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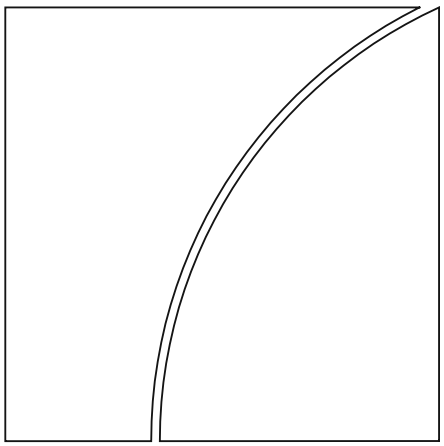

Stress-testing banks for climate change – a comparison of practices

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Executive summary

Financial sector authorities have become increasingly involved in climate change risks and their impact on the financial sector. Financial authorities, at the global and national levels, are increasingly taking action to require stronger preparedness by the financial industry against climate risk. The authorities' involvement is needed partly because of the growing materiality of climate risks for the financial industry, but also because these risks are expected to materialise over a much longer time horizon than the private sector is used to considering. Enhanced disclosure of exposure to climate change risk, encapsulated in the 2017 report by the Task Force on Climate-related Financial Disclosures (TCFD) of the Financial Stability Board (FSB), was a first step in this direction. Since then, growing efforts have been made to quantify banks' and insurance companies' exposures to climate risks.

In this vein, authorities have launched stress tests for banks, and more exercises are planned for the near future. Considering that traditional risk management approaches are unsuitable for measuring climate change-related risks, authorities and the industry have turned to stress tests to try to assess the extent of firms' vulnerability to climate change. Such exercises have been completed in the Netherlands and France, and numerous others are underway, for instance in the Banking Union in Europe, the United Kingdom, Australia, Singapore and Canada. Stress tests are seen as useful tools because of their forward-looking nature and their flexibility. In particular, they can be adapted to capture additional risk drivers such as those related to climate changes.

Adapting traditional stress tests to climate-related risks for banks raises challenges, as discussed in the paper. Traditional stress tests were designed to study the impact of external shocks on the solvency of banks. Assessing climate-related impacts requires some fundamental changes. For instance, the risks are expected to materialise over much longer time horizons than those used in respect of traditional banking sector risks. In addition, data covering future climate patterns may be unavailable or unreliable, given the changes in climate patterns that are underway. Moreover, measuring the impact of climate risk requires granular exposure data, ideally by sector and region, in order to differentiate and assess risks along these dimensions. However, these data may not currently be available. In addition, modelling techniques need to be adapted in order to support an exercise that, at a minimum, needs to be composed of four parts. One part refers to modelling the climate variables, the second is to measure the impact of climate on macroeconomic variables, the third is to break down the overall macroeconomic impact across sectors and the fourth one is to quantify the combined impact on financial firms.

Notwithstanding these challenges, three pilot exercises reviewed in the paper offer valuable lessons. The paper shows how the technical challenges of a climate risk stress test have been addressed in pilot exercises conducted by the Dutch and French authorities in 2018 and 2021 respectively, and in the exercise currently underway in the United Kingdom. These pilots are seen as highly relevant by the authorities and the industry. They are viewed as a starting point for managing climate-related risks and as particularly useful in beginning to identify and assess an increasingly important source of risk. They can also act as a catalyst to further develop modelling techniques that would be better suited to capturing climate risk and to the collection of relevant data. However, at this stage the stress tests are considered to

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be exploratory and preliminary, and it is clearly acknowledged that much remains to be improved. Authorities mainly seek to acquire knowledge, help to build capability in financial firms, gather information and assess banks' strategic outlook.

An open issue for all authorities is the nature of their follow-up with the industry, although for now climate stress tests are not expected to trigger new capital requirements. Bank stress tests have traditionally been associated with setting a minimum level of capital for each bank and requirements for remedial action when the hurdle rate is not met. For climate risk-related exercises such a requirement is considered premature given the preliminary nature of the exercises and the high-level of uncertainty attached to their results. For this reason, some authorities prefer to describe their current exercises as "scenario analysis" rather than "stress tests". Irrespective of the labelling, the predominant view in the official community at this time is that no new capital requirements will be introduced on the basis of the outcomes of these stress tests.

The outcome of climate change stress tests may inform other supervisory actions. Public communication by authorities engaging in such exercises indicates that they plan to use the exercises in supervisory reviews, and supervisory expectations have been set accordingly. As a result, climate stress test exercises, and the ways in which they inform banks' decisions regarding their business models and their day-to-day risk management, can become the basis of supervisory discussions. Indeed, they can facilitate a smooth transition for the banks to a lower carbon economy. Ultimately, such stress tests also contribute to the safety and soundness of the financial system as a whole.

Section 1 – Introduction

1. **Climate change risks may be elevated for banks, and they can primarily be categorised as physical risks and transition risks.** There is a growing consensus that risks related to climate change are potentially material, meaning that their impact may result in significant economic and financial losses, that their materiality is increasing and that they could have a negative impact on financial stability (see eg FSB (2020)). Among these risks, physical risks are those that arise from acute extreme weather events such as floods, storms or heat waves, and chronic physical risks, which include gradual changes in precipitation, rising sea levels or increasing temperatures. Transition risks are generated by adjustments towards a low carbon economy. They include changes in public policies, in legislation, in regulation, in technology and in customer sentiment.[2] A third risk category, liability risks[3], may also arise from climate change and transitioning. However, these risks are not usually covered in climate risk stress testing exercises for banks for the time being and are therefore not included in the scope of this paper.

2. **There are several channels through which banks are exposed to climate change.** They are exposed both directly, due to their activities, and indirectly. Direct risks include increasing costs of energy usage, refitting their premises to comply with climate-friendly building standards and data centres at risk from disruption from flooding or cyclones. Indirect risks include shocks affecting macroeconomic conditions and the impacts of disruptive transition paths and/or extreme weather events. These shocks in turn affect banks' exposures, that is the assets and customers that banks finance or the investments that they make. The creditworthiness of their customers and/or the value of financed or collateralised assets and investments may be negatively impacted by climate change (eg investments in carbon intensive

[2] The definition of physical and of transition risks used throughout this paper are those used by the Basel Committee on Banking Supervision (BCBS). See the respective glossaries of BCBS (2021a,b).

[3] Liability risks includes litigation costs, damages paid as a result of court decisions or of settlements out of court, reputational risks and compliance risks due to corporations and public sector entities not complying with requirements or meeting expectations to promote a low carbon economy. It is included in some climate risk stress tests, such as the one currently underway in the United Kingdom, but only for the insurance firms.

industries or exposures to real estate that may be severely affected by floods, rising sea levels or stronger hurricanes). Only some of these risks may be covered by insurance contracts and the availability of such protection is more limited in countries with less developed financial sectors (FSB (2020)).

3. **Since 2017, initiatives have been undertaken to address climate risk for financial institutions, starting with enhanced disclosure**. In 2017, the Task Force on Climate-related Financial Disclosures (TCFD) of the FSB, which includes a wide range of market participants, issued recommendations aiming to improve climate-related disclosures. Since then banks and other financial institutions, as well as supervisory authorities, have developed a range of methodologies to integrate climate-related exposures within their risk analysis.[4] The IFRS Foundation is working on developing global sustainability reporting standards. These will cover reporting of climate risk exposures (IFRS Foundation (2021)). More recently, the FSB has issued a comprehensive roadmap for addressing climate-related financial risks (FSB (2021)).

4. **There are growing efforts to develop risk management practices and related guidance on climate-change risks**. In late 2017, a group of central banks and financial supervisors created the Network for Greening the Financial System (NGFS). The NGFS has spearheaded growing efforts to incorporate climate-related risks within prudential and financial stability frameworks. In April 2021 the Basel Committee on Banking Supervision (BCBS) published two reports which, respectively, analyse climate-related risk drivers and their transmission channels and discuss the range of measurement methodologies that are either currently available to banks or under development (BCBS (2021a,b)). These reports followed a survey and stocktaking exercise on regulatory and supervisory initiatives on climate-related financial risks among the BCBS membership (BCBS (2020)). Efforts are underway within the BCBS to develop common supervisory guidance for banks' risk management of their climate change risks. National stress testing exercises covering climate change risks have also been undertaken, and relevant documents published since 2017 (see Bolton et al (2020)).[5]

5. **Quantifying the impact of climate change risks on the financial sector and for individual institutions is essential.** There have been growing efforts to achieve some type of quantitative assessments in order to size risk exposures and assess the corresponding potential losses. These efforts are among the first steps towards developing a comprehensive risk management framework for this risk. In addition, the quantification of risk allows a bank to compare exposures within a given business line but also across jurisdictions, therefore allowing it to make appropriate selections and price their riskiness.

6. **However, it is more difficult to use traditional risk quantification techniques that rely on past data and on statistical risk modelling when assessing the impact of climate risk.** Contrary to financial risks covered in traditional banking analysis,[6] there may be cases where there are no data available because the transition risks may be unprecedented. For physical risks, existing data are either irrelevant or no longer sufficiently reliable as past weather patterns are breaking down and weather conditions are becoming both more extreme and more unpredictable. Finally, there are also cases where data may exist but have not been gathered by banks so far because climate change risks were not deemed to be material and so did not justify such efforts.

[4] For an overview of the methodologies used or under development by banks and supervisors, see BCBS (2021b). For an overview of environmental risk analysis, and of methodologies related to Environmental, Social and Governance (ESG) scoring and integration, see NGFS (2020c).

[5] Researchers are developing studies to better understand the relation between climate change risks and financial stability, and to fill methodological gaps in this area. For an overview of the relevant literature, see Battiston et al (2021).

[6] For banks, these financial risks include credit, market, liquidity and operational risks (including legal and compliance risks). Climate risks materialise through these categories. This terminology is adopted throughout this paper.

7. **As a result, both public and private sector participants are increasingly relying on stress testing.**[7] Stress tests are simulation exercises conducted to assess the resilience to a hypothetical scenario of either a single bank or the system as a whole (Baudino et al (2018)). The forward-looking nature of stress testing exercises makes them better suited to assess future exposures and potential losses that cannot be extrapolated from past data, such as those related to climate risk. Moreover, banks regularly conduct stress tests for internal planning, for risk management and for regulatory/supervisory compliance purposes. These tests have also been performed by authorities for system-wide analysis and supervisory objectives. Accordingly, stress testing methodologies are familiar to both the private and official sectors.

8. **For this purpose, authorities are developing specific scenarios.** The NGFS published scenarios with the help of the climate science community and they can be used for climate-related stress testing exercises. There are two main benefits from the NGFS scenarios first published in June 2020 (NGFS (2020a)) and updated a year later (NGFS (2021b)). First, they were specifically designed to address the need of prudential authorities and central banks to assess the resilience of the financial sector.[8] Second, because these scenarios are publicly available, they can be employed by multiple authorities, therefore allowing for some degree of comparability across jurisdictions. By using them, each jurisdiction can also avoid having to duplicate expertise and employ human and financial resources to develop its own scenarios.

9. **Adjustments are also needed for climate risk stress tests in terms of techniques and modelling approaches.** Climate risks differ in several respects from the traditional financial risks that banks manage. Firstly, the time horizon is much longer. Secondly, as already mentioned, there are less or no historical and reliable data to analyse the potential future impacts of climate changes. Thirdly, a higher level of granularity of exposure data is required, as the impacts of climate risks depend heavily on sectoral-specific features and on the location of the exposure. Finally, modelling techniques are in their infancy and not as well developed as for traditional financial risks.

10. **This paper aims to shed light on the key design features of a climate risk stress test for banks, and the main challenges associated with them**. Building on the "pilot exercises" that authorities have launched since 2017, with the involvement of the financial industry (generally banks and/or insurance firms) to various degrees,[9] methodologies are being improved and increasingly adapted to climate risks. This paper aims to contribute to the ongoing development of stress testing exercises conducted by

[7] Following BCBS (2021a,b) stress testing in the context of climate risk analysis is defined as "the evaluation of a financial institution's financial position under a severe but plausible scenario. The term "stress testing" is also used to refer to the mechanics of applying specific individual tests and to the wider environment within which the tests are developed, evaluated and used within the decision-making process." Some authorities or firms have also conducted scenario analysis in relation to climate risk. BCBS (2021a,b) define scenario analysis in this context as "a tool that is used to enhance critical strategic thinking. A key feature of the scenarios analysed is to explore alternatives that may significantly alter the basis for "business as usual" assumptions. Accordingly, they need to challenge conventional wisdom about the future". The distinction between scenario analysis and stress testing in the area of climate change is still under discussion, in particular because more tailored techniques need to become available and because policy and risk management implications need to be clarified. For instance, the Bank of England (BoE (2021a)) considers its 2021 exercise a scenario analysis, with the goal of allowing policymakers to probe the resilience of the United Kingdom financial system to a wide range of risks, and as a tool to enhance participants' strategic thinking on how to manage those risks. In this paper, the term stress testing refers to the BCBS definition, with emphasis placed on the techniques employed for this analysis, irrespective of possible policy implications.

[8] Other publicly available climate-related scenarios include those from the International Energy Agency (IEA) and from the Intergovernmental Panel on Climate Change (IPCC). However, neither set of scenarios were developed for the financial sector.

[9] Other types of stress testing exercises have focused on the impact on non-financial companies. For instance, Ens and Johnston (2020) conducted an analysis of the impact of climate change on energy intensive sectors.

supervisory authorities and applied to banks. The examples used throughout are based on public information.[10]

11. **Three supervisory climate risk stress tests are used to illustrate how these challenges are met in practice.** The three exercises are: (i) the test conducted by the Bank of France/French Prudential Supervision and Resolution Authority (BoF/ACPR)[11] for France; (ii) the test conducted by the Netherlands Bank (DNB)[12] for the Netherlands; and (iii) the test developed by the Bank of England and the Prudential Regulation Authority (BoE/PRA) for the United Kingdom,[13] which is scheduled for completion in 2022. Publications for the three exercises are used throughout the paper to illustrate the main steps that need to be considered when designing and implementing such exercises. For other exercises that are underway or planned in the near future, no complete documentation is yet available.[14] For instance, the European Central Bank plans to disclose the results of its top-down financial stability climate stress test later in 2021 (de Guindos (2021)), complementing its initial findings on the materiality of exposures to climate risks for banks, insurance firms and investment funds (ECB, 2021). Others such as the supervisory side of the ECB (ECB (2020a)), the Australian Prudential Regulation Authority (APRA (2020)), the central bank and the supervisory authority in Canada (Bank of Canada (2020)) and the Board of Governors of the Federal Reserve System (Brainard (2021)) are currently developing their own climate risk analysis for banks, but no full documentation is yet available.[15]

12. **The choices to be made when designing a climate risk stress test exercise are presented here on the basis of a general framework for stress testing**. Baudino et al (2018) proposes an approach for developing a stress testing exercise with a definition of its objectives, and the following three main building blocks: (i) governance; (ii) implementation, including scenarios, technical requirements and design; and (iii) outcomes, including results and publications. While climate risks require significant adaptations to each of the three building blocks, especially the implementation part, the overall framework can be applied to climate risk stress tests and is used in this paper.

13. **The rest of the paper is structured in three sections**. Section 2 discusses the main conceptual issues associated with supervisory climate stress testing exercises for banks. Section 3 compares the three stress testing exercises and Section 4 concludes.

[10] In other cases, authorities have provided guidance to financial firms about the conduct of stress tests for climate risks. For instance, the Monetary Authority of Singapore (MAS) issued guidelines for banks about environmental risk management, including stress testing (MAS (2020)). Firm-level stress tests for climate risk are not covered in this paper, as emphasis is put on authorities' approaches to actually conducting such exercises.

[11] See Allen et al (2020) and ACPR (2020, 2021).

[12] See Vermeulen et al (2018, 2019). The DNB exercise also covered insurance and pension funds.

[13] See BoE (2019b, 2021a,b).

[14] The European Banking Authority (EBA) recently conducted a pilot exercise covering 29 volunteer banks. These provided raw data on non-SME exposures in EU countries (EBA (2021b)). The exercise focuses on the identification and quantification of exposures to climate transition risks. It also includes a scenario analysis, at the aggregate level, but this is not the core of the report. The report's objective is to explore available methodologies and inform how a climate risk stress test framework for credit exposures could be designed. Overall, the EBA sees the exercise as a contribution to identifying the challenges that supervisors and banks are facing and to determine the greenness of activities. It is also expected to support classifying and measuring climate risks. Eventually, it should also support banks in their transition efforts.

[15] FitchRatings (2021) lists several upcoming stress testing exercises by authorities around the world. ECB (2021) provides a detailed summary of past, ongoing and planned climate risk stress-testing and sensitivity exercises by institutions in Europe.

Section 2 – Conducting climate change stress tests for banks – conceptual issues

14. **This section discusses the changes needed to adapt traditional stress testing to climate risk-related exercises.** Overall, a climate risk stress test does not differ much from a regular, solvency focused one when it comes to identifying the exercise's objectives and deciding on its governance and desired outcomes (Baudino et al (2018)). Section 3 shows how these elements are used in the three stress testing exercises under study. However, there are very significant differences in terms of scenario design, modelling approaches and related data issues. These adjustments are discussed in this section.

Scenario design

15. **A comprehensive stress testing scenario would ideally reflect both physical and transition risks.** The scenarios would need to include all physical and transition risks that may generate potentially material losses for banks. Transition policies towards a lower carbon economy can generate their own disruptive impacts on the economy, especially if the efforts to transition are insufficient. Scenarios also need to take into account cumulative and feedback effects arising from both sets of risks and economic impacts.

16. **The design of scenarios and the modelling and calibration of shocks involve specific complexities.** Scenarios used in stress tests for banks seek to describe the aggregate macroeconomic environment during a prior stress episode. Large amounts of data, drawn from prior downturns and/or crises episodes, are generally available to estimate correlations between the stress scenarios' variables and banks' financial performance (in the balance sheet, and profit and loss statements) under stress. However, in climate change stress testing, climate change scenarios need to include physical and transition risk variables, translate these into key macroeconomic variables and then translate these macroeconomic variables into potential financial losses. The hard to predict nature of the physical and transition risk drivers makes it challenging to incorporate these factors in the scenario design, although drawing on additional modelling expertise may help to alleviate some of these complexities.

17. **A climate stress test needs to use long time horizons.** While a time horizon of up to three years is typically used to model credit, market and operational risk, time horizons for climate change stress testing need to cover several decades and usually range between 30 and 50 years. Such long time spans correspond to the horizons over which climate change risk factors are expected to fully materialise. However, such long time horizons considerably increase the uncertainty surrounding the quantifications of both exposure sizes and potential losses. With the exception of newly originated long-dated real estate and project finance exposures, banks' exposures to sovereigns, other financials, corporates and households rarely exceed a few years, thus making it necessary to introduce ad hoc assumptions about the evolution of bank portfolios over a very long period of time. Furthermore, such long horizons can give banks a way to reduce the impacts of climate-related risks, as they can minimise them by introducing assumptions about technological innovation, divestment or other management actions.

18. **A relatively high number of scenarios may need to be used.** To reflect the high degree of uncertainty, it is necessary to use a relatively high number of scenarios in a climate risk stress test. This produces a wider range of outcomes in terms of the reference metric (eg exposures at risk or possible valuation losses in assets or liabilities) than in a traditional financial stress test. Such a wider range can help financial authorities and firms to better understand the possible implications of policy choices (transition risk) or of the aggravation in climate patterns (physical risk). It may also help in identifying vulnerabilities, and risk concentrations in particular, therefore making it possible to mitigate them.

Data availability

19. **Climate risk assessments are currently limited by a lack of usable data.** As already mentioned, historical data are less relevant to climate risk assessments, even where they exist. It is therefore more difficult to estimate linkages between climate events, climate and environmental policies, the economy, the financial system and individual institutions.[16] Moreover, the literature[17] shows how a lack of usable data for assessing climate-related risks can come in multiple guises. Apart from the limitations of past data in providing information on physical and transitional risks going forward, there is also a lack of data on the relationship between climate risk events and credit losses[18], generally because such data, which need to be both very granular and localised, have not traditionally been collected by banks.

20. **While considerable efforts are underway to collect data and improve their usability, simplifying assumptions still need to be made**. To close data gaps in relation to climate change, the NGFS identified data items needed by the financial sector for the purpose of climate-related risk analysis[19] (NGFS (2021a)). Subsequently, it plans to undertake studies to determine the availability of this data, its sources and possible access limitations. Finally, it intends to provide guidance and recommendations on how to bridge the identified data gaps.[20]

Modelling blocks and interlinkages

21. **The translation of climate change into financial impacts on bank exposures requires four main analytical steps.** The four steps can be summarised as follows. A first step covers the description of climate phenomena and their impact on a specific climate metric. The next step is the quantification of the impact of the changes to the climate metric on a traditional macroeconomic indicator, such as GDP. Next, a breakdown into sector and geographies may be needed, considering the differentiated impact of climate change across them. Finally, all elements are combined to compute the impact on banks. This chain of steps is a significant source of modelling complexity and uncertainty, particularly as it implies linking together several models that were not initially designed to operate together. The four steps and challenges associated with each of them are described in detail below.

22. **The first step involves the development of a climate risk block.** It typically includes the use of models to project the trajectories of climate risk variables. These climate risk variables include, in particular, carbon price pathways and greenhouse gas emissions (GHG emissions), with the latter determining the temperature pathway. An important consideration is the need for the climate model and its climate risk variables to reflect the fact that countries, and regions within countries, are not all exposed to the same sets of climate risks and in the same ways. A parsimonious approach would be to model individually the countries to which a banking system is most exposed, and the rest of the world in regional

[16] Consequently, and as recently highlighted by the BCBS (see BCBC (2021b)), considerably more work is needed to integrate climate risk models within financial models and to generate the types and amounts of data required to estimate correlations.

[17] See, for instance, BCBS (2021b) and Cleary et al (2019).

[18] While the insurance sector regularly collects, compiles and publishes losses resulting from insured claims that arise from natural catastrophes, there are no such statistics available on an industry-wide basis and few, if any, banks seem to collect such data systematically on a bank-specific basis.

[19] NGFS (2021a) identifies three avenues to bridge the data gaps: (i) global disclosure standards and their implementation; (ii) a global taxonomy; and (iii) metrics, certification labels and methodological standards to improve data reliability and comparability.

[20] As part of its efforts to address data gaps, the NGFS has made data and resources available for scenario design in a dedicated section of its website.

aggregates. This nonetheless still requires that the climate risk variables used for physical risks and for transition risks are available at country and regional levels.

23. **The second step connects the climate risk block with a macroeconomic block.** This second step consists in using the variables provided by the climate model to determine macroeconomic variables such as GDP, unemployment, inflation, through a multi country-level macroeconomic model. This step is essential to reconcile climate risk variables with concepts that can translate into economic and financial impacts on the financial system. Once again, differentiating the impact of climate change across countries may require separate modelling of the economic impacts on the most relevant trading partners for any given country. This is especially relevant for economies that are most exposed to international trade and where the banking system has significant international exposures. However, modelling the multi-country impact can be demanding. In countries with mostly domestically oriented banks, or as a first step in conducting climate-related stress tests, a domestically focused exercise may be considered sufficient.

24. **The third step breaks down the macroeconomic effects to reflect their differentiated impact on economic sectors.** This can be achieved through the use of sectoral models.[21] There can be several levels of disaggregation. More granular assessments generally require using sectoral classifications for corporate exposures[22]. These can be international sectoral classifications or even taxonomies developed to identify sustainable activities, the most elaborate of which is currently the EU Taxonomy.[23] However, even these tools need to be complemented by more granular assessments when the aim is to assess climate change impacts on individual counterparts. The most granular level of assessment involves firm-level disaggregation and the assessment of economic impacts at counterparty levels for corporates, especially the larger ones. For real estate exposures in particular, granular risk differentiation implies identifying the precise location of the exposures, especially those in areas that are the most vulnerable to climate change.[24]

25. **Fourth, the financial impacts on banks and on their exposures are then computed.** The assessment of changes in the valuation of assets and liabilities on banks' balance sheets requires the use of financial metrics such as stock market valuations, equity indices, and bond indices for fixed income instruments. Changes in these metrics will reflect transition risk, as the market valuation of assets in each sector will be differently affected depending on their carbon intensity. They will also reflect physical risk, as losses in some sectors especially exposed to physical hazards are expected to be higher, increasing their probabilities of default (PD) and/or loss given default (LGD). For banks' loans, the impact of climate change risk tends to be reflected through adjustments to counterparties' PDs and LGDs depending upon which sector they belong to.

[21] Typical examples of sectors and/or activities that are more vulnerable than others to transition risk include the energy sector, and in particular the coal, oil and gas industries. The transportation sector is also vulnerable, particularly car and aircraft manufacturers, and airlines. Exposure to physical risks will largely depend upon the location of the asset or counterpart, for instance whether it is located in an area that is subject to flooding. To understand how transition risks materialise across different sectors of the economy, United Nations Environment Programme Finance Initiative (UNEP FI (2020)) has developed Risk Factor Pathways (RFPs). The NGFS scenarios can be used to calculate these RFPs.

[22] For a more elaborate discussion on the need for further risk differentiation and granularity, see BCBS (2021b).

[23] The EU Taxonomy (Regulation (EU) 2020/852) is a green classification system that translates the EU's climate and environmental objectives into criteria for specific economic activities for investment purposes. It recognises as green, or "environmentally sustainable", economic activities that make a substantial contribution to at least one of the EU's climate and environmental objectives, while at the same time not significantly harming any of these objectives and meeting minimum social safeguards. It is a transparency tool that will introduce mandatory disclosure obligations on some companies and investors, requiring them to disclose their share of Taxonomy-aligned activities.

[24] See, for instance, Regelink et al (2017), for an early exploration of flood risk by a financial authority and Abcouver et al (2020) for a recent economic impact assessment of future flooding in the Netherlands conducted by a bank.

Granularity of exposures

26. **A key consideration is the desired level of granularity in the output of the macroeconomic and financial blocks.** A relatively low-level of data granularity may be sufficient if the purpose of the scenario is to allow for a tentative top-down macroprudential assessment of a financial system's main vulnerabilities.[25] In such cases, using an internationally recognised sector classification[26] and the average carbon intensity per sector globally or for each jurisdiction may be sufficient. More granular data will be needed if the purpose of the exercise is to assess banks' exposures to the most emission intensive sectors. This may be limited to the energy sector only, including exploration, mining or drilling and power generation, or it could be extended to a wider range of sectors. Banks and financial authorities can complement sectoral analyses[27] by individual assessments of the larger counterparts.

27. **Assessing the resilience of individual banks requires the highest-levels of data granularity**. Ideally, firm-specific data are needed for as many of the bank's corporate exposures as possible, although for practical reasons exposures against small and medium enterprises are mostly reflected through simplifying assumptions and the assessment is made on a portfolio basis, especially if the portfolios are sufficiently granular and well diversified. High data granularity is also needed for household exposures, particularly those related to real estate, with this being achieved through assessing individual properties.[28]

Second round effects and management actions

28. **Because a climate risk shock affects the whole economy, a fully fledged stress test would ideally include second round effects and feedback loops.** As highlighted in recent reports that survey current practices,[29] there are currently significant gaps in the assessment methodologies with regards to second round effects that could lead to either underestimating or overestimating the potential risks and losses that may arise over a long time horizon. For instance, most existing measurement methodologies have been developed to cover large corporates. In particular, they focus on exposures to sectors that are the most exposed to transition risks, since these represent one of the largest sources of potential losses for banks. More generally, current stress testing approaches for climate risk lack feedback analysis, as second round effects between climate change variables, macroeconomic variables and financial outcomes for banks are poorly captured. Given these limits, second round effects and feedback loops are currently assessed on the basis of expert judgement only.

29. **A decision about how to reflect banks' management actions needs to be made.** One option is to assume a static balance sheet, which is frequently used in regular financial stress tests with short-term horizons. However, assuming a fixed balance sheet over a time horizon of 30 to 50 years is highly unrealistic. In addition, the carbon intensity of the balance sheet may change over time both because of the bank's actions and because the counterparties themselves are expected to reduce their carbon footprints. Nonetheless, adopting a static balance sheet may allow the authorities to better understand

[25] For examples, see Regelink et al (2017) for a high-level macroprudential assessment on the Dutch financial sector or ACPR (2020) for a similar assessment of climate-related risk affecting French banking groups.

[26] Examples of internationally recognised classification systems of corporates according to their activities include the International Standard Industrial Classification of all Economic Activities (ISIC), The European's NACE classification or the Global Industry Classification Standard (GICS) developed by MSCI (Morgan Stanley Capital International) and Stand & Poor's Dow Jones.

[27] For an example of sectoral analysis involving the outlook of sectors sensitive to transition risks, see for instance the webpage of the International Energy Association (IEA) and its reports on fuels, technologies and sectors, with examples including iron and steel, cement and international shipping. See https://www.iea.org/fuels-and-technologies.

[28] In practice, assessments of real estate exposures can involve different levels of sophistication and granularity. Such assessments are often limited to identifying exposures' location through postcodes but can also involve satellite imagery, geology and the precise topographical location of individual exposures, especially the larger ones.

[29] See, in particular, NGFS (2020b) and BCBS (2021b).

what types of risks could arise under different scenarios, keeping banks' business models unchanged over the time horizon. In this approach, a fixed balance sheet can be used as a proxy for banks' current business models and their implications.

Section 3 – Climate risk stress tests in practice

30. **This section presents examples of the main design choices regarding the building blocks of a climate risk stress and their objectives.** These choices are illustrated through a comparison between the climate stress test exercises conducted by BoF/ACPR, the DNB and BoE/PRA.

Objectives of a climate risk stress test

31. **The objectives of the three climate risk stress tests are to acquire knowledge, help to build capability in financial firms, gather information and assess banks' strategic outlook**. The three stress tests are considered to be exploratory and preliminary. They are experimental exercises that are presented as "pilot exercises" by both the banks and the authorities. Overall objectives are to learn more about the size, the distribution across the financial system and the risk drivers of climate-related exposures. They are also intended to help identify and address data gaps, and to encourage banks to become more familiar with climate risk and to manage their climate risk exposures accordingly.

32. **Climate stress tests are not currently used for quantitative regulatory requirements.** Given the multiple challenges and uncertainties related to these assessments, authorities have indicated that capital requirements are not expected to be modified or imposed in the near future. The global standard setter for banks, the BCBS, recognises that existing financial risk categories that are traditionally used by banks and reflected in the Basel framework (ie credit risk, market risk, liquidity risk and operational risk) can be used to capture the impact of banks' climate-related exposures (BCBS (2021a)). However, further analysis is needed to determine whether the climate-related financial risks are appropriately reflected in the current regulatory capital framework, and whether additional policy measures should be taken to address any potential gaps where warranted. Some national authorities have indicated that capital requirements may ultimately be affected, if only at a later stage, to reflect the high relevance of climate risk (Bailey (2020)).[30] In any event, authorities may develop supervisory expectations for banks stating that the latter need to embed processes allowing them to better understand climate risks (eg BoE (2019a)).

33. **Reflecting the objectives of these exercises, no hurdle rates in terms of minimum capital levels have been introduced.** In regular stress testing exercises that measure banks' resilience to solvency and liquidity shocks, hurdle rates are employed to identify outliers – the weakest banks – which are usually required to undertake remedial action. For a climate risk stress test, there is no commonly agreed metric to identify outliers or assess financial impacts on banks' overall resilience.[31] However, in some cases, the average impact on banks' solvency ratios at the end of the exercise is included in the analysis (Vermeulen et al (2019)).

34. **A microprudential perspective is taken in these exercises**. With the emphasis put on improving awareness and on banks' risk management practices, these exercises have a microprudential focus. However, a financial stability perspective is also relevant, for instance in terms of interactions between banks and insurance companies. Nonetheless, while macroprudential stress tests that allow

[30] Industry representatives also share the view that it is currently premature to attempt to reflect financial firms' exposures to climate risk in quantitative regulatory requirements (eg Institute of International Finance (2021)).

[31] Some authorities are considering the introduction of some reference ratios for disclosure requirement, rather than stress testing results (eg EBA (2021a)). Even this, however, is difficult to implement in the absence of a clear and well established definition of what constitutes "green" exposures.

assessments of risk and possible capital shortfalls at the system-wide level have been developed for traditional solvency focused exercises, this is not yet possible for climate risk exercises.

Governance

35. **Authorities leading these pilot exercises are central banks and financial supervisory authorities, and the degree of the industry's involvement varies.** In the Dutch example, the central bank conducted the exercise without involving private sector participants (see Table 1), although it had access to exposure data for banks, insurance firms and the country's largest pension funds.[32] In the French case, the ACPR managed the exercise but both banks and insurance firms were involved, while the BdF provided the analytical framework. In the United Kingdom, the BoE designed the exercise, and its financial stability department and the PRA, via the relevant committees under the BoE, were involved. Banks, insurance firms and a large reinsurance firm also participated.

36. **These exercises show a combination of top-down and bottom-up approaches**. As usually defined in stress tests, a top-down approach reflects the fact that the exercise is managed almost entirely by a single authority, which provides the scenario, the key assumptions and runs the exercise. In contrast, a bottom-up approach is one where firms produce the results through their own modelling and may sometimes also include assumptions of their own as to the extent to which these may better reflect their individual circumstances. In the Dutch example, the approach is purely top-down, while the French and United Kingdom exercises combine elements of a top-down and of a bottom-up approach.

System-wide supervisory stress tests – sample

Three examples — Table 1

	BdF/ACPR	DNB	BoE/PRA
Are firms involved in the exercise?	Yes	No	Yes
Sample: Banks	Nine banking groups	Three banking groups	Seven banking groups
Sample: Insurance companies	15 insurance groups (22 insurers and reinsurers)	29	Five (life) six (general) one (specialised)
Sample: Pension funds	Not covered	50	Not covered

Acronyms:

BdF – Bank of France; ACPR – French Prudential Supervision and Resolution Authority; DNB – Netherlands Bank; BoE – Bank of England; PRA – Prudential Regulation Authority.

Sources: ACPR (2020, 2021), Allen at el (2020), BoE (2019c, 2020, 2021a,b), Vermeulen et al (2018, 2019).

37. **Although the exercises focus on banks' exposures to climate-related risks, insurance firms are involved as well**. As discussed in the FSB's report (FSB (2020)), climate-related risks can have a very material impact on banks' resilience, and therefore on their ability and willingness to allocate credit to other economic agents and sectors of activity. These impacts may be particularly large when the

[32] The DNB used the information it has on securities holdings to size most of banks' bond and equity exposures. This was completed by a targeted survey of corporate loan portfolios at the largest banks, with detailed information on default probabilities, loss given default and maturities. Securities and corporate loans were also classified according to the issuer or the borrower's industry. However, real estate exposures, although significant, were excluded because of significant data gaps in measuring their energy efficiency.

climate-related risks cannot be mitigated or insured. However, insurance companies may not have sufficient loss absorption capacity to provide insurance cover for banks' possible loss exposure. In addition, insurance companies typically adjust their (non-life) insurance coverage and pricing yearly on the basis of losses that occurred in the previous year. While insurance contracts may, to some extent, mitigate future losses, reductions in insurance coverage and regular risk repricing may increase the insurance protection gap. This can result in insurance becoming unaffordable, especially in geographical areas that are highly vulnerable to climate change impacts (see BCBS (2021a)). In this vein, including insurance companies in a stress test for banks can make the exercise significantly more realistic.[33]

38. **In all three cases, insurance firms are considered to be an essential part of the exercise to complement the assessment of the banks**. As explained by the BoE (BoE (2019b)) and by ACPR (ACPR (2020)) in its guidance, including insurance firms in the stress test also provides the additional benefit of allowing for a realistic reconciliation exercise based on submissions by all of the banks. This is achieved by introducing a second round into the stress test exercise, whereby the consistency of banks' and insurance firms' results are assessed and crosschecked. One particularly useful feature of this second round is that banks are required to evaluate the impact of a reduction in the insurance cover provided for climate-related risk by insurance firms.

39. **Financial firms may be involved in supervisory stress tests in various ways.** In the French case, firms' involvement is on a voluntary basis, with both banks and insurance companies having been invited to join. Three banking groups and 29 insurers joined the exercise, which also involved the creation of a number of working groups to define the modalities of the exercise. In the United Kingdom exercise, the seven largest banks and 12 largest insurance firms (five large life insurers, six general insurers and 10 selected syndicates of the Society of Lloyd's) operating in the United Kingdom are taking part in the exercise.[34] In both cases, participating banks and insurance companies are expected to run the stress test based on a scenario designed and approved by their respective authorities. The authorities also provide a broad methodological guide that firms are required to follow.

Implementation

Scenario design

40. **The three pilot exercises have treated physical and transitional risks in different ways.** The Dutch pilot does not include physical risks, while the other two include both physical and transition risks. As mentioned in the first NGFS' Guide (NGF (2020a)), physical and transition risk scenarios are often modelled separately. "Business as usual/hot world" scenarios are essentially physical risk scenarios that assess the impact of increasing and unrestrained physical risks with little or no transition to a lower carbon emission economy. All other scenarios, however, associate physical with transition risks, but only to a limited extent. In particular, only rising temperatures are fully integrated at present in the revised NGFS scenario (NGFS (2021b)). When scenarios assess the impacts of both categories of risk drivers, they need to be consistent. This requires, for instance, aligning emission pathways and temperature outcomes and the use of consistent input assumptions. Care needs to be taken to avoid overstating the impacts of these risks in a scenario that combines them.

[33] For instance, in the BdF/ACPR pilot, insurance firms are part of the exercise. In particular, insurance and reinsurance firms are expected to use their own models to project the impact of specific physical risks (in particular droughts, floods and hurricanes) to determine the claims of their policyholders.

[34] The BoE conducted a stress test for insurance companies in 2019, which included an exploratory section covering insurance companies' exposures to climate-related financial risks (BoE (2019a)). This earlier experience is considered helpful to the insurance companies involved in the bank focused exercise of 2021. For a discussion of climate risk assessments in the insurance sector, see Cleary (2019).

41. **The number and calibration of the scenarios depend upon the objectives of the exercise**. In all three cases, multiple scenarios need to be used, drawing on the NGFS set of scenarios (see Box 1). The "business as usual" or "worst case" scenarios, with high and growing global emissions, are useful for exploring physical risks and assessing to what extent their impact can damage the economy and lead to increasing losses for the financial system. The "orderly transition" scenarios – the "best case" – allow mapping of the preferred adjustment path through which physical risks can be mitigated without generating large transition risks and disrupting the economy and financial system. The intermediate scenarios explore various alternatives and assess trade-offs between the two extremes.

Box 1

NGFS scenarios

The NGFS developed climate-related scenarios that have been used by several authorities conducting climate risk stress tests. The first vintage of these scenarios was published in June 2020 (NGFS ((2020a,b)), and the second one in June 2021 (NGFS (2021b,c)). In the latter, the NGFS updated its scenarios to include countries' commitments to reach net zero emissions and to cover an expanded set of macroeconomic variables, including short-term macroeconomic variables. It also increased country-level granularity and provided an online portal through which users can explore the physical risks from climate change.

In both the 2020 and 2021 vintages, the scenarios fall into four categories: (i) the "hot house world" scenario; (ii) the "too little, too late" scenario; (iii) the "orderly" transition scenario; and (iv) the "disorderly" transition scenario (see Figure 1). In the 2021 version, however, in each of the three quadrants for which a detailed scenario is provided (ie excluding the "too little, too late" case) there are two options. The more granular options are provided in order to reflect more closely the policy choices by the relevant authorities, technological change and the high-level of uncertainly in terms of outcomes, especially for physical risk. Moreover, in the June 2020 version, the NGFS scenarios were based on input data and analysis from the Intergovernmental Panel on Climate Change (IPCC) climate report (IPCC (2018)). For the 2021 edition, the NGFS has been able to design more tailored scenarios on the basis of the latest developments in the area of climate policies. All scenarios are classified according to policy targets, policy reactions, the level of technological change, the amount of carbon dioxide removal and the amount of variation in country policies that is assumed. The NGFS' website now includes a portal that allows users to explore and use the scenarios.

In both the 2020 and 2021 versions, all scenarios use the same Shared Socioeconomic Pathway 2 (SSP 2) "middle of the road" scenario, which projects socioeconomic changes up to 2100 and world population peaking around 2070.① The scenarios vary depending upon whether additional policies take place in order to meet the Paris Agreement targets, and when they take place, ie immediately, stringently or gradually, or only after a delay, making it necessary for them to be harsher. The impacts related to timeliness and stringency of policy measures are reflected in the scenarios through variations in carbon emissions prices.

The NGFS plans to conduct further work to better include physical risks in transition pathways as the latter do not currently reflect most of these risks and do not capture most interactions. It also plans to better capture the climate change impacts on commodity volumes and prices.

When presenting its 2021 scenarios, the NGFS stresses that climate risks could affect the economy and financial system through a range of transmission channels, for both transitional and physical risks. The size of economic impacts also varies depending on a number of policy choices, for instance the introduction of a carbon tax, the level of revenues from it and the use of these revenues for investment or debt reduction. The six available scenarios are presented below.

Orderly scenarios

Net zero 2050. Global warming is capped at 1.5°C through stringent climate policies and innovation. Global net zero CO2 emissions is reached around 2050. Some jurisdictions (eg the United States, European Union and Japan) reach net zero for all GHGs.

Below 2°C. The stringency of climate policies increases gradually, so that there is a two thirds chance that global warming remains below 2°C.

Disorderly scenarios

Divergent net zero. Emissions reach net zero around 2050 but with higher costs due to divergent policies introduced across sectors leading to a quicker phase-out of oil use.

Delayed transition. This assumes annual emissions do not decrease until 2030. Strong and harsh policies are needed to limit warming to below 2°C. CO2 removal is limited. Physical risks and transition risks are higher because of the delay.

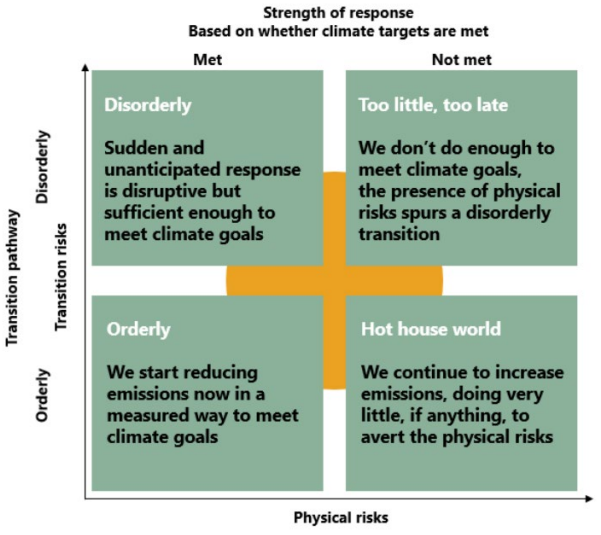
Hot house world scenarios (ie current policies are implemented, but no additional measures are taken)

Nationally Determined Contributions (NDCs)②. This includes all pledged policies even if not yet implemented. Since these are insufficient to reach net zero by 2050, the increase in the mean temperature reaches 2.5°C by this date.

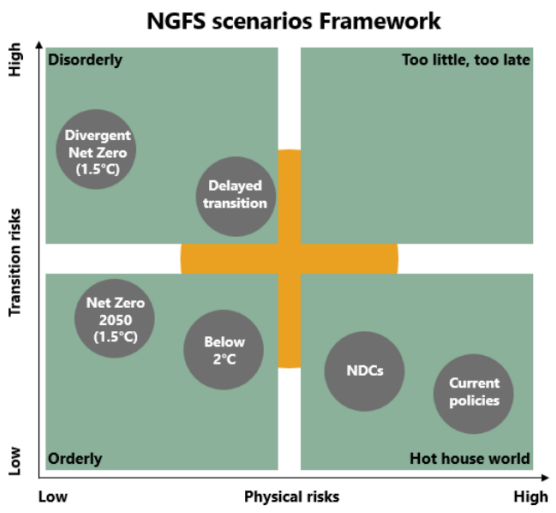
Current policies. This assumes that only currently implemented policies are implemented, and this is the "worst case" scenario. As a result, the increase in the mean temperature exceeds 3°C, with changes in the frequency and severity of severe weather events such as heatwaves, droughts, wildfires, tropical cyclones and flooding. There are impacts on health, labour productivity, agriculture, ecosystems and sea levels.

Figure 1: NGFS scenarios in 2020 and 2021

2020 scenarios



2021 scenarios*



* Relative positioning of scenarios within the quartiles is approximate, based on an assessment of physical and transition risks out to 2100.

Sources: NGFS (2019, 2021b)

① Riahi et al (2017). ② NDCs are non-binding national plans on climate actions, including climate-related targets for GHG emission reductions, policies and measures governments aim to implement as a contribution towards achieving the global targets set out in the Paris Agreement.

42. **Pilot exercises are largely based on the NGFS scenarios.** Both the French and United Kingdom pilot exercises use an orderly transition, a disorderly transition and a late transition scenario. These two scenarios are similar to – and calibrated upon – those developed and proposed by the NGFS in 2020. The worst case scenarios – termed "no additional policy action" for the BoE/PRA and "business as usual" for BdF/ACPR – are also largely derived from the NGFS's "current policies", but with some key differences. In both cases, the pilots use a 30-year modelling horizon up to 2050. Both scenarios consider that in the

absence of additional policy measures, GHG emissions will continue to rise and global mean temperatures will exceed preindustrial levels by more than 4°C. They also both consider that physical risks, whether chronic (eg rising sea levels) or acute weather events (eg flash floods), will increase considerably in both frequency and severity, especially after 2050 and until the end of the century (see Table 2).

System-wide supervisory stress tests – scenarios

Three examples Table 2

	BdF/ACPR	DNB	BoE/PRA
Physical risk	Yes	No	Yes
Transition risk	Yes	Yes	Yes
Time horizon	30 years	Five years	30 years
Static/dynamic balance sheet	Static for first five years, then reassessed every five years	Static	Static, with impact assessment every five years
Number of scenarios	Three for transition risk and one for physical risk	Four for transition risk	Three①
Transition variables	Two (energy technologies; climate policies)	Two (energy technologies; climate policies)	Three (energy technologies; climate policies; consumer preferences)
Physical variables	Increase in temperature of 1.4°C–2.6°C	Not applicable	Global and regional temperature pathways

Acronyms:

BdF – Bank of France; ACPR – French Prudential Supervision and Resolution Authority; DNB – Netherlands Bank; BoE – Bank of England; PRA – Prudential Regulation Authority.

① All three BoE/PRA scenarios were run for the period 2020–50. Two of the scenarios focused on transition are calibrated to risks in the period 2020–50. The scenario focused on physical risks is calibrated to the risks that would be seen in the period 2050–80. This is to capture the irreversible increase in physical risks that are set to arise at that point.

Sources: ACPR (2020, 2021), Allen at el (2020), BoE (2019c, 2020, 2021a,b), Vermeulen et al (2018, 2019).

43. **The BdF/ACPR and the BoE/PRA pilots have both tailored the 2020 NGFS scenarios to some extent.** Regarding their "business as usual" scenario, the French authorities assume that all measures taken in the period 2020–50 have limited impact on physical risks because these depend upon GHG concentrations that accumulated in the atmosphere during the previous 20–25 years. However, the BoE/PRA made a different choice because it recognised that in the absence of a rapid transition, some physical risks would start to appear before 2050, even if the most material shocks would take place in the second half of the century. Accordingly, to ensure that the scenario captured these future severe risks without lengthening the modelling period, the "no additional policy action" 30–year scenario that runs up to 2050 is calibrated to include the risks anticipated for the period 2050–80 (see Table 3).

BdF/ACPR and BoE/PRA pilot exercises

Comparing scenarios derived from the NGFS — Table 3

Scenarios: common elements	
Orderly transition/ early policy action (reference)	• Early and decisive policy actions • Gradual implementation • Consumers and corporates align behaviours gradually with carbon neutral economy • Orderly pricing of transition by financial markets • Rise in global average temperature less than 2°C but higher physical risk
Disorderly transition/ late reaction/ policy action	• Late and insufficient actions to meet GHG emission targets in 2030 • Harsher actions needed to catch up • Behaviours change as a result of these measures • Sharp repricing of assets with macroeconomic shock • Sharp increase in energy prices – carbon removal technologies less efficient than expected to offset emissions • Rise in average temperature < 2°C but disruption to the economy and higher physical risks
Current policies/ no additional action/ "business as usual" (worst case scenario)	• No new policies • Companies and consumers do not change behaviours • Limited technological transition (carbon removal) • Climate targets not met • Rise in average temperature > 4°C by 2100 • Limited transition risks/no transition • Increase in physical risks (chronic and acute)
BoE/PRA or BdF/ACPR: additional components	
Current policies/ no additional action/ "business as usual" BoE component	Material physical risks between 2050–80 brought forward to 2050
Current policies/ no additional action/ "Business as usual" ACPR component	Measures before 2050 have very little impact on physical risks
Swift and abrupt transition (or "sudden transition") scenario (ACPR only – variant)	• Renewable technology not as mature as in orderly transition • Higher energy prices requiring new investments • Abrupt and unexpected rise in carbon prices as of 2025 • Redirection of investments towards carbon free/renewables • Productivity/supply shock due to higher carbon prices and rise in fossil fuel prices penalises activity • By 2050, production lower, unemployment higher than under the orderly transition scenario • Lower public revenue, higher public expenditure • Rise in temperature < 2°C with economic disruption and higher physical risks

Acronyms:

BdF – Bank of France; ACPR – French Prudential Supervision and Resolution Authority; DNB – Netherlands Bank; BoE – Bank of England; PRA – Prudential Regulation Authority.

Sources: ACPR (2020), Allen et al (2020), BoE (2019c, 2021a).

44. **The DNB's transition stress test, developed prior to the scenarios by the NGFS, used a different approach.** Its scope was limited to transition risks only. It calibrated its scenarios along two dimensions that reflect key aspects of these risks – policy and technology – and used a short-term time horizon of two years. Its "policy shock" scenario is essentially a disorderly transition scenario following delayed policy action. Its "confidence shock" scenario, where corporates and households postpone, respectively, investments and consumption because of uncertainties regarding policy actions and technology, presents some similarities to a "business as usual" scenario. However, its "technology shock" scenario, where the share of renewable energy doubles in five years, and the "double shock", where a technology breakthrough is associated with a delayed policy response, are not covered in the NGFS scenarios.

45. **All three pilot exercises use multiple scenarios**. The respective authorities preferred to specify three to four scenarios. This allows focus on more in depth analysis of the economic and financial impacts of climate risks on specific sectors of the economy, especially for transition risks. It also allows focus on geographical risk differentiation and analysis of differences in the impacts of climate change depending upon the location of the exposed counterparty or asset.

Modelling approaches and methodologies

46. **Both the BdF/ACPR and the BoE/PRA pilots used an Integrated Assessment Model (IAM) to quantify the impact of climate change on macroeconomic variables.** IAMs[35] integrate economics and climate science, and the most comprehensive IAMs also integrate energy systems, changes in land use, agriculture, technology, infrastructure and health.[36] IAMs link the projection of GHG emissions to a corresponding set of carbon prices and derive economic growth impacts.[37] The BdF/ACPR and the BoE/PRA pilots use an IAM model to provide GDP pathways, carbon prices and GHG emissions for the scenarios. These variables are then used as inputs in the macroeconomic model and applied to a number of country blocks.[38] This model is complemented by a sectoral model in order to assess economic impacts on specific sectors (see below in this subsection) and by financial models to assess firm-specific and exposure-specific impacts (see Table 4).

47. **The macroeconomic impacts are modelled in similar ways in the three exercises.** All three exercises used macroeconomic variables (such as GDP, inflation, unemployment and interest rates), and a NiGEM[39] macroeconomic multi-country model. One of the main advantages of such a model is that it allows the determination of economic and financial impacts on banks' international exposures, which represent a large proportion of the respective banking systems' assets in the Netherlands, in France and in the United Kingdom.

48. **An important difference between these pilot exercises is the extent to which they recognise sectoral impact assessments.** In the DNB's energy transition stress test, the sectors are identified

[35] IAMs are only one type of economic model used to assess climate risks, even if they are the most commonly deployed to assess banks' climate risk exposures. A detailed overview and taxonomy of climate economy models can be found in Nikas et al (2019).

[36] For a description of climate change IAMs, see Nordhaus (2017).

[37] For an overview, discussion and comparison of the various types of climate economy models that are used, and their main advantages and limitations, see (BCBS (2021b) and NGFS (2020).

[38] All three pilot exercises use the National Institute Global Econometric Model (NiGEM) macroeconomic model, which breaks down the world into a number of country blocks. For credit risk, the BdF/ACPR pilot requires the modelling of exposures in at least four blocks: France, the European Union excluding France (but including the United Kingdom in this exercise), the United States and the rest of the world. Depending upon the importance of trade relationships, specific economies that are part of the "Rest of the World" (Japan for instance), may be modelled separately (ACPR (2020)).

[39] National Institute Global Econometric Model (NiGEM) includes individual country models for each OECD country as well as for some large emerging market countries (eg India, Brazil or South Africa) with the rest covered as regional blocks.

according to their direct GHG emissions only. In the case of the French pilot, sectoral interdependencies are also accounted for as substitution effects resulting from higher relative prices generated by the implementation of a carbon tax kick in, thus reflecting both direct and substitution effects.[40]

System-wide supervisory stress tests – model

Three examples

Table 4

	BdF/ACPR	DNB	BoE/PRA
Variables developed by industry	No	No	Yes (with exposure-specific variables in the scenarios)
Transition risk shock	Increase in carbon prices and total factor productivity shocks①	Increase in carbon prices; technology shocks, ie a sudden positive supply shock in green energy	Increase in carbon prices and specification of policies on the energy efficiency of buildings and on internal combustion vehicles
Models used to map climate risk factors to macroeconomic variables	IAM② determines carbon price pathways. Prices then used in NiGEM③ to determine GDP impacts (there is a consistency check to align the IAM's GDP projections, NiGEM and the sectoral components)	NiGEM, a multi-country macroeconomic model	IAM determines carbon price pathways. Prices then used in NiGEM to determine GDP impacts (there is a consistency check to align the IAM's GDP projections, NiGEM and the sectoral component)
From macro to sectoral breakdown	Static, multi-country, multi-sector model assesses the impact of carbon prices and productivity shocks on 55 WIOD sectors	Sector vulnerability determined through factors based on embedded CO2 emissions for 56 sectors	Sector vulnerability determined through factors based on embedded CO2 emissions, and on physical risk exposures
From macro/sectoral to financial	BdF's rating model to determine PDs; stock market valuation changes based on computed elasticities of valuations to carbon price changes and on credit spreads	Use of a top-down approach to calculate losses for financial institutions, based on losses in exposures (corporate loans, bonds and equities), with loan losses according to sectoral classification	Modelled by financial institutions, but some reference yield curves are provided by the BoE
Sectoral breakdown	WIOD④ classification	NACE⑤ classification – 56 sectors	SIC⑥ codes

Acronyms:

BdF – Bank of France; ACPR – French Prudential Supervision and Resolution Authority; DNB – Netherlands Bank; BoE – Bank of England; PRA – Prudential Regulation Authority.

① Increases in carbon prices triggers a rise in production costs for businesses and a loss of purchasing power for households, particularly in the two adverse scenarios (late reaction and swift and abrupt transition). In the swift and abrupt transition scenario, the activity is

[40] The sectors that suffer the largest losses under the French pilot exercise are refined petroleum and coke, agriculture and mining. This is mostly because of the additional economic costs imposed through carbon taxation. However, this cost is passed onto the prices of sectoral outputs after allowing for producers in the various sectors to substitute electricity and gas for petroleum. This therefore reflects both the direct effects of carbon taxing – the higher costs related to the direct GHG fossil emissions – and the fact that introducing a carbon tax has indirect effects as it encourages substitution in favour of greener sources of energy.

penalised by both the rise in fossil fuel prices and the adverse productivity shock. This negative supply shock further reduces economic activity while maintaining higher inflation and unemployment than under the reference (orderly transition net zero 2050). ② IAM stands for Integrated Assessment Model because it integrates both economics and climate science variables. The most comprehensive IAMs integrate energy systems, changes in land use, agriculture, technology, infrastructure and health. ③ National Institute Global Econometric Model (NiGEM) includes individual country models for each OECD country as well as for some large emerging market countries (eg India, Brazil or South Africa) with the rest covered as regional blocks. ④ WIOD is short for World Input-Output Database. The classification that is referred to includes 56 sectors classified according to the International Standard Industrial Classification revision four (ISIC rev 4). ⑤ NACE, short for Statistical Classification of Economic Activities in the European Community, is the statistical classification of economic activities and the standard classification system used in the European Union. ⑥ SIC, short for Standard Industrial Classification, refers to four-digit numerical codes that categorise the industries that companies belong to, based on their business activities.

Sources: ACPR (2020, 2021), Allen at el (2020), BoE (2019c, 2020, 2021a,b), Vermeulen et al (2018, 2019).

49. **Sectoral modelling involves downscaling a macroeconomic aggregate, typically GDP, to sector levels where the contribution of each sector to the aggregate becomes the sector's gross value added.** In order to create sector-level impacts, the DNB chose to develop sector-specific "transition vulnerability factors" (TVFs), with the average TVF of the economy (weighted by the value added of each sector) being equal to one.[41] After adjustments reflecting the risk drivers of each scenario, the TVFs are multiplied by the stock prices derived from the macroeconomic model. This produces sectoral stock price impacts that can be used to estimate sectoral losses. The BdF/ACPR exercise identified seven sectors or groups of NACE sectors as being the most sensitive to transition risks. These are the ones whose added value deteriorates the most under the exercise's scenarios.[42] The BoE/PRA pilot also identifies the most exposed sectors by developing vulnerability factors, but these also account for physical risks, and change over time as sectoral emissions profiles change. The vulnerability factors were used to produce gross value added paths for each sector. For transition risks, the analysis includes the sectors relying more on carbon intensive processes. For physical risk, sectors that are highly dependent on physical infrastructure in certain areas may be more vulnerable to it.

50. **Financial risks are modelled in various ways and at varying levels of granularity in the three exercises.** The analysis of the macroeconomic and financial impact via NiGEM is complemented with various in-house financial models, for instance to produce yield curves. For instance, the French pilot exercise used four financial models (see Allen et al (2020)). The first was the central bank's in-house rating model that enables the assessment of credit risk on over a quarter of a million groups and standalone companies in France. The second financial model discounts scenario-based dividend streams, while the third allows for the discount of insurers' liabilities and the fourth projects corporate credit spreads for each of the scenarios. Finally, the BoE/PRA approach defined common sets of assumptions and variables for industry participants to apply to their respective government, corporate and household exposures, including both mortgages and unsecured lending under each scenario.[43]

51. **Both the BdF/ACPR and the BoE/PRA pilots include attempts to combine a sectoral analysis with more granular assessments.** In the BdF/ACPR pilot, the sectoral assessments are

[41] The TVF of each sector is the embodied emissions of a sector relative to its added value. Embodied emissions include all emissions created in the production process of a firm's final goods. See Vermeulen et al (2018).

[42] Mining, quarries and the refining of petroleum products were among the seven sectors that were most vulnerable to transition risk. The pilot exercise also identifies 13 "other sectors of interest" based on their importance in the banks' portfolio and on the fact that the scenarios may not fully reflect their vulnerability to the transition risk scenarios (ACPR (2021)).

[43] For more details on guidelines related to the modelling approaches that industry participants are to follow, see BoE (2019, 2020, 2021b).

complemented to some extent by the ability to use the BdF's rating model[44], and, in particular, by the ability to distinguish the effect of the same impact, within each sector, on investment grade and non-investment grade corporates. The former, because of their stronger economic and financial fundamentals, will be better able to withstand the shocks included in the rating model. In addition, banks were required to conduct a more granular analysis of 15 large counterparties that were deemed to be particularly relevant due to their activities[45] and were common to all banks participating in the exercise. In the BoE/PRA pilot, the minimum expectations for corporate exposures in banks' banking books are that all participating banks should conduct a counterparty-level analysis for their top 100 non-financial exposures. They were also required to conduct a counterparty-level analysis for the three largest companies in each of the sectors most impacted by the scenarios (eg airlines, oil and gas, car manufacturers) if not already in the top 100, and for their five largest financial exposures. Both pilot exercises also contain detailed reporting instructions regarding participants' largest exposures, and allow for some level of extrapolation and portfolio averages for smaller exposures. For instance, in the case of the BoE/PRA pilot[46], information provided on the largest exposures typically included the industrial classification, asset types, country of exposure and the main risks which the counterparty faces (transitional and physical, including the specific physical hazards to which it may be exposed). It also included information on how it may adapt to them or mitigate them, the location of the exposures, participants' views as to how the counterparty's PD is expected to evolve under each scenario and projection period.[47]

Static versus dynamic balance sheet assumptions and reconciliation exercises

52. **Two of the three pilot exercises include elements of a dynamic balance sheet.** The BdF/ACPR pilot combines a static and a dynamic balance sheet assumption. The pilot has a constant balance sheet assumption from 2020–25 to assess banks' short-term vulnerabilities. It also has a dynamic balance sheet feature from 2025–50 upon which participants can reflect their management decisions and adjust their exposures to the climate change scenarios. However, to limit the burden on banks, the integration of management actions takes place at five-year intervals. The BoE/PRA exercise allows for a second round of submissions to allow participants to include management actions. The exact modalities are still to be determined since, "a decision on the form and content of this second round will be based on analysis of participants' initial submissions. The second round could focus, for example, on exploring particular potential interactions between participants' responses" (BoE, 2021b). In both pilots therefore, participants' ability to take corrective and mitigating actions that reduce their exposure to climate-related risks may be only partially reflected, as the management actions are only reflected at specified periods.

53. **The BdF/ACPR and the BoE/PRA pilots include reconciliation exercises conducted by the authorities.** The purpose is to ensure consistency between the sum of all individual submissions from banks with the system-wide impact of the climate stress on both banks and insurance firms. One objective of such reconciliation exercises is to ensure that banks' individual assumptions regarding credit protection provided by insurance firms are realistic in aggregate.

[44] BdF's rating model assesses over a quarter of a million groups and standalone non-financial companies yearly. The central bank is recognised as an external credit assessment institution. Its rating system qualifies as an eligible credit risk assessment system and its ratings can be used to determine minimum capital requirements under the Basel framework.

[45] The firms and groups included are active in some of the sectors that are the most exposed to transition risks and include oil companies, power generation, mining companies and commodity trading.

[46] For an example and more details on the information required for each asset class under the BoE/PRA scenario, see in particular BoE (2021b).

[47] For all other corporate exposures under the BoE/PRA pilot, some level of extrapolation and portfolio analysis is expected, possibly with exposures split into segments of corporates facing similar risks. A sample of the corporates within each segment may then be subject to further analysis with the findings then extrapolated to the rest of the segment. Portfolio modelling is also permitted for smaller exposures, such as SMEs.

Outcomes – results and communication

54. **In line with the objectives of these exercises, results are not used to set firm-specific capital requirements**. While the United Kingdom exercise will only be completed in 2022, it can already be said that none of the three pilots is intended to quantify bank-level solvency ratios as an outcome. Even the Dutch exercise, which produces an estimate of the possible reduction in capital ratios across the sample of banks, assesses the system's overall vulnerability rather than determining bank-specific requirements. In particular, the results are reported only at the aggregate level, and there is no discussion of firm-specific remedial actions.

55. **The key outcome of these exercises is to provide a first assessment of risks, exposures and vulnerabilities to which participating institutions are exposed.** Considering that these initial exercises are primarily a learning opportunity for banks and the authorities, the most relevant metric in terms of outcome is a quantification of the relevant exposures (see Table 5). This measure can guide banks in rebalancing their exposures, and/or adjust their risk management accordingly. Specifically, ACPR, when presenting the results of its pilot, underlines that "the exercise thus offered financial institutions the possibility of assessing their corrective actions (eg exit from certain sectors), thanks to the dynamic balance sheet hypothesis, and of taking new risks into consideration." (ACPR, 2021). For the authorities, a better grasp of the potential losses at individual banks, and in aggregate, can help them gauge the financial stability implications of climate risk.

56. **Given the high-level of uncertainty, authorities have not made firm-level disclosures.** In the Dutch exercise, only aggregate results were disclosed. Similarly, only aggregate information derived from the BdF/ACPR exercise has been published. In the same vein, the results of the BoE/PRA pilot are not expected to include the disclosures of any specific firm balances. In all cases, transparency about potential long-term losses could be questionable and possibly counterproductive, given the very high level of uncertainty surrounding the estimates and the risk that these could cause adverse reactions from market participants or even trigger market turmoil. Aggregate disclosures would however be helpful on a system-wide level, if only to provide some indication about the overall size of the risks. Such disclosures would also help in fostering further efforts to respond to financial risks arising from climate-related events. Communication of individual results to the bank itself, however, would be helpful to provide it with a benchmark for its own calculation of climate risk and for future in-house exercises it may run.

System-wide supervisory stress tests – output

Three examples Table 5

	BdF/ACPR	DNB	BoE/PRA
Target variable	Banks: asset side losses (credit, counterparty credit and market risks) Insurers: asset values and liabilities	Asset-side losses	Banks: credit book impairments Insurers: value changes in assets and liabilities
Timeframe for impact assessment	Periods during which the scenario variability is highest, ie 2025, 2035, 2040, 2050	Once (at end of five year horizon)	Every five years over the time horizon
Output breakdown	Geographical, sectoral, key counterparties (top 15)	Range of losses in the three industries (banks, insurers, pension funds – CET1 impact for banks)	Geographical, sectoral. key exposures (top 100)
Management actions considered	Yes (via dynamic balance sheet)	No	Yes
Reconciliation exercise	Yes	No	Yes, in a separate qualitative questionnaire
Communication of results	BdF/ACPR disclose system-wide results and providing feedback to individual firms	DNB published estimate of impact (aggregate CET1 changes) on Dutch financial sector	BoE discloses system-wide results and providing feedback to individual firms

Acronyms:

BdF – Bank of France; ACPR – French Prudential Supervision and Resolution Authority; DNB – Netherlands Bank; BoE – Bank of England; PRA – Prudential Regulation Authority.

Sources: ACPR (2020, 2021), Allen at el (2020), BoE (2019c, 2020, 2021a,b), Vermeulen et al (2018, 2019).

57. **The outcome of the BdF/ACPR pilot for banks illustrates that exposures and vulnerabilities, even when "moderate", can be far from negligible.** With 50% of their exposures in France and another 25% in other European countries, the pilot finds that French financial institutions are relatively less affected by transition risks than if their exposures had been concentrated in other geographical areas. However, the exercise also shows that impacts for certain sectors and geographical areas can be considerable. In particular, the cost of credit risk for the seven most sensitive sectors could triple, with the possibility that such an evolution may even be understated because none of the scenarios up to 2050 consider an economic recession. The outcomes for physical risks are somewhat similar. While the country as a whole is relatively spared,[48] specific types of climate events (droughts and floods in mainland France and cyclones in the French Caribbean) could see the cost of claims (and therefore of insurance premiums) rise by a factor of five or six in specific regions by 2050.

58. **The impact of the Dutch pilot for banks is also significant, especially under the most severe scenario.** In the worst case scenario, there would be both a sharp and global rise in carbon prices due to strong and abrupt policy measures and a doubling of the share of renewables in the energy mix within five years as a result of technological breakthroughs. These combined shocks could result in overall losses of up to 3% of banks' total stressed assets, with this representing slightly more than 4% of the Common Equity Tier 1 ratio of Dutch banks.

[48] This conclusion, and the similar one reached for transition risks – that countries benefiting from moderate climates will generally be less affected than those subject to tropical climates - confirms a finding included in BCBS (2021a,b).

Section 4 – Concluding remarks

59. **The use of stress tests is an important step forward to measure the impact of climate risks on banks.** Stress tests are useful for sizing potential impacts of climate risks, even if only imperfectly. This is because they are forward-looking and can be used to inform business decisions. While there are currently limits to quantifying the impact of climate risk, the ability to reliably measure climate-related exposures and their potential losses is essential to promote efficient risk management, and the safety and soundness of the financial system. Pilot stress test exercises should be seen as a first key step towards that goal.

60. **Authorities and banks are incrementally building up expertise by conducting more climate stress tests.** Various climate-related stress testing exercises are taking place or have been announced for the near future, while past exercises are to be repeated. This is the case, for instance, for the BdF/ACPR exercise, which is expected to take place regularly, with the next iteration possibly taking place in 2023/24. Forthcoming exercises are building upon previous findings and seek to improve on past exercises and address limitations, such as the need to better integrate the physical risk component into exercises that focus on transition risks.

61. **Methodological changes are, however, needed to make stress tests better suited for climate risks**. Data issues need to be addressed through targeted data collection efforts and increased granularity to address geographical and sectoral risk concentrations. Refinements in modelling approaches to better integrate physical risks and to deal with long time horizons are needed. Enhancements to the ways in which climate scenarios translate into macroeconomic and financial variables, possibly including second round effects, are also important to improve reliability. Stress tests have so far focused on credit risk and on corporate and residential mortgage loans in particular. Climate change impacts on other credit risk exposures and on market, liquidity or operational risk remain largely unstudied, prompting the BCBS to call for more efforts and research (BCBS (2021a,b)).

62. **Given the early stages, there are not yet well established, common practices for banks' climate risk stress testing across countries**. Each exercise therefore tends to be somewhat ad hoc, and such tailoring may be helpful to cover unique aspects in each country. The independent development of different approaches may also foster innovation in this new field. However, there may also be benefits in developing some commonality in approach, or at least common principles in order to obtain some comparability. This may also be welcomed by the industry in order to avoid situations in which international banks are required to undertake parallel exercises with possibly inconsistent methodologies.

63. **Regulatory implications of climate risk stress tests are yet to be defined**. The important differences between climate risk stress tests and traditional, solvency focused stress tests have a bearing on the policy implications of these exercises. In particular, the issue is whether the climate stress tests are suitable as a basis for any quantitative requirements or whether they are better suited as a trigger for targeted discussions between supervisors and financial firms. In addition, and notwithstanding considerable efforts over the past years and the guidance by the NGFS, scenario design for climate risk remains a major challenge.

64. **Using stress tests to adjust banks' strategies is important for both banks and regulators**. Stress testing by a bank will bring strategic implications related to climate change to the attention of senior management and the board of directors. Concrete examples of such implications may lead to reviewing exposures and possibly reducing them with regard to certain sectors or geographical areas. They could also lead to exiting certain activities altogether if the climate-related risks involved are deemed to be too high, or impossible to assess with sufficient accuracy or to mitigate adequately.

65. **Climate stress tests may be included in yearly supervisory reviews**. At a minimum, climate stress test exercises, and the ways in which a bank acts on their outcomes, can inform discussions with its supervisor regarding its business model, its internal governance and its risk management. Ensuring that a

bank's management develops a long-term strategy so that its business model evolves as whole economies transition to lower carbon economies is likely to become a key supervisory priority in the near future. These exercises can help ensure a bank's long-term viability and the sustainability of its activities.

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