STAFF
CLIMATE
NOTES

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Summary

Climate change presents risks and opportunities for the real economies and financial sectors of the IMF's global membership. Understanding the risks is key to prepare for a successful transition to a lower carbon global economy. This will unlock the many opportunities for technological progress and structural transformation along the path that financial sectors around the world will need to adapt to and support. This note lays out the IMF staff's emerging approach to assessing the impact of climate change on banking sector stability risks conducted in the context of the IMF Financial Sector Assessment Program (FSAP). The note starts with a primer on climate change risk, both transition and physical, explaining some of the technical terms and concepts used in this work. It explains the approach to standard risk analysis in FSAPs and how this would be modified in broad terms to incorporate climate risk. The note then discusses different approaches to the analysis of physical versus transition risk, their implications for the macro-economy and across sectors in the real economy and different geographies, and how all these effects map into the banking sector. The note illustrates concepts with examples of applications from recent FSAPs and takes note of the many challenges confronting this work, including data gaps and uncertainty regarding climate projections and long simulation horizons in conducting the climate risk analysis. As such the note is focused on methods that IMF staff are deploying to raise awareness of the risks, and adaptation needs, including need for banks to develop tools to manage climate risks and for financial sector supervisory authorities to identify pressure points in the financial system adequately respond and supervise this risk.

INTRODUCTION

Climate change is already having significant impact on the global economy. The Intergovernmental Panel on Climate Change (IPCC), a body of the UN responsible for advancing knowledge on human-induced climate change, argues that human-induced climate change, including more frequent and intense extreme events, has caused widespread adverse impacts and related losses and damages to nature and people, beyond natural climate variability (IPCC 2022).

Countries need effective policies to manage the risks and harness the opportunities from climate change. Climate change poses risks to economic and financial stability, but also presents opportunities for growth and job creation offered by the transition to a greener economy. Working with member countries, the IMF is helping them to develop tools to identify, assess and respond to the risks related to climate change, as a crucial input to gauging how to manage them. A key pillar of this work involves engagement with member countries seeking to understand the policy implications of climate risk for their jurisdictions by evaluating the magnitude of risk and potential pressure points for the financial system due to physical climate shocks and in the transition to a low-carbon economy.

Economic and financial analysis of the impact of climate change can raise awareness of the risk, and adaptation needs and opportunities. These include the need for banks to develop tools to manage climate risks and for financial sector supervisory authorities to adequately supervise this risk. This would potentially drive gradual early adjustment and help inform policies needed to enhance risk management and the resilience of the financial system. The analysis and assessment of the financial stability risks from climate change would also help inform broader core activities of the IMF, including on surveillance and capacity development.

Climate risk analysis considered by IMF staff is not a standard stress test. In a standard stress test, the analysis assesses bank resilience based on pass-fail criteria regarding whether capital falls below given regulatory minima. Standard stress tests are based on well-established historical relationships between macro-financial stress and outcomes for bank and systemwide capital and liquidity. They also draw on scenarios that are judged to be plausible based on historical experience. Unlike conventional stress testing, climate risk analysis is not currently focused on quantifying possible capital needs of financial institutions relative to regulatory minimum requirements. This is due to various challenges, but mainly uncertainty regarding climate modeling and long simulation horizons in conducting the climate risk analysis. The largest consequences of climate physical risk, at the global level, are expected to emerge over a 30–80-year horizon. However, material risks could arise even over shorter horizons given rising incidence and impact of extreme events, sizable uncertainty over modeling, and the fact that individual, less geographically diversified countries may face particularly acute risks. Moreover, risks arise that the market valuation of companies, and thus banks, in the near term could be materially impacted as markets are increasingly able to price in, up-front, the effects of longer-term risks on prospective cashflows of businesses. These issues are elaborated upon later in the note.

The focus of this note, at this early stage, is on the methodologies. The note starts with a primer on climate change risk, both transition and physical, explaining some of the technical terms and concepts used in this work. It explains the approach to standard risk analysis in FSAPs, and how this would be modified in broad terms to incorporate climate risk. The note then discusses different approaches to the analysis of physical versus transition risk, their implications for the macro-economy and across sectors in the real economy and different geographies, and how all these effects map into the banking sector. The note illustrates concepts with examples of applications from recent FSAPs and takes note of the many challenges confronting this work, including data gaps and uncertainty regarding climate projections and long simulation horizons in conducting the climate risk analysis. As such the note is focused on methods that IMF staff are deploying to raise awareness of the risks, and adaptation needs, including the need for banks to develop tools to manage climate risks and for financial sector supervisory authorities to adequately supervise this risk.

CONTEXT

The IMF's increased focus on climate risk analysis has been contextualized and discussed extensively in reports to its Executive Board. These include the recommendations of the 2021 Comprehensive Surveillance Review (CSR, IMF (2021d)), the 2021 FSAP Review (IMF, 2021g), and the action plan laid out in the 2021 IMF Climate Strategy (IMF, 2021h). The CSR and FSAP Review called for a more systematic integration of climate change into the IMF's surveillance, recognizing its significant macroeconomic and financial implications. The reviews emphasize the need for identifying the channels through which climate change may impact macrofinancial stability and of using longer time horizons in making those assessments.

The 2021 IMF Climate Strategy presented a road map for acting on the recommendations of the CSR and FSAP reviews. The Strategy highlighted areas for further development of the IMF's surveillance including: (1) expanding coverage of climate risk mitigation and transition in surveillance; (2) deepening coverage of adaptation and resilience building; (3) strengthening staff resources to engage on climate change analysis, including by internal and external upskilling; (4) building departmental climate hubs with workplans to foster learning and development of climate analysis; (5) enhancing collaboration with other international institutions; and (6) strengthening capacity development support on climate change.

In this context, the IMF has started implementing a work plan to incorporate climate change considerations in risk analysis, regulation and supervision, and monetary policy operations. The IMF is working closely with international organizations on various climate issues spanning climate risk analysis (World Bank), supervision (World Bank and standards setters), and Principles of classification and nomenclatures (OECD, World Bank) among other topics. The IMF is closely involved in the work of the Network for Greening the Financial System (NGFS), a coalition of central banks working to understand the implications of climate change for the financial sector, by co-leading the workstream on climate risk disclosure and is closely engaged in the workstreams on scenario design and analysis, supervision, and data. The IMF is enhancing its capacities to analyze different aspects of the impact of climate change on the financial sector (IMF 2021b, 2021c) and implementing steps to offer capacity development support on climate risk analysis and supervision of climate risk. The integration of climate risk analysis work in the FSAP, the premier instrument for the IMF to assess risks to financial systems and policies to mitigate and manage these risks (Annex 1), is a key component of the strategy and the focus of this note.

APPROACH TO CLIMATE RISK ANALYSIS IN FSAPs

Climate risk analysis requires assumptions on the potential future paths for global emissions of greenhouse gases—and thus temperatures—and their effects. These are dependent on many factors, not least policies to reduce emissions, develop new technologies, and foster adaptation and resilience to the effects of climate change.

Significant international effort has been made to develop scenarios for how global climate could change. These scenarios are typically based on different possible pathways for emissions of greenhouse gases and associated changes in global temperatures. Commonly used reference scenarios for future paths of emissions and temperatures are those used by the IPCC, which are based on so-called Representative Concentration Pathways (RCPs). These describe paths for future levels of greenhouse gases[1] (covering radiative forcing of 2.6, 4.5, 6.0, and 8.5 watts per meter squared by 2100), and Shared Socioeconomic Pathways (SSPs), which look at five different scenarios for how socioeconomic systems around the world might evolve in the absence of policy changes to mitigate climate change.[2] The resulting temperature scenarios are illustrated in Figure 1 (see IPCC, 2021, for more details).

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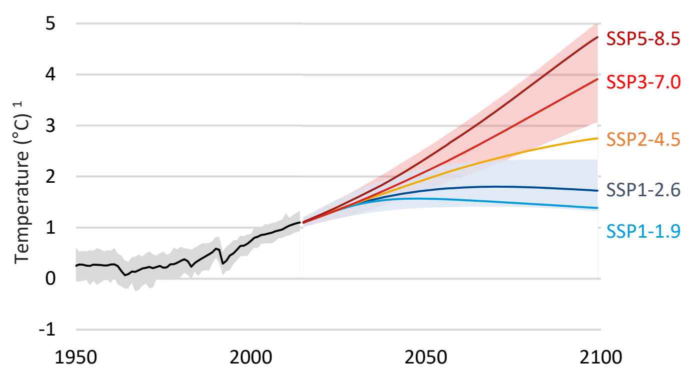
[1] According to NASA, by volume, the dry air in Earth's atmosphere is about 78.09 percent nitrogen, 20.95 percent oxygen, and 0.93 percent argon. A brew of trace gases accounts for the other 0.03 percent, including the greenhouse gases carbon dioxide, methane, nitrous oxide, and ozone. Greenhouse gases in the Earth's atmosphere trap warmth from the sun and make life possible. An overabundance of greenhouse gases leads to a rise in global temperatures—known as the greenhouse effect.

[2] The SSPs lay out high-level assumptions on the evolution of the level and structure of economic activity and distribution of human populations among other variables, as the world experiences climate change. The RCP pathways measure how concentrations of greenhouse gases in the atmosphere will change in the future as a result of human activities, expressed in watts per meter squared. SSP-based scenarios are referred to as SSP*x*–*y*, where SSPx refers to the Shared Socioeconomic Pathway describing

Physical and transition risks

It is common to distinguish between physical and transition climate risks (Annex 2). The IPCC (2021) provided an updated analysis in 2021[3] on the outlook for climate change and physical risk. In its report, it was noted that many changes in the climate system are becoming larger (increases in the frequency and intensity of hazards) in direct relation to increasing global warming giving rise to *physical risks*—risks arising from physical impact of climate change. In addition, low-likelihood, high-impact outcomes, such as ice-sheet collapse, abrupt ocean circulation changes, and global warming at rates substantially larger than previous model pathways cannot be ruled out. There is a high level of confidence that these low-likelihood outcomes would "worsen" throughout the 21st century, with a medium level of confidence of their exact magnitude. So-called general circulation models (GCMs) developed by climate scientists simulate the response of the global climate system and different indicators of climate change to increasing greenhouse gas concentrations under the reference scenarios. Specific hazards' models (for example, hydrological models to analyze floods) build on GCMs[4] to project the frequency and intensity of hazards (essentially damaging climate related events such as storms and floods, etc., Table 1), grouped in different categories. Furthermore, limiting human-induced global warming requires limiting cumulative CO_2 emissions. This gives rise to the *transition risks,* that is, those resulting from policy, technology, legal, and market changes that occur during the move to a low-carbon economy. Transition risks include assets becoming stranded, reputational damage, and financial distress of polluters. Underlying global climate change scenarios is that the larger are the policy steps taken to reduce the carbon intensity of economic activity, the lesser will be the rise in temperatures. As such, there are trade-offs between the economic and financial effects arising from: (1) the physical impacts of continued temperature rise versus (2) policies to mitigate temperature rise.

Figure 1. Emissions and Temperature Scenarios Used by the IPCC



Source: IPCC, 2021 Summary for Policymakers.
[1] Global surface temperature change; increase relative to the period

Table 1. Physical Risk Hazards, Indicators

Heat and Cold	Wet and dry	Wind	Shown and Ice	Coastal	Open ocean
Mean air temperature	Mean precipitation	Severe wind strom	Snow, glacier and ice sheet	Costal flood	Ocean chemistry
Extreme heat	Heavy precipitation	Mean wind speed		Sea level	Marine heatwave
Frost	River floods				Mean ocean temperature
	Aridity				
	Drought				
	Fire				

Source: Adapted from EEA (2021).

the socioeconomic trends underlying the scenarios, and y refers to the level of radiative forcing (in watts per square meter, or W m-2) resulting from the scenario in the year 2100 (IPCC 2022). See also Bellon and Massetti (2022).

[3] See IPCC (2021).

[4] See IPCC, which notes that General Circulation Models or GCMs, representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. While simpler models have also been used to provide globally or regionally averaged estimates of the climate response, only GCMs, possibly in conjunction with nested regional models, have the potential to provide geographically and physically consistent estimates of regional climate change which are required in impact analysis.

Recognizing the complexity of this analysis and the importance of common starting points to illustrate the benefits of joint action, central banks around the world joined in 2019 to establish the **Network for Greening the Financial System (NGFS).** This network comprises 105 central banks and supervisors from advanced, emerging, and developing economies that are focusing on the need for (1) common and improved disclosure of climate risks, (2) developing reference scenarios and guidance on integration of climate risk analysis into macroeconomic and financial stability surveillance, (3) adapting supervisory and regulatory frameworks to address financial sector risks posed by climate change, and (4) broader collection of climate risk data. Our climate risk analysis framework is closely connected with the work of NGFS and its scenarios that build on IPCC's scenarios, with efforts to look at shorter term horizons and country specificities of the IMF's diverse membership.

Starting point: Standard FSAP risk analysis

FSAP risk analysis typically entails the development of scenario-based stress tests for assessing bank solvency and liquidity. FSAP stress tests are top-down exercises run by IMF teams, typically on bank level data with some degree of sectoral break-down. The most basic component of an FSAP stress test is top-down solvency analysis.[5] The solvency stress testing methodology assesses credit, market, interest, and FX risks and their impact on bank profitability and capitalization over a 3–5 year stress testing horizon.

The process starts by using different macroeconomic modeling frameworks to design adverse macroeconomic scenarios. These scenarios are based on the narrative of risks included in a Risk Assessment Matrix (RAM), and typically characterized by negative GDP growth, rising unemployment, balance of payment and exchange rate shocks, and falling asset prices.

These adverse scenarios are then used as input into country-specific estimated relationships between macro drivers and risk factors (such as credit risk, interest income, etc.) based on their historical relationship, to generate impacts on bank income and capital. Uncertainty over the "true" model linking macro drivers and financial sector risks and variables can generally be controlled for (for example, using methods such as Bayesian Model Averaging (Raftery 1995, Hoeting and others 1999, and Viallefont and others 2001, Gross and Población, 2019). The assessment of bank resilience is then based on whether bank capital falls below certain regulatory thresholds (so-called "hurdle rates") conditional on the macro-financial scenarios.

In some cases, granular data for individual corporate and household balance sheets are available and can be used in the solvency analysis. In this case, in addition to modelling risks at a more aggregated top-down level, the impact of adverse scenarios is assessed using corporate and households' micro data (Gross and Población 2017, Gross and others forthcoming). Such a micro analysis provides a more granular perspective which can be important in identifying threshold effects.

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[5] FSAPs often add other dimensions of systemic risk analysis including on contagion, interconnectedness, systemic liquidity, etc. In recent years, the perimeter of analysis has been expanding beyond banks to encompass other financial institutions and market infrastructures.

Incorporating a climate risk analysis module

The first step in the climate risk analysis is to assess which climate risks and hazards are the most relevant for the country under consideration. This assessment is based on a climate risk assessment matrix (C-RAM) that IMF staff compile based on aggregate climate risk metrics that can be derived from a variety of sources for transition risk (carbon tax gap, share of the carbon-intense industry, etc.) and physical risk (change in hazards' projections relative to history, damages due to different hazards, etc.). These metrics are used to identify which risk is relevant and material, following which a narrative of the risk and transmission channels is described. For a country where climate risks are important, two additional steps are added to the bank solvency stress testing framework to incorporate physical and transition risk:

(1) **Temperature and emissions scenarios.** These scenarios present the starting point of the analysis and are taken from the IPCC/NGFS.

(2) "**Climate" scenarios.** A design of climate scenarios entails mapping emissions and temperature scenarios into the evolution of physical risks (that is, projections of frequency and severity of relevant hazards) and transition risks (that is, pathways for carbon taxes).

To map climate scenarios into the resiliency of banks, two approaches could be used depending on the level of data granularity. A *macro approach* could be used to map climate scenarios into macro and sectoral scenarios and use the standard stress testing methodologies to assess the implications of climate risks for the banking system's resiliency.[6] If more granular data are available, a preferable, *micro-macro approach* focusing on borrower-level (corporates and households) assessments and their implications for banks can be considered. The additional micro granularity is valuable in the context of climate risk analysis, as discussed below.

Design and implementation challenges

There are several challenges in designing and implementing climate risk analysis.

- Climate change is a long-term phenomenon where the largest consequences of physical risk and the benefits of policy actions are typically judged to emerge over a 30- to 80-year horizon, well beyond the conventional 3- to 5-year horizon typically considered for risk analysis in FSAPs and other stress testing exercises. However, in conducting the stress tests, staff consider both the conventional and longer-term horizons given sizable uncertainty over modeling and policies. Among these are the increasing likelihood that the realization of long-term costs (including from stranded assets) could feed back into shorter-term horizons via a reassessment of market valuation of companies and thus banks. However, long time horizons come with high uncertainty about how policy and socio-economic factors might evolve. There is also a very wide range of climate models to choose from giving rise to sizable model uncertainty. Inherent uncertainty in modeling increases with the complexity of the system. This generates higher-than-typical uncertainty regarding projections of emissions and temperature. As such, there are many pathways for emissions and temperatures with high levels of uncertainty around them, though the general tendency is for a clear increase in temperatures without policy action to decarbonize.

- Modeling macroeconomic outcomes of physical and transition risk is complex. Challenges include (1) translating the impact of transition policies into macroeconomic and sectoral outcomes; this requires

[6] See Aligishiev, Bellon, and Massetti (2022) for a comprehensive overview of models that could be used to assess the impact of climate shocks on macroeconomic variables.

combining macro and sectoral models and modeling changes in the structure of the economy due to transition—something we do not observe in the historical data over the short term—while the timelines and magnitudes of transition policies may shift, including as unexpected physical risks emerge, new technologies are developed, or in response to other shocks. Moreover, the framework does not fully take into account adaptation to changing climate conditions, which is relevant in the long run as ongoing adaptation will reduce exposure and vulnerability to climate change.[7] This endogenous reaction to climate change is very difficult to fully model and is one of the areas requiring further work; and (2) designing credible macro scenarios due to physical and transition shocks over a long horizon of up to 80 years.

- Bank risk analysis or stress testing often makes the simplifying assumption that the structure of bank balance sheets does not change over time (for example, the “static” balance sheet assumption). This assumption is particularly problematic in the case of assessing climate change considering the long horizons of the analysis over which it could reasonably be expected that there will be significant structural changes to economies and banking systems.

- Assessment of projections of physical risk models and their calibration requires special scientific expertise. History provides little guidance and extreme events cannot be ruled out over the near/medium term as the distribution of such events is likely shifting over time, with nonlinear threshold effects and tipping points of uncertain timing and possibly systemic impact.

- Climate risk analysis puts a premium on granular data, arguably even relative to standard stress testing, given the sectoral and geographical specificity of climate risks—physical risk exposure is highly location specific, while carbon exposures vary significantly at the firm level. But disclosure of transition risk exposures is limited, modeling projections of both risks is highly uncertain, with major work remaining on estimating damages from physical risks. And hazards data in a user-friendly format are expensive.

- Finally, physical and transition risks—currently analyzed separately due to complexities of analysis in each case—should in principle be jointly analyzed within one framework since the risks are interconnected. For example, higher carbon taxes and lower carbon emissions will increase transition risk but will have positive consequences on climate change (lower physical risk).

While scenario analysis offers a “what-if” framework that is suitable to deal with uncertainty about future climate and policy events over a long horizon, it is important to note that the methodologies presented here are still work in progress.

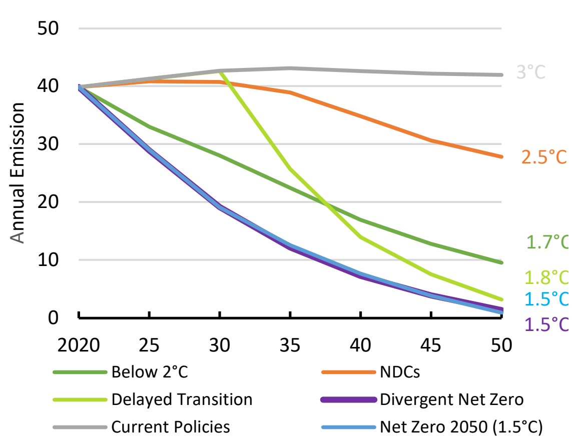
[7] See Aligishiev, Bellon, and Massetti (2022) for an overview of models that could be used to model adaptation.

DIFFERING APPROACHES TO PHYSICAL AND TRANSITION RISK ANALYSIS

Temperature and emissions scenarios

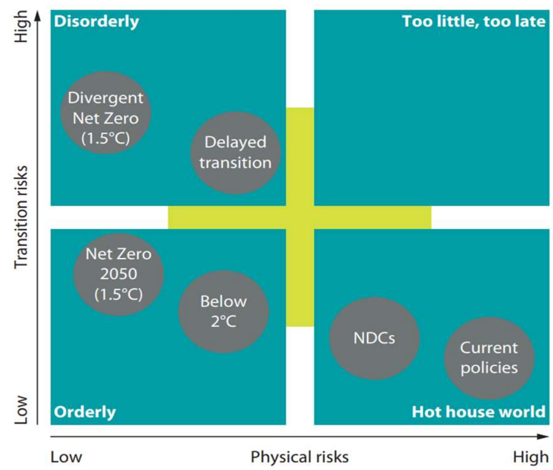
FSAP teams are generally seeking to use, as a starting point for their analysis, the NGFS reference scenarios for emissions and temperature, and the concomitant pathways developed for both physical and transition risk (see NGFS 2021b for more details). The NGFS emissions and temperature scenarios (Figure 2) draw primarily on IPCC emissions pathways for the period up to 2100 and projections for consequent climate impacts—and combines them with pathways for GDP, population, and the urbanization rate--to help contextualize the setting of each emissions pathway. The scenarios also make a range of assumptions about how technology evolves.

Figure 2. CO_2 Emission by Scenario



Source: IISAS NGFS Climate Scenarios Database, REMIND model.
Note: NDCs = nationally determined contributions.

Figure 3. NGFS Scenarios Framework



Source: NGFS Climate Scenarios for Central Banks and Supervisors, 2021.

Currently, six global scenarios have been published by the NGFS, divided in three clusters (Figure 3). Each scenario is characterized by paths for emissions, temperatures, and carbon taxes. Physical and transition risk are seen as interconnected—strong and immediate policy action would raise near term transitions risk but limit physical risk; by contrast, delayed and weak action would lead to higher physical risk, lower transition risk today but even larger transition risk in the future. The scenario clusters include:

- **Orderly transition.** Climate policies are introduced early and become gradually more stringent, consistent with the Paris Agreement. Both physical and transition risks are relatively subdued. This cluster includes two scenarios: (1) a scenario that limits global warming to 1.5°C by the end of the century relative to pre-industrial level through stringent climate policies and innovation, reaching global net zero CO2 emissions about 2050 and (2) a scenario that gradually increases the stringency of climate policies, giving a 67 percent chance of limiting global warming to below 2°C.

- **Disorderly transition.** These scenarios involve higher transition risk due to delayed or divergent policies (for example, carbon prices increase abruptly after a period of delay and not all countries follow their Paris commitments).

- **Hot house world.** These scenarios assume that current climate policies are maintained resulting in high levels of emissions such that the global temperature rise exceeds 3°C by the end of the century.

There is no or limited transition risk, but physical risk is severe. The nationally determined contributions (NDCs) scenario, which falls under this cluster, includes all pledged policies even if not yet implemented.

Physical risk analysis

After having explained how general bank stress testing frameworks are designed and then adapted to the needs of climate change risk analysis, we now explain in greater detail the specifics of the approaches to assessing physical and transition risk.

Our physical risk framework seeks to assess the impact of climate change on the economy and the banking sector for countries where physical risk is relevant. A changing climate leads to changes in the frequency and intensity, of weather and climate extremes, and can result in unprecedented extremes. These hazards cause damages to physical assets, markets, and productivity that in turn can affect the resilience of the banking sector.

We focus on both long-term horizons spanning up to 2100, but also the standard FSAP horizon of 3 to 5 years. Both long- and near-term analysis are challenging. The long-term analysis uses distributions of projections of hazards for shock calibration and assumes static balance sheets. This latter assumption is particularly unsatisfactory in the face of structural change engendered by the response to climate change, but alternative approaches are not currently feasible. Shorter horizons are considered due to the possibility of extreme events happening over the near term and the fact that low-likelihood outcomes, and global warming at rates substantially larger than expected pathways cannot be ruled out. To account for this uncertainty over the magnitude of the shock, the projected distribution of some hazards over a long term could possibly be used to calibrate a severe climate-related shock over the near term. An alternative is to pick a point on the tail of the distribution of physical risk hazards from the recent history, though this could understate the effect of climate change and possible non-linearities.

We start with NGFS temperature and emissions scenarios, discussed in the previous section, that will affect projections of frequency and intensity of relevant hazards for a specific location. Data for hazards' projections are obtained from private vendors or, in some cases, from country authorities. Typical hazards include precipitation, cyclones, floods, droughts, wildfires and heatwaves, and chronic physical risk (for example, sea level rise). These projections are aligned with NGFS scenarios. It is possible to obtain both country-level aggregate risk indicators that can be used to construct a heat map for a country-specific climate risk assessment matrix, and location-specific (that is, latitude and longitudes) granular data for the frequency and intensity of individual hazards, integrated with individual corporate data.

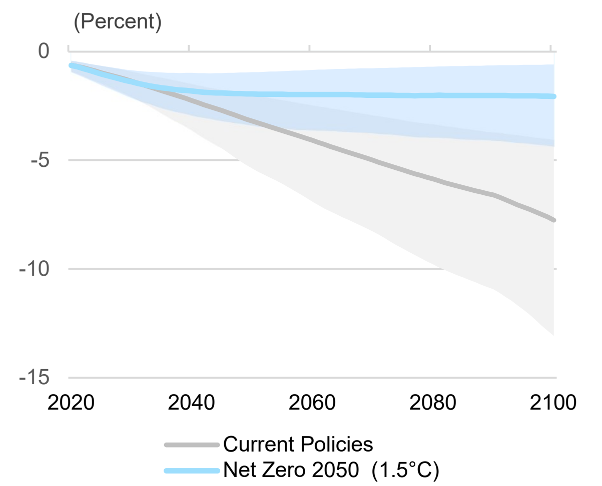
The next step is to estimate the impact of projected hazards in terms of their damages and productivity and assess, in turn, the effects on bank stability. Damages can be estimated for individual corporates or households and then linked to banks' balance sheets when data on exposures is available. In many cases we are seeking to leverage World Bank staffs experience on catastrophe modeling to estimate damages. Damages can also be aggregated at country-level and used as an input (for example, capital and productivity shocks) in macro models to generate macrofinancial scenarios accounting for losses from climate risk. A macrofinancial scenario is then used to estimate the impact on bank solvency using the standard approach for banks' stress tests.

Estimating damages

The damages generated by individual hazards (for example, the degree of capital stock destruction and/or productivity loss from a heat wave) are the key variables that link climate science with finance and economics. Damages from physical risks arise as the interaction of three components: the projections of individual hazards, the exposure of economic agents to these hazards, and their resulting vulnerability in the event the hazard materializes. There is no comprehensive public data set on damages and these granular data are only available, at a very high cost, from firms that specialize in catastrophe (CAT) modeling (CAT models were originally developed for property insurers to help manage rare disaster risks) or from the authorities, if they are available.

The approach to estimating damages from physical risks currently developed by the NGFS consortium is focused on chronic risk and based on top-down, country-level empirical relationships between GDP and temperature as a high-level approximation of the economic impacts of temperature scenarios that underlie hazard projections and their damages (Figure 4). GDP losses are calculated based on the methodology set out in Kalkuhl and Wenz (2020) at the country level for the change in *average* temperature in each RCP scenario. Estimates suggest a global GDP impact of up to 13 percent in the current policies scenario relative to a scenario with no additional warming. Resulting damages representing the impacts from chronic climate change are then exogenously introduced into the National Institute's Global Econometric Model (NiGEM—proposed by the NGFS) as a shock to capacity to generate other macro and financial variables for use in stress testing.

Figure 4. Physical Risk—Global GDP Losses

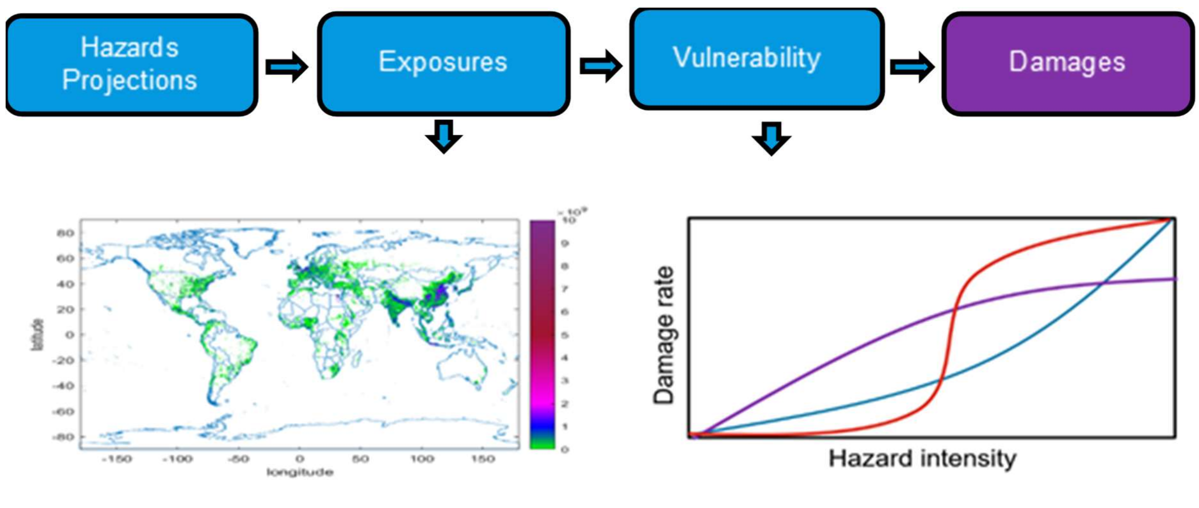


Source: IISAS NGFS Climate Scenarios Database, REMIND model.

The NGFS (2020) notes two main concerns with the current approach. First, historical trends may not hold in the future due to socio-economic changes, or because of potential structural breaks when a particular threshold is reached (for example, labor productivity drops off sharply above a given level of climate change). Second, macro-econometric approaches may still not capture all relevant transmission channels and risks such as low-probability high-impact events, sea-level rise, and extreme events. As a result, actual damages under these scenarios are expected to be larger than shown. As such, the NGFS is moving toward assessments of direct damages for acute risks only (currently available for tropical cyclone and floods), but the current approach remains in use as granular data on damages for all hazards are not publicly available.

Staff are also seeking to develop bottom-up methodologies to assess damages in a consistent manner for different hazards across countries which would then be used to calibrate macro models to assess the macro impact (Figure 5). This approach is similar to the NGFS approach on estimating damages due to cyclones and floods and approaches used by the Banque de France (ACPR 2021) and the Australian Prudential Regulation Authority (APRA 2021). Estimating damages entails linking projections of hazards to the exposures (that is, geolocation and value of assets) we are interested in, and their vulnerability (that is, the propensity or predisposition to be adversely affected when impacted by hazard events). The approach is set out below.

Figure 5. Physical Risk Analysis: Estimating



Source: Geiger and others (2017).

Hazards Projection. We are currently exploring the use of data compiled by private vendors on the projections of frequency and intensity of hazards.

Exposures. Ideally, we would like to have geolocation data on infrastructure, insured properties, physical capital, and their valuation. Since there is no publicly available data set on exposures, we are currently relying on a proxy, namely, GDP measures that have been mapped from the national aggregate to the GDP in individual geographical units (so-called downscaling[8]). We can then proxy the capital stock at risk in these disaggregated geographical locations by using standard capital output ratios applied to the gridded GDP.

Vulnerability. We then would use hazard specific damage functions from existing studies and publicly available data sets (instead using the aggregate economywide damages studied by Kalkuhl and Wenze (2019)). Damage functions vary in shape and link the intensity of individual hazards to economic damages where larger intensity leads to larger damage in a nonlinear fashion (depending on the hazard, geography, and type of exposure).

Bank stability assessment

Once projections of damages of relevant hazards are estimated for different temperature and emissions scenarios, we apply these to the bank stability assessment. There are two approaches to conducting the stability analysis and data availability directs the choice of the approach.

Macro approach. This approach incorporates analysis of capital and productivity shocks due to hazard damages on macroeconomic and financial variables using macro models. Damages are aggregated at country-level and used as an input in macro models to generate macro financial scenarios due to climate shocks. Macro models used include: NiGEM, single-country Dynamic stochastic general equilibrium (DSGE) and global models developed by IMF staff. Once macro-financial scenarios are built, the

[8] Publicly available data on downscaled GDP around the world has been developed at the Potsdam Institute for Climate Impact Research. Country-level GDP is downscaled in proportion to population data on urban and non-urban areas, which are projected to evolve under different SSPs. The "gridded GDP" map in **Figure 7** shows the downscaled GDP value in 2020 for grids, which are 100 km2 in 2005 PPP dollars.

standard FSAP stress testing approach for credit and market risks is applied to assess the risks and the impact on bank capital (see Annex 3 for an example from Philippines FSAP).

Micro-macro approach. This approach relies on an analysis of firms and households using micro models (integrated with, that is, connected to, the macro models) to estimate the impact of physical risk (and its impact on macro variables) on individual balance sheets. In this case, granular damages data are used to estimate damages to firms' and households' balance sheets in specific geographies, taking into account the mitigating effect due to insurance of assets if data are available.[9] The financial risk exposure of the banking sector—including via collateral valuation—to specific geographies is used to link damages to the earnings of banks.

Transition risk analysis

Transition risk reflects the policy reaction to climate change. The proposed focus for FSAPs, in line with the NGFS scenarios, is on carbon taxation in countries that are vulnerable to transition risk. The logic of the framework is the following. The introduction/increase in carbon taxation will increase the cost of carbon emissions, which will weigh on the financial performance of carbon intensive firms, induce relative price shifts that disincentivize the non-renewables sector, and promote growth of renewables (especially if carbon tax proceeds are invested in renewables), all of which will have an impact on the wider economy and the banking sector.

The FSAP approach to transition risk analysis may start with NGFS scenarios on emissions and temperature. The next step is to derive a carbon price to achieve specified emissions in different scenarios.

The impact on banks' health could be derived using two approaches. If granular bank exposure data are available, the impact on firms' balance sheets is used to estimate the impact on banks. We assess the impact of carbon taxes directly on firms' balance sheets—using national or vendor-provided, firm-level data. The assessment of firms' health could be complemented by the analysis of macro and sectoral effects of carbon taxes using macro and computable general equilibrium (CGE) models (for example, ENV model (Chateau, Jaumotte, and Schwerhoff 2022), the G-CUBED model (McKibbin and Wilcoxen 2013[10]). In this context, we are leveraging CGE models developed by the IMF and World Bank staff (see for example the ENVISAGE model (Van der Mensbrugghe 2019)). The macro-financial and sectoral scenario is used to estimate the impact on bank solvency using the standard approach for banks' stress tests, even without a granular assessment of firms' health. Data and modeling availability determine the choice of the approach.

Staff plans to consider scenarios ranging from a standard 3- to 5-year horizon to longer-term scenarios (30 years) to be able to analyze the opportunities from carbon taxes. We are also considering upfront shocks to carbon prices for the purpose of sensitivity analysis.

Staff are also exploring the idea of a so-called "Climate Minsky moment," (Annex 4) where current asset valuations could shift abruptly, driving upfront changes in credit risk from longer-term climate drivers. Such a sudden shift in valuation perceptions could arise if there is technological breakthrough or if consumers, firms, or financial markets suddenly change their expectations regarding how future

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[9] This might, however, have adverse second-round effects on the insurance and re-insurance industry.

[10] The G-CUBED model is a multicounty, multisector, general equilibrium model that can be used to study a variety of policies in the areas of environmental regulation, tax reform, monetary, and fiscal policy and international trade.

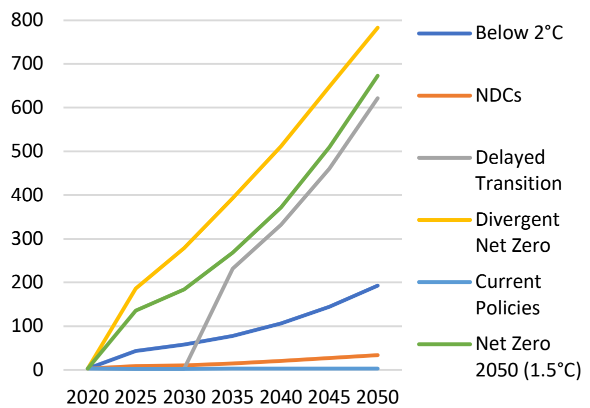
policies, technologies, or physical risks may evolve, interact, and therefore impact asset valuations (for example reflecting a surprise regarding the true extent of exposure of firms to carbon).

Scenario design—where do carbon tax paths and other variables come from?

There are two approaches for deriving paths for carbon taxes consistent with achieving the benchmark emissions and temperature pathways examined by the IPCC (NGFS).

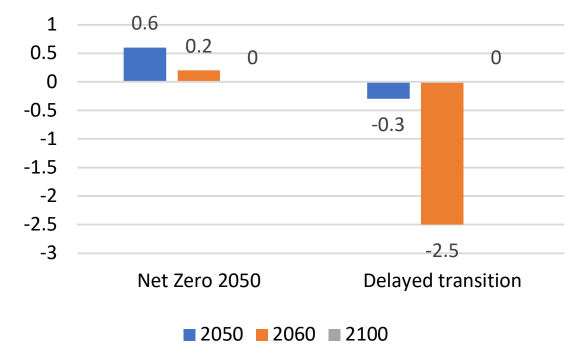
Figure 6. Carbon Price Development

(\$2010 per tonne CO_2)



Source: IISAS NGFS Climate Scenarios Database, REMIND model.
Note: NDCs = nationally determined contributions.

Figure 7. Transition Risk: GDP Impacts Relative to Prior Trend



Source: IISAS NGFS Climate Scenarios Database, REMIND model.
Note: NDCs = nationally determined contributions.

NGFS (2021) approach. Carbon prices are available from NGFS scenarios (Figure 6),[11] which are derived using Integrated Assessment Models (IAMs)[12] for a given GDP path (taken from SSPs or semi-endogenously derived in the case of some IAMs) as a proxy for energy demand. IAMs are used to model the interaction between energy, land, economy, climate systems, and policy needed to meet a particular temperature outcome[13]. Assumptions regarding policy and technologies (for example, carbon dioxide removal, the availability of solar, wind, and geothermal resources) play an important role in IAMs. Multiple models were used to produce the scenarios to capture a range of uncertainty in the results. The NGFS methodology then uses the NiGEM macro model to derive paths of other macro and financial variables consistent with carbon and GDP pathways from the IAMs. This approach, however, takes GDP as given and does not provide comprehensive sectoral impacts.

IAMs suggest that a carbon price of around \$160 per tonne would be needed by the end of this decade to incentivize a transition towards net zero by 2050 (Figure 7). They suggest that world GDP impacts from transition risk are slightly positive in the Net Zero 2050 scenario as negative impacts on demand from

[11] Carbon price refers to the rate of a carbon tax, or the price of emission permitted. Other mitigation policies are represented either implicitly (with the carbon price acting as a proxy for the level of effort they represent) or explicitly (like, for example, energy-sector fuel taxes and consumer subsidies in the REMIND model, one of the three IAMs used to create the scenarios).

[12] All IAMs consider at least two carbon dioxide removal technologies, including afforestation and reforestation. While IAMs cover agriculture and land use activities, and contain projections of all greenhouse gases, the focus here is on carbon taxes, as tool to reduce CO_2.

higher carbon prices and energy costs are more than offset by the recycling of carbon revenues into government and private investment into new technologies, and lower employment taxes. GDP impacts are negative in the disorderly scenarios as the speed of the transition combined with investment uncertainty affects consumption and investment.

Although the NGFS approach offers a critical global perspective, there is scope for extensions. The NGFS scenarios offer a globally consistent modeling framework linked to alternative global climate pathways that include some tailoring to country-specific circumstances. However, not all IMF members are considered in all layers of the scenarios.[14] The globally consistent approach has the benefit of motivating joint action and improving cross-country comparability among other factors. But such common approaches limit the flexibility of tailoring parameters of the scenario design to more country-specific features. These could include, for example, different schemes for reinvestment of carbon tax proceeds, applying versus not applying carbon taxes for different countries or groups of countries, or for devising carbon trade policies (such as carbon border adjustment mechanisms). The NGFS is working to increase industry segmentation in the scenarios, which is important for analyzing the effects of transition policies that have differential effects across sectors. Alternatives are to consider global CGE models, with significant global country coverage, comprehensive industry segmentation, and greater flexibility regarding reinvestment, carbon tax application, and related trade policies.

CGE approach. Dynamic CGE models can be used to derive carbon tax paths, their sectoral impact (substitution from non-renewables to renewables), and GDP and other macroeconomic variables consistent with IPCC scenarios on emissions and temperature. The advantage of this approach is that the macroeconomic variables and carbon taxes are fully endogenous and that CGE models provide a fuller sectoral decomposition of transition paths, by contrast with the more aggregate output of the IAMs employed for the NGFS scenarios. Moreover, CGE models (such as GTAP and ENVISAGE, as referenced earlier), allow obtaining detailed impacts on bilateral trade effects across countries. Our initial assessment is that fully endogenizing the determination of carbon prices and output consistent with target temperature/emission paths could well produce a larger impact on GDP over the near term comparing to IAMs for the same increase in carbon taxes. However, more analysis will be needed to assess the sensitivity of the models and scenario outcomes to such methodological differences. In any event, once the paths for aggregate and sectoral GDP, other macro variables and trade are determined by the CGE model, supplementary macro-financial models can be used to derive other financial variables required for financial system impact analysis (current modeling frameworks do not generate most such variables).

Bank stability assessment

The bank stability assessment requires a mapping from carbon taxes to impacts on the macroeconomy, firms' balance sheets and bank capital. There are two approaches based on data availability:

Macro approach. Macro models are used to generate macro financial scenarios due to carbon tax shocks. Sectoral models are used to analyze cross-industry differences and opportunities from higher carbon taxes which are critical for assessing transition risks. Outputs from dynamic CGE models used for such sectorization (for example, carbon taxes, GDP) should be consistent with outputs of macro models/IAMs. Once macro-financial and sectoral scenarios are built, the standard FSAP stress testing approach for credit and market risks is applied to assess the risks and the impact on bank capital.

[14] The macro models of the NGFS comprise between 30 to 50 countries, while other CGE models such as GTAP and ENVISAGE contain 120+ countries.

Micro-macro approach. This approach assesses the impact of carbon taxes on firms' balance sheets considering firms' carbon intensity. Staff are currently experimenting with data that projects carbon taxes and greenhouse gas emissions at the firm level and linking these to carbon price paths and macro-financial and sectoral scenarios to generate estimates of firm level credit risk. The emissions are categorized as Scope 1, 2, or 3.[15] Unlike scope 1 and 2 emissions, whose measurement requires keeping track of greenhouse gasses emitted directly by a company or embodied in the energy it buys, the measurement and disclosure of scope 3 emissions involve a number of challenges, including those related to data availability, use of estimates, calculation methodologies and other sources of uncertainty. Currently the availability and quality of scope 3 emission disclosures is very limited. Mapping firm-level credit risk into bank stress tests requires bank exposure-level data (Annex 5).

What else has been done so far in FSAPs?

Climate risk has been considered in other several FSAPs. Early analyses were undertaken in FSAPs for Chile, Colombia, Norway, and South Africa to test new methodological approaches and enrich discussions with the authorities in the context of the FSAP. Brief summaries of the approach are indicated below, with transition risks analysis mostly emphasizing the impact of carbon taxes on corporate performance thus providing sensitivity analysis to complement the bank stress test.

Norway: This FSAP pioneered a micro-level, debt-at-risk analysis of transition risk posed by carbon tax increases (the scenario modelled was a one-off increase in the domestic carbon price to $75 and $150 from current levels of about $45 per tonne of CO_2 equivalent) at the level of individual firms, though the impact was not mapped directly into credit risk and bank capital. The results suggest that debt at risk (the share of firms for which the interest coverage ratio drops below a threshold value following a carbon price shock) would amount to 2.2 percent for a carbon price increase to $75 per tonne CO_2 and 4 percent for an increase of $150 per tonne CO_2.

Chile: In this FSAP for physical risk, a macro approach was taken to assess the impact of floods and droughts on capital stock, calibrated using historical data and analyzed using the IMF's global macrofinancial models. The impact of historical droughts and floods on GDP was estimated to be around 2 percent of GDP, which had a small effect on banks (0.1 percentage point reduction in the aggregate capital ratio). For transition risk, a micro analysis was undertaken of the impact of higher carbon taxes (one-off increase to $100 per tonne CO_2) on credit risk facing individual firms. Firm default rates were linked to balance-sheet vulnerability indicators using firm level data on historical probabilities of default (PDs) and balance sheets. A micro-simulation was then performed on firm-specific balance sheets to establish "stressed" vulnerability indicators due to increased carbon prices; carbon price paths and firm-specific emission footprints were used as the anchoring mechanism for this simulation. The stressed indicators were used to produce firm-level stressed PDs and the cross-sector weighted average PDs were used to inform bank stress test results in terms of additional provisions and capital impact attributable to transition risk. The results suggest that the higher carbon taxes modeled would increase PDs by 0.7 percentage points after five years, which would reduce capital ratios up to 0.5 percentage points. The sectoral impact and the impact on GDP were not assessed.

South Africa: In this FSAP the physical risk analysis linked provincial nonperforming loans to historical droughts in the provinces while the transition risk analysis conducted micro-level studies of the effects different carbon tax scenarios on individual firm performance. In a scenario of a sudden and large rise in

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[15] Scope 1 emissions are direct emissions from owned or controlled sources. Scope 2 emissions are indirect emissions from the generation of purchased energy. Scope 3 emissions are all indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions. (see https://ghgprotocol.org/sites/default/files/standards_supporting/FAQ.pdf)

the price of carbon to a mid-point estimate needed to stabilize carbon equivalent emissions, corporate debt at risk among publicly listed firms would rise from a level of around 30 percent in the baseline to around 60 percent in the shock scenario.

Colombia: This FSAP conducted a transition risk micro analysis of the impact of carbon tax increase (a one-off increase in carbon price from $5 to $75/ per tonne CO_2) on the financial performance of individual firms, similar to the Norway FSAP, but also assessed the impact on individual bank loans.

Climate risk analysis and Financial Policy

Staff's proposed climate risk analysis can inform policy considerations in surveillance and capacity development by evaluating the magnitude of risk and potential pressure points for the financial system due to physical climate shocks and in the transition to a low-carbon economy. The resulting analysis can raise awareness of the risk, and adaptation needs and opportunities, including the need for banks to develop tools to manage climate risks and for financial sector supervisory authorities to adequately supervise this risk. This would potentially drive gradual early adjustment and help inform policies needed to enhance risk management and the resilience of the financial system.

As stated at the outset, while climate risk analysis is based on stress testing methodologies, climate risk analysis is not a standard stress test. As such, their uses, while complementary to policy discussions, are distinct.

The standard stress test is used for monitoring and assessing risks over the near term and to inform the design of microprudential and macroprudential tools. It is based on well-established methodology, extensive data disclosure, and a reasonable first-order understanding of the historical relationships between macro-financial variables and bank capital. For purposes of microprudential supervision, most supervisors use stress tests as a qualitative tool when judging banks' overall resilience, risk exposures and controls. The results of the stress tests, in most of the cases, are not tied to additional capital requirements or other "binding supervisory tools" but often impact the "internal supervisory rating" of the bank and, consequently the content of the supervisory dialogue and intensity of the supervision process.

Climate risk analysis should in principle be informative of supervision and regulation, especially once methodologies have been further developed and validated. Their use, particularly for regulatory purposes, will require significant further work[16] with challenges arising not just from the complexity of climate analysis relative to standard macro-financial modeling in stress testing, but also from its evolving nature, very long risk horizons, and poor quality of data disclosure[17], reflecting also nonstandard nomenclatures[18]. This work also requires new expertise in climate science. NGFS (2022) suggests that, in the short term, in light of challenges posed by data gaps and methodological uncertainties, no jurisdiction as of yet envisage calibrating prudential policies such as capital requirements on the basis of their climate scenario analysis.

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[16] The plan would be for FSAP discussions structured around the BCBS "Principles for The Effective Management and Supervision of Climate-Related Financial Risks," supported by broader Basel Core Principles (BCPs), to contribute to the work of the risk analysis. Similarly, the outcomes of the work on risk analysis would inform the bank supervision assessors

[17] An exception is New Zealand, which passed the Financial Sector (Climate-related Disclosures and Other Matters) Act in 2021 which makes it mandatory for financial institutions (banks and other deposit takers, insurers and investment managers) and large companies to report on climate-related exposures, including strategy with regards to climate change both in terms of risks and potential opportunities, risks to the business, risk management measures, and metrics and targets used to monitor risks and opportunities from climate-related exposures.

[18] See NGFS (2022) for a overview of challenges in conducting risk assessment and designing tool to manage the risk.

As the international community conducts further work in this area climate risk analysis can be very helpful to:

- Create awareness around the prudent management of climate risks and incentivize banks in improving their frameworks.
- Inform supervisors about the potential magnitude of climate-related risks in their jurisdictions and help deepen the understanding of the transmission channels from climate-related risks to the financial system. This is key for the sound development of supervisory plans and an informed decision on how much supervisory resources should be allocated to the issue.
- Identify data gaps and banks' individual capacity to identify and manage climate-related risks. This allows supervisors to make more specific recommendations for banks to improve their risk management framework.
- Help supervisors to determine the extent to which the impact of climate risk is appropriately considered by banks in their management of credit, market, operational and other traditional risks.
- Compare the results with own evaluation of the solvency impact of climate risk. The incorporation of climate risk on ICAAP is nascent and likely to be an iterative process.
- Assess the long-term sustainability of individual banks business models.
- Build capacity to expand the Pillar 2 approaches.
- Develop metrics and indicators for ongoing monitoring of banks exposures to climate risk.

Currently, other institutions, including financial sector supervisors and central banks (for example, APRA, Bank of Canada, and Bank of England), use climate stress tests to measure the exposures of financial institutions to climate-related risks. This helps to understand the challenges to banks' business models from these risks, the implications for the provision of financial services, and desired policy responses. Ultimately, climate risk analysis will be useful in directing financial institutions to enhance their disclosure and management of climate-related financial risks.

Collaboration opportunities on climate risk analysis

The complexity of climate risk analysis presents many opportunities for close collaboration to explore synergies, gain knowledge, and develop rigorous approaches. IMF staff have worked closely with the World Bank, and colleagues from the NGFS, among other interactions. There is also rising demand for capacity development on methodologies to assess the relevance and impact of different types of climate risks. The FSAP provides an important vehicle to test new approaches and scenario designs that are relevant for the IMF's universal membership.

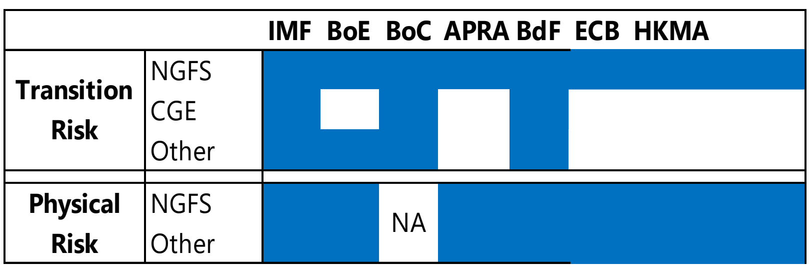
Collaboration with the World Bank. IMF staff cooperate closely with World Bank staff on climate risk work, leveraging their deep technical expertise to improve scenario design while maintaining the IMF's primary role in undertaking stability assessments. Scenario design for physical risk has benefited from this collaboration given World Bank staff expertise in catastrophe modeling. This has been demonstrated in the fruitful collaboration on the Philippines FSAP. The potential impact of Carbon Border Adjustment tax policies adopted by some IMF members, especially for the IMF's emerging market economy and developing country members, is also of interest in FSAPs. Detailed cross-border sectoral CGE modeling of associated scenarios, has been another collaboration opportunity.

NGFS. IMF staff participate as observers in the NGFS work stream on scenario design and analysis. The staff has also co-led the workstream on disclosure and are engaged in the workstream on supervision. The main objective of the NGFS workstream on scenario design and analysis is to undertake climate scenario analysis and promote its use within the regulatory community more broadly. To achieve this goal the workplan includes: (1) improving the NGFS climate scenarios developed previously developed by the NGFS workstream 2; (2) providing methodological guidance on scenario-based climate risk analysis for macroeconomic and financial stability surveillance; (3) updating the NGFS climate scenarios on a regular basis; and (4) promoting the use of the NGFS climate scenarios within the financial system. The staff have leveraged learning from the NGFS on climate and macro scenarios in the design of the approach proposed for FSAPs. As indicated previously, the staff intend to use different approaches to deriving carbon taxes including benchmarking scenario design, as feasible, of climate scenarios designed by NGFS. Indeed, transition risk scenarios designed by the work stream have already been used in FSAPs for the United Kingdom. Cross-border cooperation, at this early stage, is crucial to share experience in developing new methodologies.

What central banks and supervisors are doing

Of the 105 NGFS members, the NGFS (2021) reports that more than 30 central banks and regulators have adopted scenario analysis to better understand the macroeconomic and financial impacts of climate change (Annex 6). These range from shorter-term, top-down modelling exercises to exercises with a longer time horizon, in many cases with bottom-up participation of financial firms, with static and dynamic assumption on the evolution of their balance sheets. While it is too early to distill best practices in climate risk analysis, we present briefly six summary examples of such work (Table 2) with some comparison of the main elements of the exercises with the approach considered for FSAPs. The main takeaways are the following:

Table 2. Climate Scenario Design Approaches, IMF and Six Institutions



Source: IMF Staff
Note: APRA = Australian Prudential Regulation Authority;
BoC = Bank of Canada;
BoE = Bank of England;
BdF = Bank de France;
ECB = European Central Bank;
HKMA = Hong Kong Monetary Authority.

Transition risk scenarios. While all institutions rely on NGFS scenarios for transition and physical risk (temperature, emissions, macro impact in some cases), they take the scenarios as a starting point and build upon them to assess sectoral impacts (Bank of England 2021, Bank of Canada and Office of the Superintendent of Financial Institutions 2021) or derive carbon taxes (Bank of Canada and Office of the Superintendent of Financial Institutions as in the staff's approach). The Banque de France also considers a sudden transition scenario.

Physical risk scenarios. Some institutions (Banque de France/Autorité de Contrôle Prudentiel et de Résolution (ACPR 2021), (APRA 2021)) follow a similar approach to that proposed by staff for considering granular hazards projections and estimation of their damages, relying on damages assessments from reinsurers or national meteorological institutions.

Macro scenarios for transition risk. Some institutions (Bank of Canada, Banque de France) combine macro models with CGE models to assess the macro and sectoral impact of carbon taxes or combine them with (Banque de France) or rely on NGFS macro simulations (ECB 2021).

Macro scenarios for physical risk. Most institutions leave to banks to conduct a bottom-up assessment of the macro implications of physical risks for their exposures. Some rely on the NGFS scenarios (ECB, Bank of England) which is based on the GDP-temperature empirical relationship.

The climate work by NGFS members, while at an early stage, is developing rapidly. At this stage only a few institutions have finalized the first iteration of their climate risk analysis with published results, but the literature from central banks on approaches and methodologies is expanding fast.

CONCLUSIONS AND NEXT STEPS

While we have started with piloting of the climate risk analysis in a few FSAPs, the staff will seek to extend climate risk analysis to more FSAPs going forward. The scope of any analysis will be based on an initial assessment of each country's specific vulnerabilities and materiality of the risks. We will enhance climate modeling techniques based on the methodologies implemented in the piloting exercise. We will undertake a continuous assessment of climate data sets to make sure we have access to high quality data. Expanding skillsets and technical capabilities will be necessary to fully understand and incorporate the findings of climate science in our framework.

Cooperation is key to achieve synergies. We will continue the collaboration with World Bank staff on modeling climate risk scenarios and with the NGFS to leverage on experience from other countries. We will keep learning from authorities' climate experts and seek to use national granular data in the context of FSAP work.

While this note focuses on climate risk analysis for banks, the methodology could be applied to other financial sectors such as insurance companies (as tested in the UK FSAP) and mutual funds (taking into account that investment funds are pass-through structures where the risks are borne directly by the investors). For both insurance companies and mutual companies, stages of the framework that pertain to macro scenarios would be the same while stress testing methodology for each sector would be different.

The authors hope that the climate risk analysis framework will also be of value to members through their capacity development work. Moreover, there could be an important opportunity to provide assessments of physical risk facing financial systems in fragile states—which are relatively more exposed to certain physical risks than other jurisdictions—including in the context of Article IV consultations.

At this early stage, this note is focused on methods that IMF staff are deploying to raise awareness of the risks. This will help inform policies needed to enhance risk management and the resilience of the financial system, and support needed adaptation and transition efforts in the financial sector as a complement to the real sector.

Annex 1. The Role of the FSAP

Past financial crises have shown that the health and functioning of a country's financial sector has far-reaching implications for its own and other economies. The FSAP is a comprehensive and in-depth analysis of a country's financial sector. Conducted jointly with the World Bank in emerging and developing economies, it is a crucial part of the IMF's financial surveillance and an input to the Article IV consultations. To date, more than three-quarters of the institutions' member countries have undergone assessments.

The goal of FSAP assessments is twofold: to gauge the financial sector's stability and soundness and assess its potential contribution to growth and development.

- **To assess stability**, FSAP teams examine the resilience of the banking and nonbank financial sectors; conduct stress tests and analyze systemic risks, including links among banks and nonbanks and domestic and cross-border spillovers; analyze emerging risks, including climate and cyber risks; examine microprudential and macroprudential frameworks; review the quality of bank and nonbank supervision and financial market infrastructure oversight, including central clearing, payment systems, and fintech ecosystems; and evaluate the ability of central banks, regulators and supervisors, policymakers, backstops, and financial safety nets to respond effectively in case of systemic stress.

- **To assess development aspects**, FSAPs examine institutions, markets, infrastructure, and their inclusiveness; the quality of the legal framework and of payments and settlements systems; obstacles to competitiveness and efficiency; progress in financial inclusion; and access to retail payment digital technology. They also examine the financial sector's contribution to economic growth and development. Issues related to the deepening of domestic capital markets are particularly important in developing and low-income countries

Annex 2. Climate Risk and the Financial Sector

Policymakers and investors increasingly recognize climate change's important implications for the financial sector. Climate change affects the financial sector through two main channels.

- **Physical risk** refers to the physical impact of climate change. These risks represent losses due to increasing frequency and severity of climate-related events, also called "hazards." These include acute risks (such as storms, floods, heat waves) and so called "chronic" risks reflecting the effect of long-term changes in climate patterns, such as rising sea levels or changes to precipitation. The losses include adverse impacts on assets and resulting financial sector losses to the extent it is exposed to the affected assets, as well as negative effects on the economy due to second-round effects. Data on the history and projections of the frequency and intensity of climate indicators as a function of the IPCC reference scenarios are publicly available and disseminated through multiple global scientific cooperative channels (for example the Coupled Model Intercomparison Project (CMIP) of the World Climate Research Programme). However, such climate science data are not easily accessible and require climate science expertise for their interpretation. Similar data, as well as hazards data, are also available from commercial vendors that present the dataset with higher resolution in a user-friendly environment together with detailed methodologies and customer support.

- **Transition risk** results from changes in climate policy, technological advances, and consumer and market sentiment during the adjustment to a lower carbon economy. The staff's approach focuses on carbon taxes, both domestic[19] and external,[20] as the main source of transition risk. While policies to support transition to a low-carbon economy can take different forms (for example, subsidies to renewable energy production, caps on fossil-fuel-based power generation, etc.), the representation of transition risk as arising from application of needed carbon taxes is a convenient, powerful, and relatively tractable assumption that mitigates modeling challenges of decarbonization scenarios. This assumption is also used in the scenario design by central banks and NGFS. Moreover, other policies can generally be modeled as carbon tax policies by being transformed into carbon tax equivalent. The adverse effects on the financial sector pertain to losses of carbon-intensive industries affected by the carbon tax as well as second-round effect of carbon taxes on the economy.

Physical and transition risks are inter-twined. The faster the transition, the lesser the temperature increase and thus the smaller the physical effects of climate change. But the economic effects also depend on the pace and composition of the transition to a lower-carbon economy. Delays in transition or large divergences across countries could lead to higher economic and financial costs from both physical and transition risk.

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[19] While we analyze the impact of carbon taxes in individual countries, Parry, Black, and Roaf (2021) argue that sufficient progress to stabilizing the climate would require an international carbon price floor.

[20] See Parry and others (2021) for a discussion of the rationale, design and impacts of border carbon adjustments—a charge on embodied carbon in products imported into a jurisdiction with carbon pricing, potentially matched by rebates for embodied carbon in exports.

Annex 3. Physical Risk: The Macro Approach in Practice—The Philippines FSAP

The Philippines FSAP (2021) was a pilot that analyzed the impact of physical risk on the economy and banks using the macro approach. The climate risk analysis was undertaken together with the World Bank. The Philippines is a typhoon-prone country—hence the focus on the impact of this specific hazard.

Consistent with the previous discussion, the analysis consisted of four modules.

- **Climate scenarios**. The FSAP used existing studies undertaken by the authorities to build climate scenarios on typhoon intensity and frequency as a function of the NGFS hot house world temperature scenario. The study showed that the number of typhoons would decline but that their intensity—measured by windspeed—would increase (**Annex Figure 3.1**).

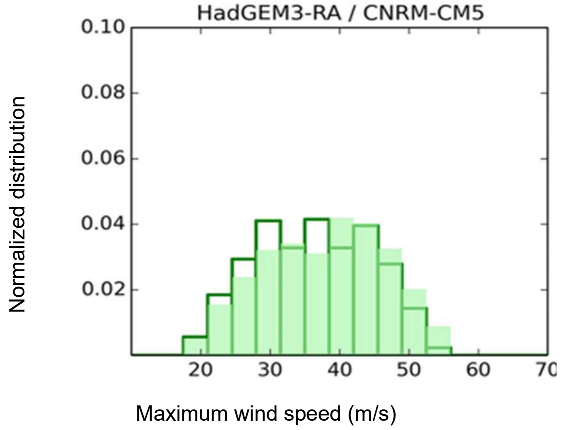
- **Damages.** The FSAP estimated potential damages to physical capital using a catastrophe (CAT) risk model developed by the World Bank and the authorities, and country-specific exposure and vulnerability data provided by the Government of the Philippines as opposed to proxies such as the gridded GDP. The model showed that under the given global warming scenario, the damage rate of physical capital—the share of lost capital in percent of existing stock— would rise by 40 percent (damage rate going up from 2.2 percent to 3.1) for severe typhoons (1 in 100 years event) and by nearly 70 percent (damage rate going up from 5 percent to 8.5) for historically rare (1 in 500 years though it is worth noting that the frequency of such events is likely rising with climate change)) typhoons (middle figure) comparing to the scenario with current climate conditions (Annex Figure 3.2).

- **Macro scenarios.** The FSAP used the damage rate to parameterize the depreciation shock to physical capital in a DSGE model calibrated for the Philippines. The shock to capital was assumed to also generate a productivity shock—in line with some empirical analysis (see for example Bakkensen and Barrage 2018)—leading to an amplification of the direct impact of typhoons on capital stock.

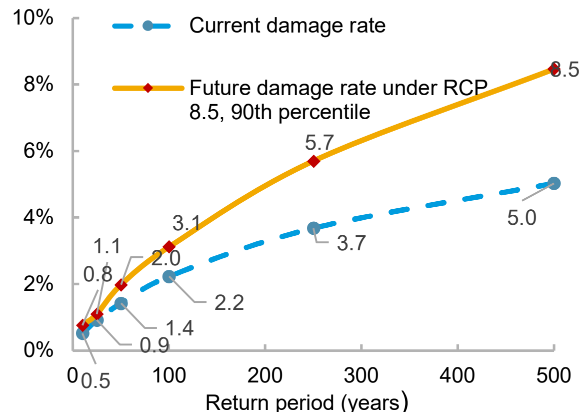
- **Banking stability assessment**. The FSAP then used the standard macro scenario stress testing approach to assess the impact on bank capital, focusing on the macroeconomic channels of the typhoon impact.

The macro-financial module showed that drawing from the historical distribution likelihood of typhoons, what have been historically rare typhoons could reduce GDP by more than 5 percentage points for once-in-100-years typhoons and 14 percentage points for once-in-500-years (at the peak).

Annex Figure 3.1. Normalized Distribution of Windspeed Intensity



Annex Figure 3.2. Physical Capital Damage Rate for the Philippines



Annex 4. Transition Risk: Climate Minsky Moment—UK FSAP

The UK FSAP (2022) piloted assessing the implications of a "climate Minsky moment" where agents price in upfront the change in companies' prospects caused by shocks associated with technology and/or policy and incorporate the new expected cash flows in the valuations of assets, leading to market and credit losses for financial institutions.

The initial shock is defined as a drastic change in expected global decarbonization policies, from hot house, "business as usual" to "orderly (but ambitious) transition to a low carbon economy." This entails a sharp steepening of the expected carbon price path which, in turn, leads to changes in expected costs and revenues across sectors and countries (depending on the carbon intensity of their production process and of the products/services they sell).

The simulation horizon is 2020–50 and **the risk horizon is** 2020–25. Cash flows are projected over the simulation horizon, so as to capture the impact of transition risks over the whole relevant time span (that is, when decarbonization policies are expected to produce the largest part of the structural transformation required by the transition to a low-carbon economy). However, risks are evaluated at the "climate Minsky point," which is assumed to occur within the shorter five-year risk horizon.

The exercise is based on **NGFS scenarios**: (1) "National determined contributions" (NDCs) as NGFS business-as-usual scenario and (2) "1.5°C with Carbon Dioxide Removal" (1.5°C+CDR) or "Net Zero 2050" (NZ2050) as orderly NGFS transition scenarios.

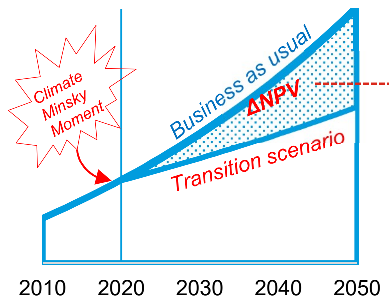
Impact on sectors (CGE modeling). A CGE model (Global Trade Analysis Project, GTAP model (Corong and others 2017))[21] was used to assess the sectoral impact in terms of the change in the expected paths for sectoral gross value added.

Impact on individual firms. The output from the CGE model was used to assess the impacts on companies within each sector. The change in expected cash flows of each firm was simulated via a suite of climate-related financial models developed by a private vendor. Firms are affected due to increasing operating costs imposed by carbon tax. For some industries (for example, fossil fuels) changes in sales are modeled as well.

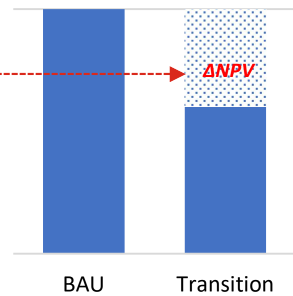
Impact on valuations and PDs. The shock to expected cash flows leads to a generalized revision of corporate asset valuations via discounting and recalculation of their market value of equity (MVE). This directly impacts equity holdings of financial institutions. Loan and bond portfolios are affected by companies' defaults (firms with change in MVE equal to –100 percent) and, for "surviving" firms, by changes in their probability of default and credit rating as a function of change in MVE and distance to default (via Merton approach) and, consequently, in credit spreads and price of their bonds (Annex Figure 4.1-4.3).

[21] The GTAP model is a multiregion, multisector, computable general equilibrium model, with perfect competition and constant returns to scale.

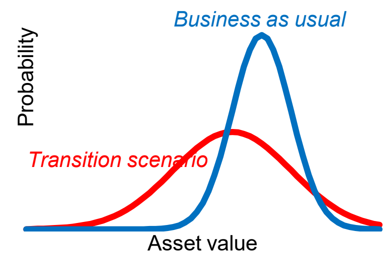
Annex Figure 4.1. Company X Earnings (Illustrative)



Annex Figure 4.2. Company X Market Value of Equity



Annex Figure 4.3. Distribution of Asset Values across Companies



Impact on financial institutions. Changes in valuation are mapped to losses on financial institutions' holdings of securities (at individual security level, when the information is available) and banks' loans (at sector level) but not into bank capital.

Results. A switch from the NGFS' National Determined Contributions to the Net Zero 2050 scenario would generate credit losses of 3.6 percent, on average, on banks' corporate loan portfolio and market losses of more than 4 percent, on average, on their equity and corporate bond holdings. Pension funds would experience losses of 3.5 percent on equity and corporate bond holdings and insurers would endure losses of 11 percent on equity, and 4 percent on corporate bonds.

Comparison with Bank of England Climate Biennial Exploratory Scenario (CBES). At the end of 2019 the Bank of England launched an initiative to explore the financial risks posed by climate change on banks and insurers. Suspended after the breakout of COVID-19, the exercise was restarted in 2021 and the results published in May 2022. The exercise conducted by the FSAP team is largely complementary to the CBES, in terms of both scope and approach, In particular:

- While the CBES is a guided bottom-up exercise (with the BoE providing the scenarios and general methodological indications and banks and insurers running the actual simulations on their own portfolios), the FSAP team adopted an entirely top-down approach.
- The largest banks and insurers are within the scope of both exercises, but the FSAP analysis also covers representative samples of UK-domiciled investment funds and corporate occupational defined benefit pension schemes.
- The CBES covers both transition and physical risk, while the FSAP analysis covers mainly the former.
- Both exercises take into consideration a very long horizon (up to 2050), but in the FSAP analysis risks—as mentioned—are evaluated within a shorter risk horizon (five years), in line with the Climate Minsky moment approach.
- Other characteristics (such as the assumption of static balance sheets) are common between the two exercises.

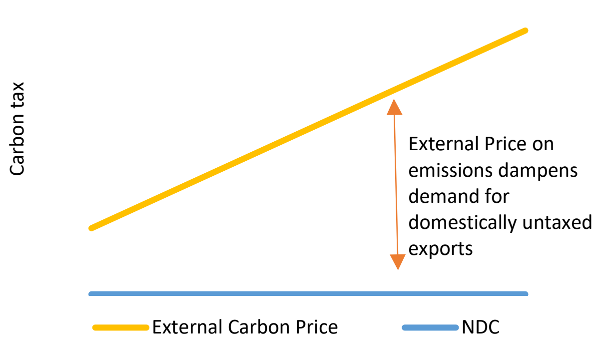
Annex 5. Modeling the Impact of Transition Risk in Emerging Market Economies

The authors are experimenting with analyzing the impact of transition risk on the financial sector of emerging market economies, in particular from carbon border adjustment taxes that could be introduced in major economies. This is particularly relevant for large fossil fuel exporters, including in the context of possible policies such as the EU Carbon Border Adjustment Mechanism (CBAM). The approach is also applied to nonfinancial firms, and banks implementing a full-fledged micro simulation, connected to a CGE model on which the authors also collaborate with World Bank staff.

The CGE models the authors are exploring derive carbon tax paths, alongside GDP, trade effects, and sectoral impacts, consistent with self-defined emissions and temperature target paths. The models are global recursive CGE models with an embedded emissions and climate module (the ENVISAGE model for example covers 121 countries, 20 regions, and 57 industries). They allow modeling the differentiated impact of external shocks on firms' sales through exports vs. domestic sales. This is important when assessing the impact of policies such as CBAMs. We are also considering the NGFS approach, as an alternative to the CGE model simulation.

A so-called Firm-Bank (FIBA) extension to the model is considered, which is a micro simulation framework connected to the CGE model.[22] It seeks to cover granular firm level data and bank exposures to the most emission intensive segments. The modeled outputs include sectoral and macro impacts in terms of GDP, trade, etc.; firm-level and aggregated industry-level probabilities of default, losses given default, and credit spreads, which are important to establish the link to banks' capital and the loss contributions from the industries considered.

Annex Figure 5.1. Impact of CBAM through External Carbon Taxation



Source: IMF Staff
Note: CBAM =EU Carbon Border Adjustment Mechanism; NDC = nationally determined contributions.

[22] The combined ENVISAGE-FIBA model framework, a conceptual discussion of scenario design, the impact assessment in such framework and a guide for modeling choices conditional on types and availability of data are described in Gross and others (forthcoming).

Annex 6. NGFS Member Institutions Currently Conducting Climate Risk Analysis

Annex Table 6.1. NGFS Member Institutions Currently Conducting Climate Risk

Asia and Pacific	Middle East and Central Asia	Europe	Africa	Western Hemisphere
Australian Prudential Regulation Authority	Bank Al-Maghrib	Autorité de contrôle prudentiel et de resolution (ACPR)/ Banque de France	South African Reserve Bank	Banco Central de Chile
Bangko Sentral ng Pilipinas		Banca d'Italia		Superintendencia Financiera de Colombia/Banco de la República
Bank of Korea		Banco de España		Banco de México
Hong Kong Monetary Authority		Bank of England		Bank of Canada
Japan Financial Services Agency/ Bank of Japan		Bundesbank		
Monetary Authority of Singapore		De Nederlandsche Bank		
People's Bank of China		European Banking Authority		
Reserve Bank of New Zealand		European Central Bank		
		Malta Financial Services Authority		
		Oesterreichische Nationalbank		
		Seðlabanki Íslands		
		Suomen Pankki		
		Sveriges Riksbank		
		Swiss National Bank / FINMA		

Source: NGFS (2021a)

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