibria rather than fundamental shifts in the economy. However, conversely, climate-economy models tend to have much more simplistic macroeconomic modelling and it is more difficult to calibrate them accurately. The NGFS scenarios (as well as other scenarios) are working to bridge this gap but in the interim it is likely that a suite of models will be required.

Methodologies for financial assessment of climate risks are also developing. Several central banks are considering how best to integrate climate scenarios into stress testing exercises. These range from shorter-term, top-down modelling exercises undertaken by the central bank, to exercises with a longer time horizon, in some cases with bottom-up participation by financial firms. A key challenge is obtaining granular enough information on how the scenario would affect economic activity to assess the financial risks.

Step 4

Communicating and using results. Communicating the results, and the key assumptions underpinning them, will help increase awareness. This may provide a basis for follow-up actions from central banks and supervisors and encourage financial institutions to improve their risk-management practices. The scenario analysis exercise may lead to further analyses 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.

Next steps

This Guide is intended to evolve over time as experience using scenarios to assess climate risks grows. For the next phase of the Guide, the NGFS will leverage further insights from the practical experiences of central banks and supervisors as an increasing number undertake scenario analysis.

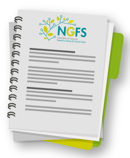
Origin of the NGFS

8 central banks and supervisors
established the Network of Central Banks and Supervisors for Greening the Financial System.

As of end-June 2020, the NGFS consists of
66 Members 13 Observers
representing 5 continents.

The NGFS is a coalition of the willing.
It is a voluntary, consensus-based forum whose purpose is to share best practices, contribute to the development of climate –and environment– related risk management in the financial sector and mobilise mainstream finance to support the transition towards a sustainable economy.

The NGFS issues recommendations
which are not binding but are aimed at inspiring all central banks and supervisors and relevant stakeholders to take the necessary measures to foster a greener financial system.



1. Introduction

The NGFS's goal is to share best practices and equip central banks and supervisors with the tools to identify, assess and mitigate climate risks in the financial system. In its first comprehensive report, published in April 2019, the NGFS recommended that central banks and supervisors integrate climate factors into financial stability monitoring and supervision. This guide is a direct follow-up to that recommendation.

The distinct nature of climate risks poses a challenge to standard risk assessment approaches. Climate risks have long time horizons with high uncertainty about how policy and socio-economic factors might evolve; they are global and economy-wide in nature; and they are complex, varying from region to region and sector to sector. These distinct characteristics are not captured by risk assessment approaches that rely on top down modelling and historical trends, are narrowly focused, and assume the structure of the economy and financial system remain unchanged.

Scenario analysis is an essential tool to overcome these challenges. It provides a flexible 'what-if' framework for exploring how the risks may evolve in the future. These scenarios can help a wide range of players better understand how climate factors will drive changes in the economy and financial system, including central banks and supervisors, financial firms, companies and policy makers.

However, the use of climate-related scenario analysis is relatively new and methodologies are still developing. Some of the main issues include the lack of integration of physical risk, transition risk and macro-financial transmission channels; lack of available data and research to calibrate the scenarios and assess impacts; and lack of technical expertise on climate science and environmental economics within the financial sector.

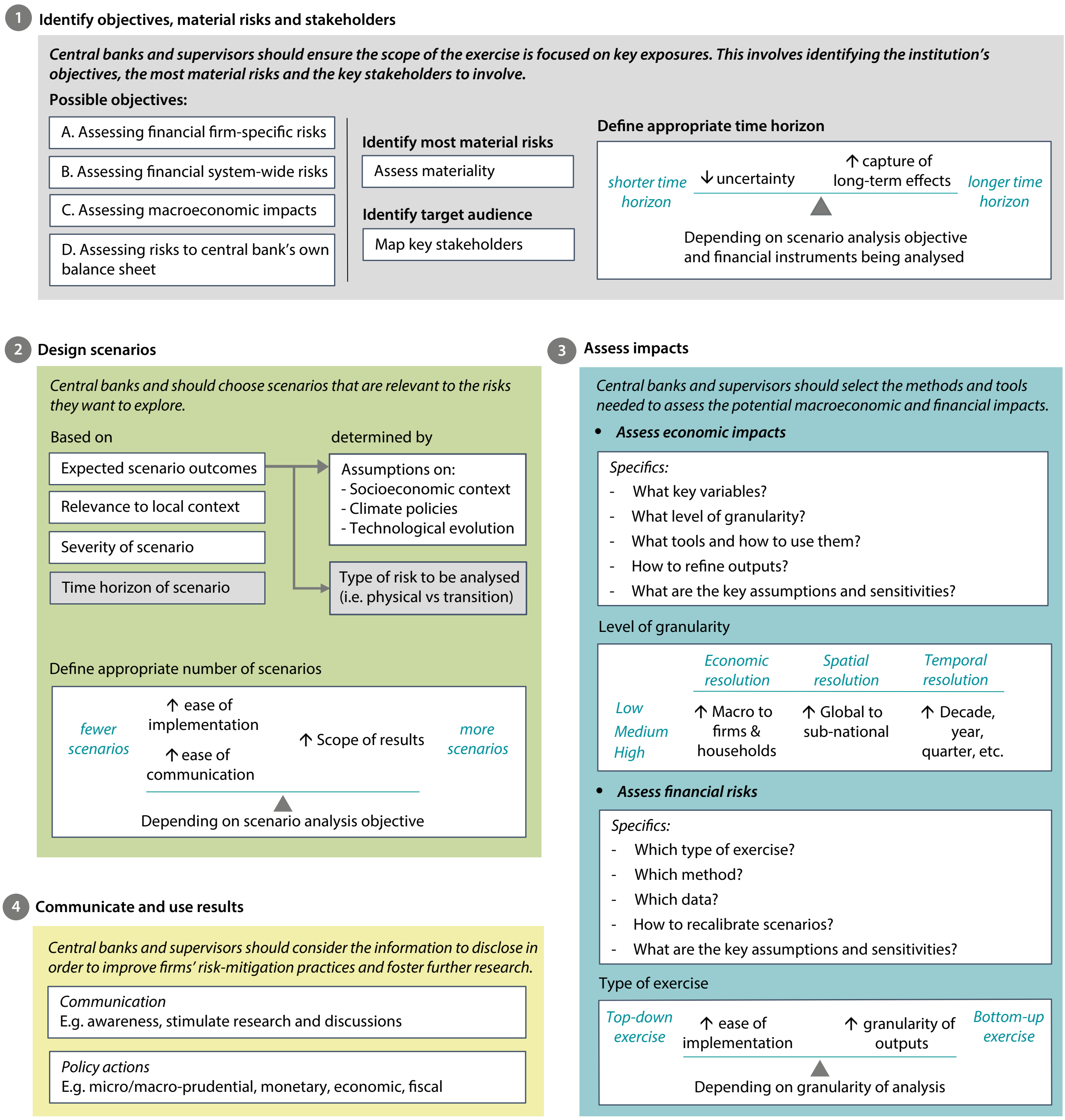
The NGFS has been working with the academic community to publish a set of standardised scenarios that can be used for macro-financial analysis in an open-source platform. This includes a standardised set of transition risk, physical risk, and macroeconomic variables and the key assumptions that they rely on. The scenarios draw primarily on existing mitigation and adaptation pathways assessed by the Intergovernmental Panel on Climate Change (IPCC) reports. Over time the aim is to work with the academic research community to make the scenarios more directly relevant for macro-financial analysis.

The guide sets out some practical considerations for how to use these climate scenarios to assess macroeconomic and financial risks. The first of its kind, it is based on the initial experiences of NGFS members that have implemented or plan to implement climate-related scenario analysis and will be enhanced over time.

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**



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.

2.1 Objectives

Central banks and supervisors should first consider how the exercise will relate to their objectives. This will help determine the breadth of analysis undertaken. There is a trade-off between obtaining a holistic view of the risks and the amount of resources needed.

Scenario analysis can be relevant for:

A. *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*;
B. *Assessing financial system-wide risks*, including their aggregate size, distribution and systemic nature;
C. *Assessing macroeconomic impacts*, including the short and long-run effects on growth, employment, inflation and terms-of-trade;
D. *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 and supervisors 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 risk assessment	Useful for
A	Assess financial firm-specific risks	Stress testing, challenging firm capital adequacy assessments	Microprudential policy Identifying risks related to safety and soundness
B	Assess financial system-wide risks	Stress testing, research on individual transmission channels	Macroprudential policy Identifying systemic risks and macroeconomic impacts
C	Assess macroeconomic impacts	Macroeconomic forecasting, research on structural changes	Understanding macroeconomic outlook Monetary policy
D	Assess risks to own balance sheet	Credit and market risk analysis, stress testing	Managing risks to own operations TCFD disclosures

2.2 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, on the basis that it would be impractical to determine 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.

Central banks and supervisors should first gather all relevant information that is available, bearing in mind that there will likely be information gaps. Good starting points include the First NGFS Comprehensive Report[1] and Technical Supplement.[2] These set out climate risk drivers and their possible impacts on the financial system and economy. This will most likely need to be supplemented

1 *https://www.ngfs.net/sites/default/files/medias/documents/ngfs_first_comprehensive_report_-_17042019_0.pdf*

2 *https://www.ngfs.net/sites/default/files/medias/documents/ngfs-report-technical-supplement_final_v2.pdf*

with jurisdiction-specific research on climate risks from the financial sector, government, industry and academia, including climate scientists.

Central banks and supervisors 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).

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 is known about the potential impacts from events where we have little historical experience.

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

	Type of risk	Research question	Source of information
Climate	Physical risk	• 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)?	• 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	• 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)?	
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?	

2.3 Stakeholders

Central banks and supervisors 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 as 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.
- **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 and influence 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.

3.1 Climate scenario assumptions

Climate scenarios are the core input into assessing the macro-financial impacts from climate change. It is important that central banks and supervisors 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.

Atmospheric concentration of greenhouse gases

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. These scenarios set out pathways for the emissions of greenhouse gases, their future atmospheric concentrations, and projections for consequent climate impacts. The research community has collectively chosen four Representative Concentration Pathways (RCPs[3]) to help standardise and improve comparability of climate change analysis. These RCPs have now been updated for the IPCC's ongoing 6th Assessment cycle (2015-2022).[4]

The NGFS is working with partners from the academic community to make these scenarios more relevant for macro-financial analysis. This includes enhancing macroeconomic modelling and improving the coherence between physical and transition risk modelling. A wider range of scenarios than the RCPs are also being considered such as the emissions pathways consistent with governments' current policies and more abrupt emissions reduction scenarios.

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 in 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 urbanisation 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.[5]

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 sources (via the 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.

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

4 O'Neill et al., 2016.

5 Riahi et al., 2017.

Climate policies

Climate scenarios also make either implicit or explicit assumptions about how climate policies may evolve. The key policy assumptions 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 integrated assessment models (IAMs) that model the interaction between energy, land, economy and climate systems.

Models vary by how explicitly and granularly they take different policy mechanisms into account. Some climate-economy models have been developed to explore the impact of specific types of policies (e.g. carbon tax) on the economy. This includes computable general equilibrium models (CGEs) and other macro-econometric models. Other models focus more on the nature and costs of transformations in the energy system, and are less explicit on policy mechanisms to get there. More detail on these approaches is provided in Chapter 4.

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.

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.

3.2 Further scenario design choices

There are a 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, time horizon and calibration.

Climate risks explored

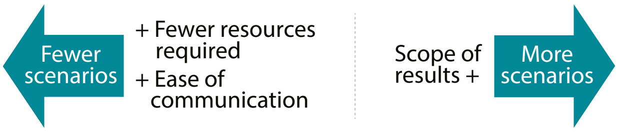
Central banks should consider the types of climate risks they want to explore. Physical and transition risk scenarios are often modelled separately. If the scenario is intended to assess the macro-financial impacts of both risks, the models should be as coherent as possible. At a high level the scenario narratives should be aligned to the same emissions pathway and temperature outcome as far as possible. The scenario models should also use consistent input assumptions (e.g. on policy, technology and the socioeconomic context). The NGFS scenarios cover both risks. Care needs to be taken to avoid double-counting of macro-economic impacts. A full integration would require simultaneously considering physical impacts and transition policies in the scenario development.

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 central banks and supervisors choose to analyse will depend on the objective of the exercise, the materiality of the macro-financial risks, and resources available. 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.

Figure 2. **Trade-offs of analysing more versus fewer scenarios**



Scenario granularity

Central banks and supervisors 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 3 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.

Table 3. **Possible levels of granularity**

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

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. In order to fully assess financial stability risks, aggregation of these granular risks is typically required.

Scenario analysis at a medium or low level of granularity will typically be sufficient for assessing the impact on the macroeconomy. It may also be sufficient to understand the aggregate risks faced by the financial sector, particularly in high-risk sectors. This type of top-down analysis can also be useful to understand the potential feedback loops between the financial sectors and the real economy.

Time horizon

The appropriate time horizon for the chosen scenarios will depend on the objective of the specific exercise. Shorter time horizons are useful to analyse the types of financial risks that could crystallise within business planning horizons and to assess the impact on regulatory capital more precisely. EIOPA (2019), Norges Bank (2019) and De Nederlandsche Bank (2018)[6] used a 5-year scenario length in their analyses of climate-related risk.

Longer time horizons are useful to gauge exposures to structural changes in the economy and financial system, and to consider how the strategic decisions of financial firms could affect the risks. Banque de France/ACPR (2020), Bank of England (2019) and Danmarks Nationalbank (2019) consider timelines of up to 2050, 2080 and 2100, respectively.[7]

6 Vermeulen et al., 2018.2 O'Neill et al., 2016.

7 Note that in the case of a 'no additional policy action scenario', the Bank of England proposes to assume that the more material risks anticipated in the period from 2050 to 2080 occur by 2050.

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.

Even when a short time horizon is chosen for analysis, it will often still be useful to have long-term scenario outputs available, for example, where financial markets are assumed to price in future expectations.

Frequency

Central banks and supervisors 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. 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

Central banks and supervisors 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.

3.3 Overview of the NGFS Scenarios

The NGFS published in June 2020 a set of reference scenarios that can be used to explore the economic impacts and financial risks from climate change. This included three representative scenarios aligned with the categories of the NGFS Scenarios Matrix – Orderly, Disorderly and Hot house world.[8] They are accompanied by five alternate scenarios to provide further context and facilitate a more robust analysis.

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 warming outcome.

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 focussed on bringing together

8 No existing climate change scenarios in the literature consistently matched the narrative of a "Too little, too late" scenario including policy disruptions at the same time. This fourth class of scenarios might be covered in the next NGFS scenario release.

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.

relevant physical and transition pathways from the existing literature in a coherent way. An update will be released in the last quarter of 2020 with refinements and improvements to the scenario assumptions, macroeconomic modelling, ,and regional and sectoral granularity.

Below is a brief description of the main assumptions and characteristics of the NGFS reference scenarios. Further detail can be found in the *NGFS Scenario Presentation, the NGFS Scenario Database* and accompanying *NGFS Scenario Technical Documentation* available here.

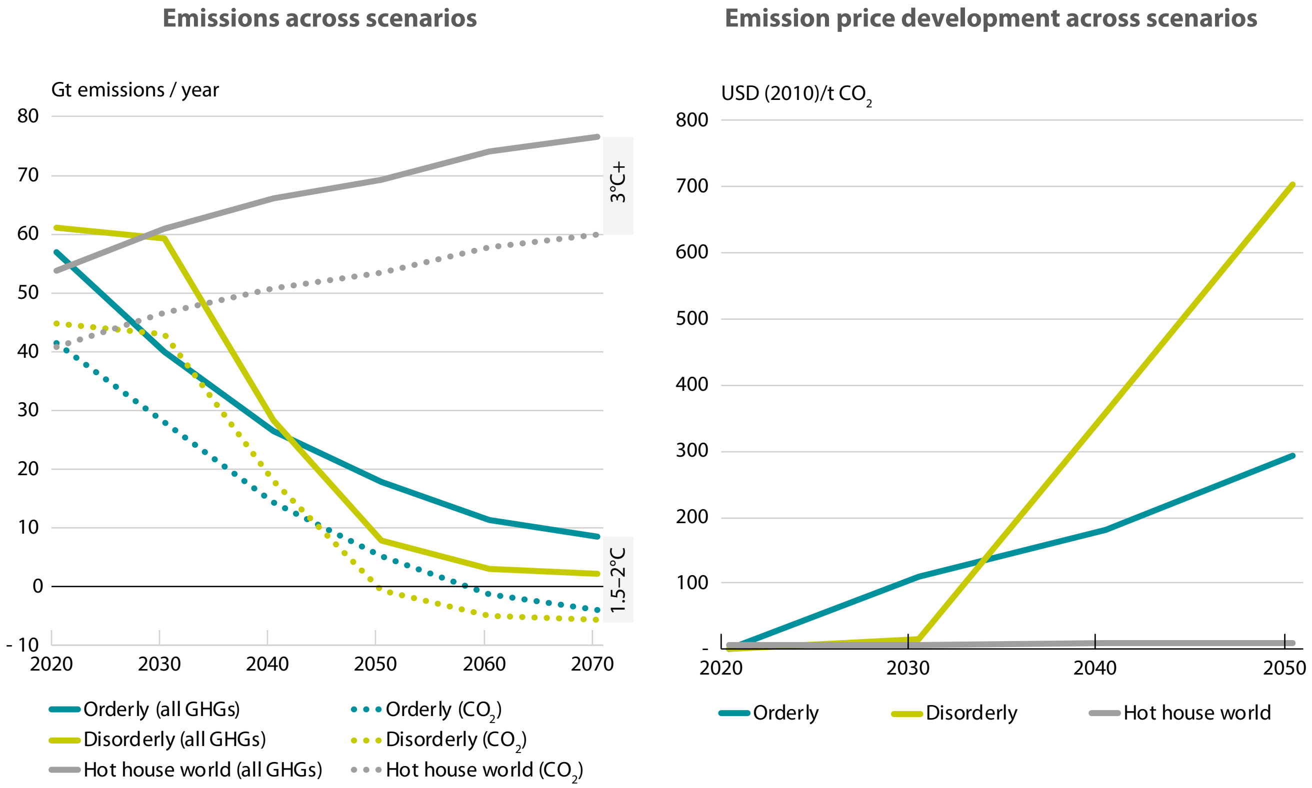
Scenario assumptions

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.

They do, however, vary according to how policy action is assumed to evolve in the future. Scenarios 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.

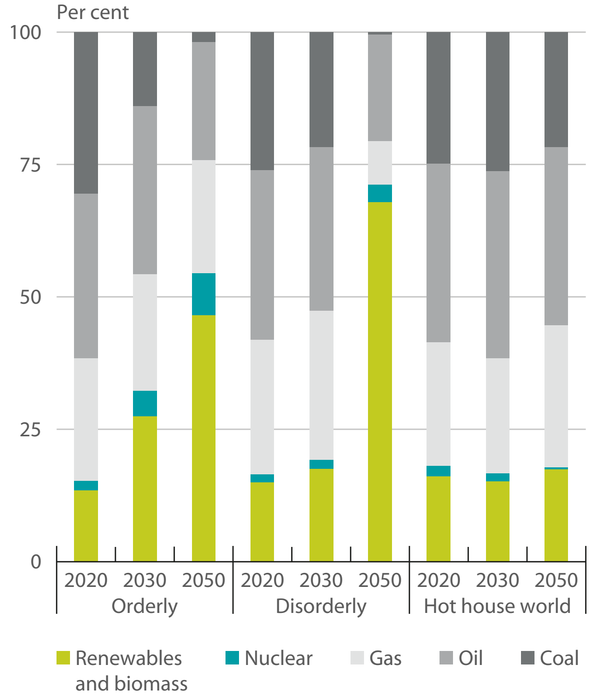
The scenarios also make a range of assumptions about how technology evolves. The availability of Carbon Dioxide Removal (CDR) technologies is a key driver in particular. If the availability of these CDR technologies is assumed to be limited, much sharper increases in emissions prices are required. In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

Figure 3. **Key aspects of the Representative scenarios**

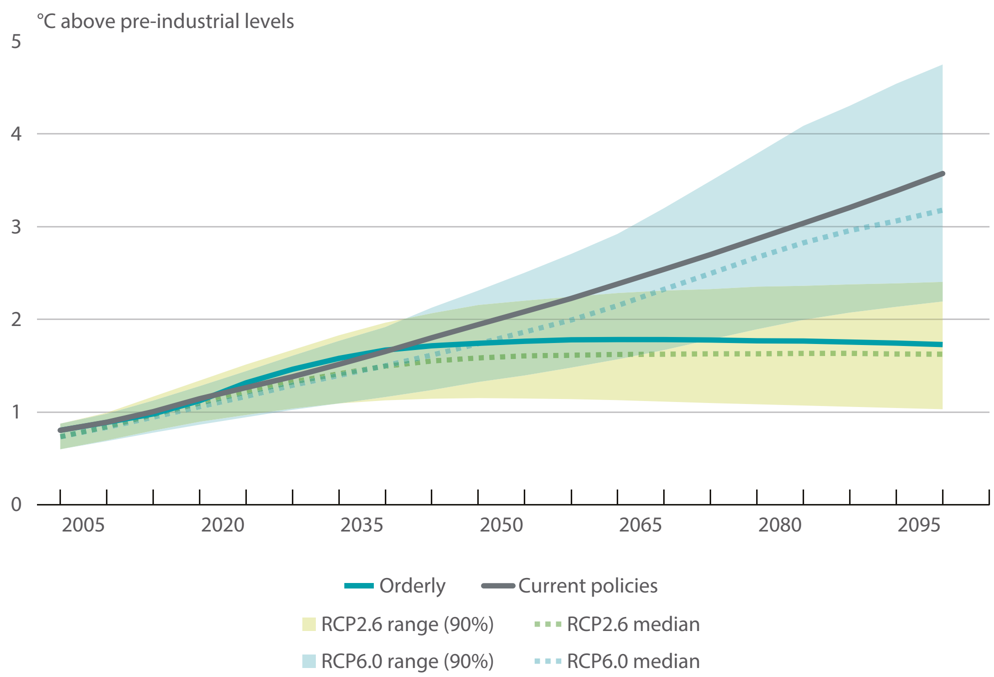


11 National Policies implemented (NPi) scenarios describe energy, climate and economic projections based on currently implemented national policies. Nationally Determined Contribution (NDC) scenarios consider policies additional to those represented in the NPi scenarios, assuming that all countries fully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

Evolution of the primary energy mix by scenario



Global mean temperature rise



Source: "IIASA NGFS Climate Scenarios Database". See "NGFS Climate Scenarios for Central Banks and Supervisors" for further details.

Description of the NGFS Reference Scenarios

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 by $10/tonne CO_2 per year[12] 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.

Two other alternate scenarios have also been selected. The first shows how Paris targets could be reached with limited use of CDR technologies. The second alternate scenario shows a pathway to limiting global warming to 1.5 °C by the end of the century. Both are more ambitious than the representative scenario and require an even higher emissions price to reduce emissions. They would be suitable to be used for orderly but more stressful scenarios in financial risk analysis.

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 NDCs 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 quickly, by around 2050. Correspondingly the increase in emissions prices is much more rapid at $35/tonne CO_2 per year[13].

Two other alternate scenarios have been also selected. The first one is the "Delayed 2 °C scenario" that is similar in its assumptions to the representative scenario, but assumes full CDR technology and is therefore less adverse. Emissions prices are more than three times less than in the representative scenario, with mild transition risks. Net zero CO_2 emissions will be reached between 2050 and 2070.

The second alternate scenario is a 1.5 °C scenario with limited use of CDR technologies. This scenario is the most disruptive scenario of the set. It assumes that an immediate global emissions price is introduced to rapidly reduce emissions in line with the 1.5 °C target while available CDR technology is limited.

3. *A "Hot house world" scenario*

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 2 °C by 2050 and close to 4 °C by 2100.

An alternate scenario, labelled Nationally Determined Contributions (NDCs), is included, taking into consideration all pledged but not yet implemented 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 °C by 2050 and over 3 °C by 2100. The estimated transition risks would still be quite limited.

12 Estimation using results from the REMIND-MAgPIE model.

13 *Idem*.

Box 1

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

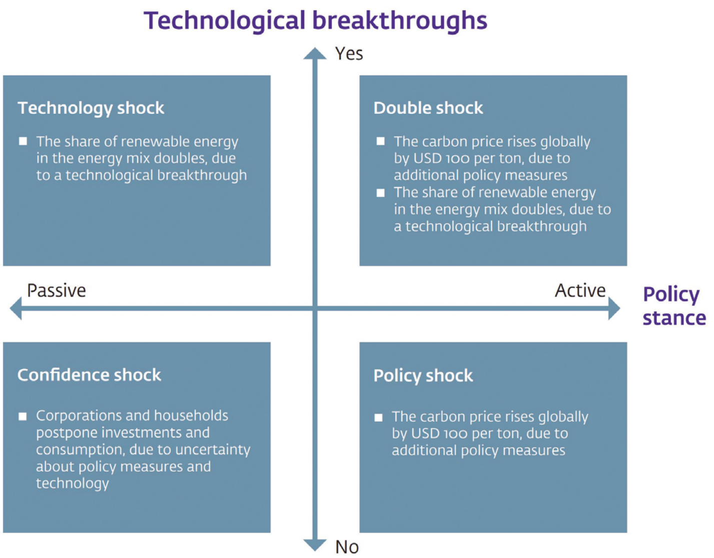
In its transition risk stress test, DNB explores four short-term disruptive energy transition scenarios (see Vermeulen et al., 2018). In line with common stress testing practice (cf. BCBS, 2018), the four stress scenarios were chosen to be 'severe but plausible,' thus capturing tail risks. To determine 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 3). This resulted in one scenario with a delayed policy response ("policy shock"), one scenario 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, are also considered in the pilot stress test that is currently being developed by the joint ESRB/ATC and ECB/FSC project team.

…/…

Figure 4. **DNB scenarios**[1]



1 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.

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 tonne 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.[2] 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 4).

2 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.

4. Assessing economic impacts

This Chapter sets out 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.

4.1 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 a knock-on impact on international trade and policy settings.
- *International competitiveness and trade flows*: How is international trade affected by the materialising of physical or transition risks? 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 on 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?

4.2 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:

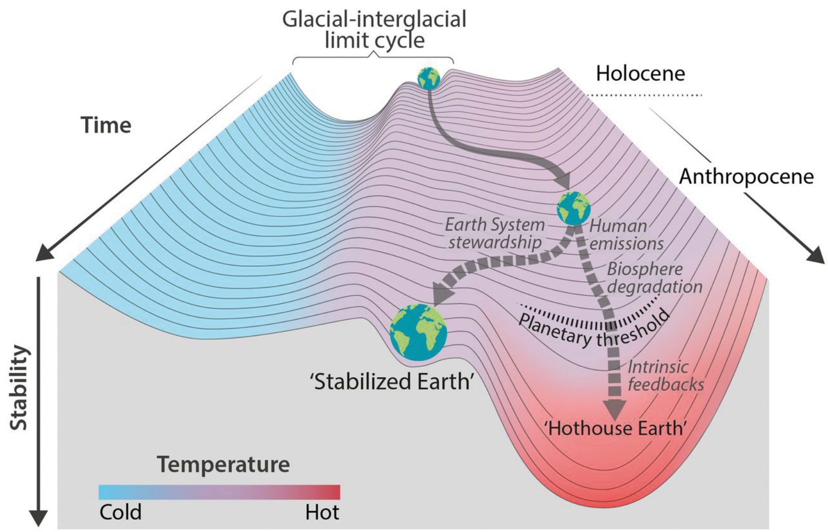
- *People:* including labour productivity, mortality and morbidity (e.g. from changes in temperature extremes) and leisure;
- *Physical capital:* due to destruction of property and infrastructure (e.g. from floods, windstorms) and diversion of resources and investment into reconstruction and replacement;
- *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.

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 5 below). 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.[8]

Figure 5. **Planetary thresholds and risks of a hot house earth pathway**



Source: Steffen et al. (2018). Figure 5 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.

4.3 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 that make them ill-suited to studying climate risks. Typically, they are used to assess short-run divergences from long run equilibria rather than investigate structural changes in the economy. Also, they usually have a limited representation of energy and agricultural systems, lack of economic sectoral granularity and their modelling horizons often do not extend much further than the business cycle.

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

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) are estimated in non-economic terms. While more complex models have now also been developed, they still tend to focus on a limited number of transmission channels and produce a narrow scope of macroeconomic indicators. The NGFS Scenarios are working to address some of these challenges.

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 4 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 4. **Types of economic models to assess climate risks**

Lineage	Model type	Description	Example
Integrated climate-economy models[1]	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[2]
	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 and 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)

1 IAM taxonomy adapted from Nikas et al., 2019.

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

Box 2

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.[1] 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.

1 Ens and Johnston, 2020.

4.4 Key assumptions and sensitivities

Transition risk

Climate scenarios are not projections. The 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:

- *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.[9]

9 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.

Physical risk

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, however in practice this will be affected by economic growth.

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

4.5 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). 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 risks

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).

5.1 Financial risks assessed

Central banks and supervisors 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.

5.2 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.
- *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. 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. These indirect effects should be captured by the macroeconomic modelling.

5.3 Methods

Top-down and bottom-up exercises

Central banks and supervisors 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. 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 3 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 Biennial Exploratory Scenario as an example of how top-down and bottom-up approaches can be combined.[10]

10 Bank of England, 2019.

Box 3

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.[1] 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.[2]

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.

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[3], 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 summarised 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.

1 Allen et al., 2020.
2 Devulder and Lisack, 2020.
3 Vermeulen et al., 2018.

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. 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. 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.

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 4 sets out how the Bank of England approached the challenges of long-time horizons in its 2021 Biennial Exploratory Scenario.
- *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 5. **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 4

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

In its 2021 Biennial Exploratory Scenario (BES), the Bank of England has proposed a detailed exploration of the impact of climate scenarios on banks' and insurers' balance sheets with a time horizon of 2020 to 2050.[1] To make this approach feasible, participating banks and insurers would have to calculate impacts over time in the following way:

- Participating institutions model the impact of the scenarios up to 2050 (i.e. a 30-year time horizon with impacts assessed at 5 yearly intervals).[2] However, the physical risk variables would be calibrated in a conservative way to capture the physical impacts in the second half of the century.
- To make the modelling feasible, in the first part of the exercise participants assume the nominal size and composition of their balance sheets to be fixed over the time horizon of the scenario. In practice this means firms assess climate-related risks at each point of the time horizon against their current balance sheet.
- In the second part of the exercise, this constraint would be relaxed, and firms identify the management actions they would take to reduce their risks. These would be reported as a mix of qualitative responses and quantitative metrics.

1 Bank of England, 2019.
2 Physical risks in the No Additional Policy Action Scenario are proposed to be assessed from 2050-2080.

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 minimise 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 has not yet been collected. For instance, available climate-related datasets often cover only public companies and very rarely privately-owned companies, to which financial institutions are exposed. This can pose a significant obstacle to the analysis.
- *Can the required data be constructed on the basis of available datasets?* Often, some data is available but distributed over various datasets, which would need to be combined to create one coherent set. See Box 5 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.

Box 5

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

The transition risk stress test conducted by De Nederlandsche Bank[1] considered the equity, bond and corporate loan portfolios (for banks), 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 were 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 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.

1 Vermeulen et al., 2018.

Outputs

Central banks and supervisors 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).

5.4 Key assumptions and sensitivities

Transition risk

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.

- *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.

Physical risk

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.

5.5 Refining the results

Given the novel nature of climate risks, both central banks and supervisors and (where relevant) participating firms will likely learn a lot about the underlying transmission channels and key sensitivities in the first round.

At the end of the exercise, central banks and supervisors should consider revisiting the scenario assumptions and performing a second round of the exercise. 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.

6.1 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

Central banks and supervisors should consider the information disclosed, given that climate scenario analysis methodologies are still evolving, and that the 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.

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 central banks and supervisors looking to share the results of their scenario analysis (see Table 6). Public disclosure can take place on websites, periodic publications (analytical notes, financial 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.

Table 6. **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

Box 6

Communication Examples

Some central banks and supervisors have communicated and/or are considering communicating the results of scenario analysis or stress testing in various ways.

- **Banco de España** will share the result of stress testing with institutions and publish it in their financial stability report.
- **Bank of England** will disclose aggregate system-wide results of their climate stress tests including means and ranges, and provide feedback to individual firms.
- **Banque de France/ACPR** will disclose only aggregate system-wide results and provide feedback on an individual basis to specific firms to ensure the coherence of the overall exercise.
- **De Nederlandsche Bank** has published a first estimate of the possible impact of a disruptive energy transition on the Dutch financial sector.
- **Monetary Authority of Singapore** (MAS) intends to share the results of any climate stress tests with all participants to encourage the adoption of best practices, and spur development in terms of modelling techniques and climate data gathering.

6.2 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".[11]

11 Battiston, 2019.

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Annex – Examples of scenario analysis

This annex sets out more information on how individual central banks and supervisors have used climate scenarios to assess macroeconomic and financial risks. These are summarised in Table 7 below.

Table 7. **Examples of published climate-related risk assessments by central banks and supervisors**

Authority	Publication	Type of method	Description
Bank of Canada	*Link*	Scenario analysis to better understand macroeconomic and financial system risks (desk-based)	Explore illustrative scenarios to assess transition and physical risks related to climate change. Examine macroeconomic, sectoral and technological shifts using a CGE model (supported by results from an IAM.)
Bank of England (i)	*Link*	Stress test (firm-based)	Participating institutions (large UK banks and insurers) are required to calculate the impact on their exposures for three detailed climate scenarios provided by the Bank of England.
Bank of England (ii)	*Link*	Stress test (firm-based)	Insurers analysed impact of physical and transition risk on both their assets and liabilities in three policy scenarios.
Banque de France/ ACPR (i)	*Link*	Financial system exposure analysis (desk-based)	Analysis of exposures of French banks and insurers to sectors with high GHG emissions.
Banque de France/ ACPR (ii)	*Link*	Stress test (firm-based)	Pilot exercise to assess the resilience of large French banks and insurers to four climate scenarios including transition (banks and insurers) and physical risks (insurers only).
Danmarks Nationalbank	*Link*	Financial system exposure analysis (desk-based)	Analysis of how projected sea-level rise could affect financial institutions' mortgage collateral in Denmark.
De Nederlandsche Bank	*Link*	Stress test (desk-based)	Analysis of how the asset-side exposures of Dutch banks, insurers and pension funds are affected in scenarios of a disruptive energy transition.
ECB	*Link*	Financial system exposure analysis (desk-based)	Analysis of large exposures of European banks, insurers, investment funds and pension funds to climate-sensitive sectors.
ESRB/ATC-ECB/FSC	*Link*	Stress test (desk-based)	A forthcoming example is one jointly conducted by the ECB, the European Systemic Risk Board and the European System of Central Banks: this stress-test is a 'pilot' exercise and ultimately aims at identifying data gaps and methodological limitations for the assessment of climate-related risks. It investigates the materiality of transition risks for banks' solvency and their lending capacity, also looking at the implications for the overall economy using a dynamic setting.
MAS	Not published	Stress test (firm-based)	Selected general insurers were required to assess the impact on their exposures through insured properties (by considering a list of flood-prone areas in Singapore) as well as the possible implications on their business lines under a climate variability scenario featuring an extreme flooding event.
Norges Bank	*Link*	Identification of vulnerabilities and triggers (desk-based)	Exploration of various scenarios for the oil industry, and of how the Norwegian economy and financial sector may be affected in these scenarios.

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