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A framework for macro-financial analysis of climate risks[1]

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[1] This contribution was prepared for the workshop. The views expressed are those of the authors and do not necessarily reflect the views of the Central Bank of the Republic of Türkiye, the BIS, the IFC or the other central banks and institutions represented at the event.

A framework for macro-financial analysis of climate risks

Christian Schmieder, Abhishek Srivastav and Miroslav Petkov[1]

Abstract

This paper presents an accessible top-down framework to evaluate the forward-looking impact of climate risk vulnerabilities on bank credit losses and capital ratios at the country level. By incorporating key transmission channels of climate risk—both physical and transition risks—we build upon the scenario analysis framework established by Hardy and Schmieder (2013). The framework enables the simulation of short-, medium-, and long-term scenarios through 2100, providing insights into both immediate and structural vulnerabilities that could affect bank solvency. Additionally, the framework allows exploring the compounded impact of climate-related risks coinciding with conventional banking crises.

Keywords: Scenario Analysis, Climate Vulnerabilities, Bank stability, Macro-financial analysis, Physical Risks, Transition Risks

JEL classification: Q54, G21, G32

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1. Introduction

Insurance companies have long been concerned about weather- and climate-related risks. In recent years, climate risk analysis in general, and scenario analysis in particular, has extended to other financial institutions, notably banks (eg BCBS 2021, ECB 2023, Federal Reserve Board 2023/2024, Financial Stability Board 2025). Extreme weather conditions observed around the world in recent years have reinforced this interest (see Figure 2).

This paper introduces a framework for macro-financial analysis of climate risks. We offer an accessible top-down scenario analysis approach to evaluating banks' exposure to climate-related financial risks. The framework allows for forward-looking simulations of potential outcomes of credit losses and capital ratio levels under different climate scenarios across countries and over time. Additionally, it enables assessments of the relative contribution of climate risk to potential overall solvency risk faced by banks under adverse short-term adverse conditions.

Two core components of our framework are:

- the climate risk scenarios established by the Network of Central Banks and Supervisors on Greening the Financial System (NGFS) and
- a "traditional" scenario analysis concept for banks (Hardy and Schmieder, 2013), which maps GDP trajectories into bank solvency metrics.

Traditional financial stability analyses assess financial vulnerabilities, ie imbalances arising from exposures of financial institutions that give rise to potential losses driven by different levels of economic and financial shocks as observed in the past. These exercises are characterised by a fairly stationary loss distribution function, whereby one can establish proxies for the magnitude of losses, say in a '1-in-20' or '1-in-100' years scenario.

By contrast, climate risk is a growing structural risk factor, exposing banks to increasing levels of "average" vulnerabilities (akin to the expected loss concept), and, in parallel, more extreme tail events (akin to potential unexpected losses). Tail events can occur short-term (especially the materialisation of physical risk), but also involve adverse structural trends with lasting effects, which can be reinforced by tipping points. Our contribution encompasses two main aspects:

1. We offer an accessible framework for conducting forward-looking macro-financial analysis of climate risks across a wide range of countries, building upon the "traditional" bank scenario analysis framework developed by Hardy and Schmieder (2013). This allows one to capture cross-country evidence to identify potential vulnerabilities that are common to the specific types of economies, advanced and emerging market economies. Given the substantial modelling complexity involved by default, we believe our work is a valuable complement to the intricate frameworks established by central banks and regulatory authorities.
2. Introducing a novel element, we enable the simulation of potential vulnerabilities transmitted through cross-border channels. This provides insights on how an increasingly financial interconnectedness could have the potential to engender material cross-border spillovers.

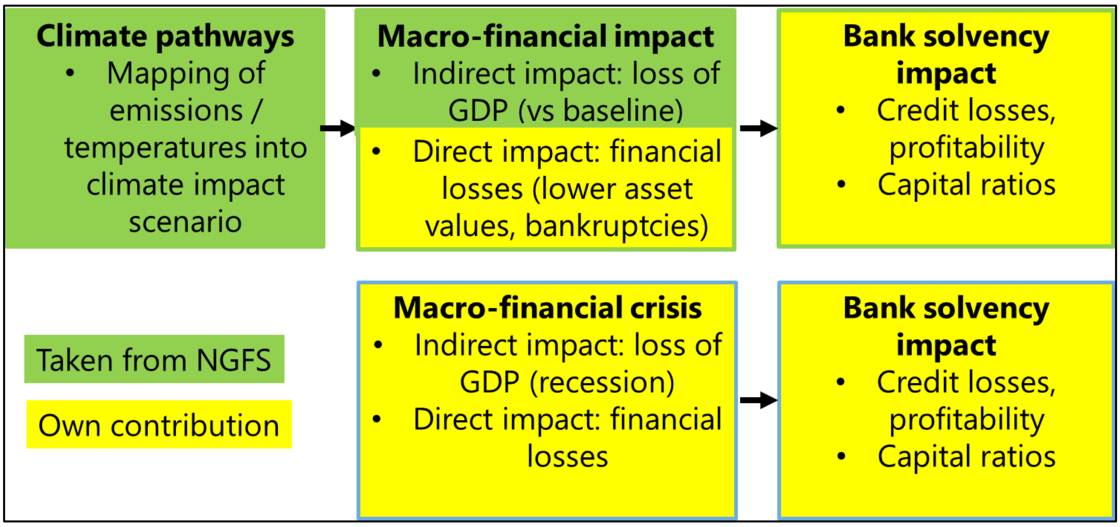
Our paper highlights that climate risk scenario analysis presents a distinct complexity compared to traditional scenario analyses. In addition to the challenge to simulate the impact of macro-financial scenarios on solvency outcomes at the bank level (second row in Figure 1), climate scenario analysis involves an additional third element, namely to translate climate scenarios into bank level parameters (first row in Figure 1). To keep the framework manageable, it is based on a mapping of GDP trajectories (which are available for both the climate and macro-financial scenarios) to key bank solvency parameters.

The framework serves several key policy purposes, which will be assessed in a follow-up paper focussing on outcomes:

1. To monitor bank vulnerabilities over time, across countries, and to assess the relative importance of physical versus transition risks on bank solvency.
2. To assess the relative importance of climate risk vis-à-vis other key solvency risk factors, most importantly macro-financial conditions.
3. To conduct reverse stress tests to assess the capacity of the banking sector to withstand adverse conditions.

Figure 1: Scenario analysis concept

Scenario analysis for climate risks is more complex than "traditional" scenario analysis for banks, which is already intricate in itself



Note: Our own contribution is strongly based on Hardy and Schmieder (2013)

Source: Authors

Our insights underscore several caveats, highlighting the urgency for further research:

- First, the framework foresees static bank balance sheets and will typically focus on the most severe NGFS scenario, current policies, thereby establishing an upper bound for the impact at the country level. We note that tipping points could significantly alter our findings, especially in the long(er) term, which are not reflected in the current NGFS scenarios. However, newly emerging scenarios can be readily captured by the framework.

- Second, we assume that historically calibrated GDP elasticities of bank solvency parameters (credit losses, capital ratios) serve as meaningful predictors for the cause-and-effect relationships for indirect climate risk-related losses materialising through economic output.
- Third, we assume that we implicitly capture at least some of the feedback loops and second-round effects using the integrated NGFS scenarios and GDP elasticities of bank solvency observed during past banking crises.

The remainder of this paper is structured as follows: Section 2 reviews related studies. In section 3, we outline our framework and section 4 concludes.

2. Related work

As the available data will improve, the focus of climate risk analysis will gradually shift from assessing vulnerabilities (ie exposure to climate risk) to investigating actual risks (ie an assessment how climate risk could materialise and affect institutions) (FSB 2025). Risk analysis involve comprehensive and high-quality granular data, as well as complex concepts. Our framework tries to fill a gap, namely to run meaningful climate risk scenario analysis that focus on identifying the impact via macro-financial risk transmission channels using less granular data. Our approach provides high-level macro insights on the main channel, which can then be used to conduct a focused deep dive with more granular data.

Climate risk scenario analysis focussing on the ultimate risks of financial institutions is undergoing rapid development, propelled by public initiatives aimed at mitigating potential financial stability risks associated with climate change (BCBS, 2024; FSB, 2025; NGFS, 2024;). These evolving frameworks typically built upon established bank solvency frameworks (eg Acharya et al., 2023; Adrian et al., 2022; Bank of England, 2024; Baudino and Svoronos, 2021; BCBS, 2022; ECB, 2023; Federal Reserve, 2023/2024; FSB, 2025; NGFS, 2023; Reinders et al., 2023). Incorporating climate risk into these frameworks requires two key adjustments: expanding the framework to encompass relevant transmission channels through which climate risks can impact bank solvency, and extending the time horizon covered by the analysis to include medium- to long-term risks.[2]

Scenario analysis carried out by central banks and regulatory authorities (eg NGFS, 2021; ECB, 2023; Federal Reserve Board, 2023/2024) suggests that at the aggregate level, near-term risks tend to be contained for most banks, at least on a stand-alone basis, although they could be noteworthy under tail risks conditions, and will grow over time. There is consensus (eg Acharya et al., 2023; NGFS, 2022) that transition risks, particularly regulatory and technological risks, will mainly matter in

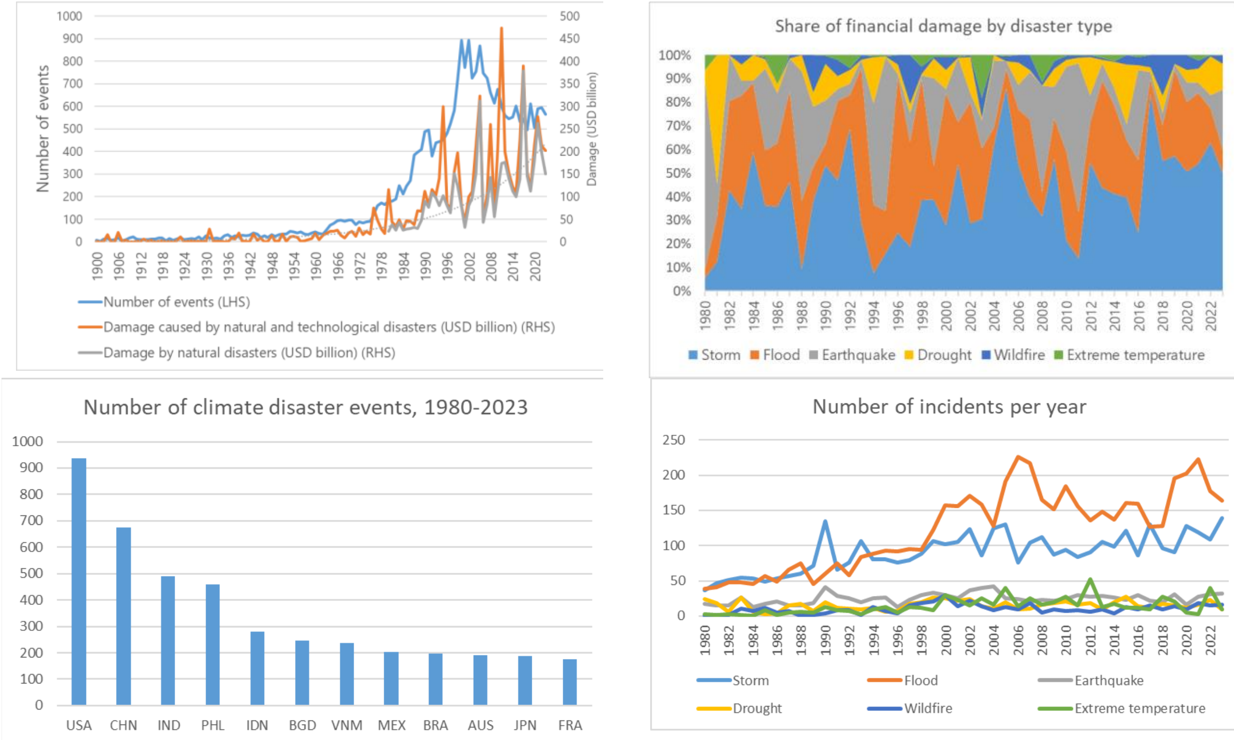
[2] The IPCC refers to a medium-term horizon of 2025-2074 and a long-term one from 2070-2099.

the near term (ie the next 25 years)[3], both through the market risk and credit risk channel, at least for the advanced economies. At the same time, physical risks are expected to gradually become the most critical climate risk type over the next three decades, especially through the credit risk channel.

Figure 2: Evolution of natural disasters over time

The financial impact of natural disasters has increased over time (1900-2023)[4] and some countries are more affected

The bulk of financial damage caused by natural disasters relates to storms and floods



The natural disasters included in the left graph are storms, floods, drought, wildfire and extreme temperature, while earthquakes were left out. The data on the financial impact is adjusted for inflation, with 2015 as the base year.

Source: EM-DAT.

At the same time, studies quantifying the potential impact of climate risk on capital requirements are still rare. Moreover, the ECB (2022) found that only a handful of frontrunners had voluntarily allocated economic capital for climate risks as part of their Internal Capital Adequacy Assessment Process (ICAAP).

[3] This assumes that climate policies are put forward during the coming years, which is the baseline for most scenarios.

[4] EM-DAT contains data on the occurrence and impacts of over 26,000 mass disasters worldwide from 1900 to today, but is more representative since 2000. The database is compiled from various sources, including UN agencies, non-governmental organisations, reinsurance companies, research institutes, and press agencies.

Climate risks encompass chronic or acute physical risks[5] stemming from climate-related hazards as well as transition risks (i.e., changes in climate policies and regulation, consumer preferences, or technological adjustments). The financial impact of adverse natural disasters measured in USD terms has been on a steep upward trend in recent years, which is, however, at least partly owed to more systemic recording (see Figure 2, upper left graph). While financial losses from storms and floods have been dominant physical risk materialisations until today (see Figure 2, right graphs), NGFS scenario analysis suggests that the impact from droughts and heatwaves will also increase substantially over time. The crossing of tipping points (a Minsky moment or Green Swan[6]) could result in steeper loss trends at shorter time horizons, also increasing the unexpected component of climate risk. The exposure of countries and financial institutions to physical risks varies widely (Figure 2, bottom left graph), and (smaller) banks with concentrated regional assets are therefore particularly exposed to climate risks.

3. Concept

The focus of this paper is on bank solvency in general, and the implications of climate risk on bank solvency more specifically, with a focus on credit risk. We recognise that other risk types also matter, including market risks (eg for transition risks) or liquidity risks (eg in case of a materialisation of severe physical risk scenarios affecting a large share of the balance sheet of specific banks).

Unlike in the case of "common" solvency risks faced by banks, such as bank credit losses, which are fairly stationary over time (Figure 3, top left), historical benchmarks for assessing the impact of climate change on bank solvency are not available. Moreover, to the extent they are accessible, they may not be representative due to the steep upward trend in the climate impact (Figure 3, bottom left). However, we can extrapolate potential future losses through scenario analysis, leveraging the work conducted by the NGFS on the macro-financial impact of climate risk scenarios. These extrapolations consider the evolving relationships between climate pathways and macro-financial conditions on the hand and the realised upward trend in the impact of natural disasters on the other. A comparison of aggregate numbers for the losses from natural disasters in the US with credit losses vis-à-vis non-public sector counterparties shows that the former could become relevant for banks (Figure 3, right graph)., especially if risks are concentrated in regions and/or institutions.

To simulate the potential impact of climate risk on bank losses and capital ratios, we integrate relevant transmission channels into the scenario analysis framework developed by Hardy and Schmieder (2013). This allows us to model both an isolated climate risk-related shock and an adverse event that may occur simultaneously with

5 Physical risk are direct manifestations of climate change on economic activity and asset values, including from floods, storms, heat waves and wildfire. Rising sea levels and flooding can cause economic damage by destroying housing and factories, heat waves can jeopardise agricultural activities (eg crop production), depress worker productivity and lead to an escalation of energy expenditure.

6 See Green Swan 2023: Climate transition in the real economy: what should central banks know about it? (bis.org).

a "traditional" macro-financial shock and/or financial crisis, with or without international spillovers.

Climate risk scenario analysis presents a distinct complexity compared to traditional scenario analyses. Our framework is designed to enhance comprehension of the fundamental elements at play, acknowledging that the lack of granular data used for our simulations (by design of our framework which is meant to be candid) may limit the precision of outcomes. As depicted in Figure 1, analysing climate risks on bank solvency involves three primary components and two translations of impact (see also Adrian et al., 2022):

- The first component involves establishing climate impact scenarios, which entails mapping emission and temperature pathways into physical and transition risk scenario realisations. For this aspect, we rely on NGFS input[7].
- The second component is to map climate impact scenarios into macro-financial scenarios, distinguishing between indirect effects on bank solvency through macroeconomic conditions and direct effects on losses and profitability. We draw upon NGFS analysis, which discerns between chronic and acute physical risk outcomes (i.e., their frequency and severity) and transition risks (determined by climate policies, technology, and evolving user behaviour).

The third component involves translating macro-financial scenarios into bank solvency parameters, utilising the work by Hardy and Schmieder (2013), as further elucidated below. We use the climate risk and macro-financial impact of different climate risk scenarios provided by the NGFS as key inputs for our work. Related work by the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA) are important benchmarks for the NGFS, but mainly focus on the possible evolution of greenhouse gas emissions (IPCC)[8] and are limited to the impact of transition risk until 2050[9] (IAE). Alternative modelling approaches find a similar GDP impact, including some scenarios which suggest more conservative outcomes than the NGFS (Kotz et al, 2024).

[7] We note that NGFS machinery builds upon other frameworks, given the complexity of the subject matter and multidisciplinary nature of the issue.

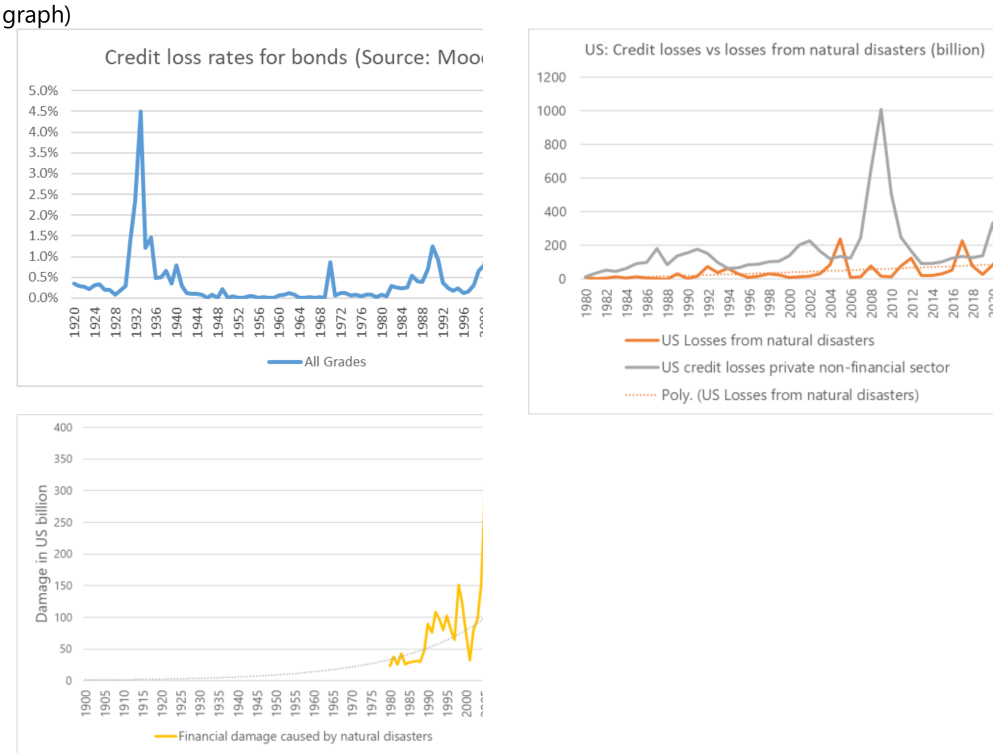
[8] Regarding assumptions on socio-economic drivers, the NGFS scenarios are based on IPCC work, while the IPCC frameworks uses input from the NGFS modelling.

[9] Ie the IEA does not project physical risk impacts and does not provide an outlook beyond 2050.

Figure 3: Climate risk related vulnerabilities are different from traditional solvency risks

Credit losses, the main driver for bank solvency, are fairly stationary (upper graph), while the financial impact of natural disasters has increased substantially over time (bottom graph)

Hence, over time, financial losses from climate risks could become a significant contributor to bank losses, at least at the regional level



The natural disasters included in the bottom left graph are storms, floods, drought, wildfire and extreme temperature, ie earthquakes were left out. The data on the financial impact is adjusted for inflation, with 2015 as the base year. Right hand graph: the two series are not directly related to bank exposures, but are meant to provide context of the magnitudes in general.

Source: Moody´s (2023) and EM-DAT.

The NGFS distinguishes between seven hypothetical scenarios, simulating potential low, median and high climate and macro-financial impacts through 2100 (Figure 4) to capture the distribution of outcomes. A main distinction is between orderly (Figure 4, bottom left scenarios in top left graph) and disorderly scenarios (Figure 4, upper left in top left graph). In the former case, climate risk policies are assumed to be implemented decisively early on, while disorderly scenarios assume delayed and divergent policy implementation. The hot house world scenarios (bottom right) assume decisive action in some jurisdictions but insufficient global efforts, whereby critical tipping points are exceeded, resulting in irreversible chronic physical risk (sea-level rise) and higher acute risks, too. The fragmented world scenario (top right) simulates the impact of a combination of delayed policy action and international divergence. The current policy scenario simulates a scenario without further measures, the most conservative benchmark. Key characteristics of the scenarios in terms of policy ambition, policy reaction, assumed technology paths, mitigation policies and regional variations is provided in Annex 2.

The NGFS uses a combination of models to simulate – with an attempt towards an integrated and consistent approach – transition and physical risks as well as macro-financial impact (Figure A1.2):

- Transition pathways are simulated based on three integrated assessment models[10],
- Physical risks are modelled using Earth System Models and Climate Impact Models and
- A macro-financial model (NiGEM[11]) uses the outputs of the other models as well as information from the international disaster database Emergency Events Database (EM-DAT) to project a series of macro-financial variables at the regional and country levels (Figure A1.3).

As acknowledged by the NGFS and documented by others (e.g., Acharya et al., 2023; Adrian et al., 2022), there exists a certain trade-off between the costs of mitigation policies (i.e., transition risk) and the realisation of physical risks, which would greatly benefit from internationally coordinated agreements and actions (Figure 4, top left graph). Key outputs of the NGFS machinery are temperature pathways (Figure 4, top right graph), the projected increase of carbon prices (Figure 4, bottom left graph) and the cumulative loss of GDP growth (bottom right graph).

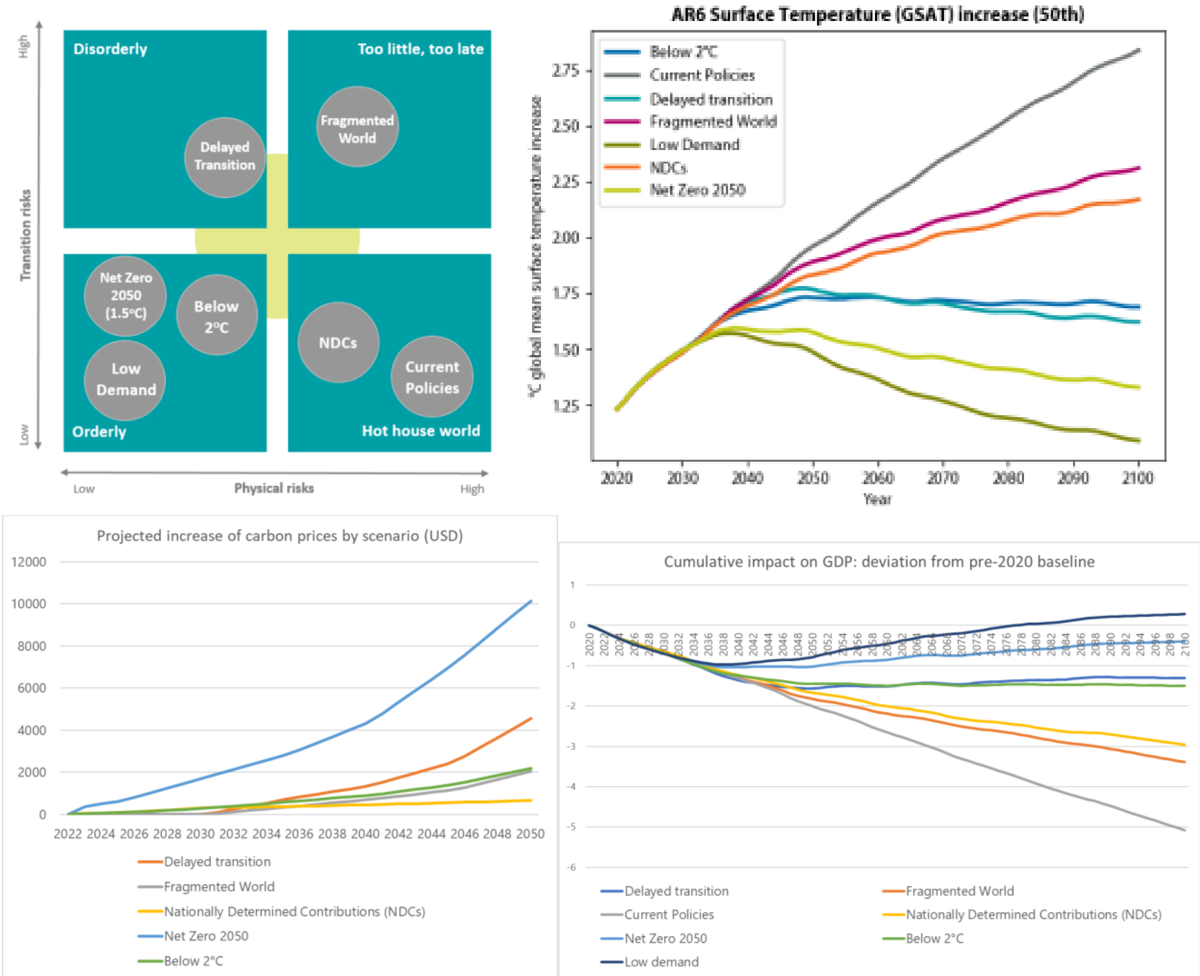
The transmission channels from climate risks to financial risks are illustrated in Figure A2.4: the materialisation of climate risk vulnerabilities is projected to gradually worsen economic conditions at the macro-level and micro level, which has implications on bank solvency (credit, market and operational risk), including through cross-border contagion and liquidity risks. The ultimate impact will depend on banks´ exposure to climate risks.

10 REMIND-MAgPIE, MESSAGE-GLOBIOM, and the GCAM models. We use outputs from the first model, which are most comprehensive in terms of the available variables, observing that their outcomes are generally fairly similar, at least at the aggregate level.

11 The National Institute Global Econometric Model (NiGEM).

Figure 4: NGFS climate scenarios

NGFS scenarios (Phase IV)



Note: NDCs: Nationally Determined Contributions; right graph: temperature increase relative to preindustrial conditions

Source: NGFS (2024)) [the scenarios have been updated sligthly since then]

The NGFS scenarios suggest the following main conclusions on the impact of climate risk on GDP growth paths:

1. There is substantial variation across countries, reflecting different exposure to climate related vulnerabilities (physical risks) and different levels of exposure of the industry to fossil fuels and trade (transition risk).

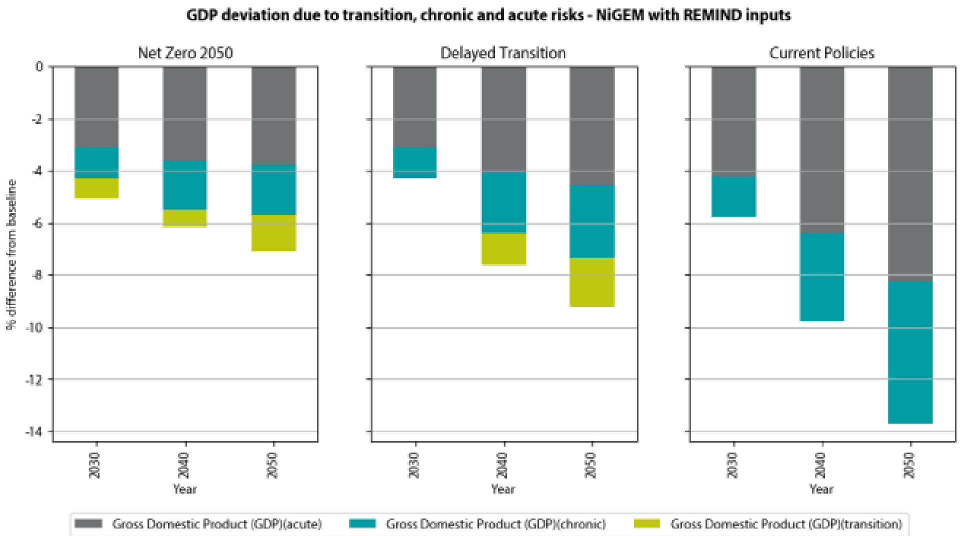
[12] Climate change's impact on economic output should be a significant area of focus, as highlighted by Acharya et al. (2023). Structural Dynamic Integrated Climate-Economy (DICE) models, as used by the NGFS for its scenarios, simulate climate change as a tax on consumption. This means that the economic damage is most severe when changes in GDP are highest, ie during boom periods. On the other hand, climate disaster models, such as those proposed by Weitzman (2012/14) and Barro (2015), assume that substantial physical risks from climate change and low GDP growth can coincide. In this model, low GDP states are the result of climate disaster realisations.

2. Vulnerabilities from chronic physical risks (modelled based on temperature pathways) are the dominant driver on GDP trajectories in the long-term and have a growing impact, while acute physical risk are the dominant structural driver until 2050 (Figure 5). Moreover, physical risks can have a strong short-term impact in case of a major acute climate risk event (eg storm, flooding).
3. Transition risks tend to impact GDP trajectories particularly in the near time, especially for the more ambitious climate scenarios (such as Net Zero 2050), but clearly lose relative impact vis-à-vis physical risk over time.
4. At the global level, GDP by 2050 is projected to be about 5-7 percentage point below a world with climate risk conditions frozen today, while GDP would be 14 percentage points below for the current policies. By 2100, the cumulative GDP loss is projected to be more than 20%.
5. In the near term (until 2030), the more ambitious climate risk scenarios may be more costly in terms of economic output, but they are associated with a net benefit from 2040.

It is important to note that the macro-financial impact provided by the NGFS does not incorporate the short-term impact of acute physical risk, costs related to sea-level rise or wider societal impacts from migration or conflict.

Figure 5: Impact of NGFS scenarios – aggregate outcome by scenario

GDP variation due to transition risks and physical risks (chronic vs acute)



Source: NGFS (2024) [the scenarios have been updated sligthly since then]

We differentiate between three steps to simulate the climate impact on bank solvency: in the first step, climate impact scenarios are established; second, those scenarios are translated into macro-financial impact; in the last step, the macro-financial scenario is mapped into bank solvency parameters, including credit losses and capital ratios. For steps 1 and 2, we mostly leverage NGFS work, while step 3 is based on the Hardy and Schmieder (2013) framework.

By contrast, traditional scenario analysis "only" requires a partial element of step 2 (establishing macro-financial scenarios) and step 3, which in itself is already a very complex undertaking (see Annex 1).

As illustrated in Figures 1 and A2.4, our contribution is three-fold:

1. We provide a framework to map the NGFS outputs into bank solvency, complementing the GDP trajectories provided by the NGFS with short-term scenarios for acute physical and transition risks.
2. We allow for the simulation of potential vulnerabilities transmitted through cross-border channels.

We establish findings on the relative impact of key drivers of climate risk vulnerabilities for banks, their evolution over time and variation across countries. We also allow for a simulation of a joint materialisation of a climate risk scenario with financial crises. Table 2 compares our approach with other frameworks used for climate scenario analysis, including by the Central Banks of France, the United Kingdom, and the ECB as well as the IMF in its Financial Stability Assessment Programmes (FSAPs). Moreover, the NGFS (2021) compared the approaches of 31 members, for which we have summarised relevant parameters in the table.

Our framework has the following features:

- To our best knowledge, it is the only one which is publicly available, using public data sources, but at the expense that the modelling is top-down at the aggregate, country-wide level, rather than informed by more granular, restricted data.
- It allows for a comprehensive modelling of risk types, ie
  - both climate risk and "traditional" solvency risks,
  - projects credit losses and capital ratios, and
  - distinguishes between structural medium/long-term risks vs short-term risks on the one hand and physical vs transition risks on the other (Box 1, Table 1). We attempt to avoid double-counting of potential impact, eg through direct and indirect channels.
  - allows to explicitly consider the impact of potential distress transmitted through cross-border channels, which may be an important transmission channel going forward, originating from trade (ie supply chains) and financial networks (Box 2).
- It enables simulations of the impact of climate risk and traditional financial risks for five-year periods for all decades until 2100, using the seven NGFS scenarios for long-term structural risks; the projection of short-term risks is based on a simplified approach (Table 1).
- We distinguish between banks based in advanced economies and emerging market economies, and – for the simulation of capital ratios – by the regulatory approach for credit risk (standardised approach or IRB).

- For the scenario analysis of financial risks, we distinguish between three scenarios – moderate, adverse and severely adverse, corresponding the worst in 15-20/30/50 year stress periods (Annex 1).

Box 1

Physical and transition risk modelling

For the modelling of physical and transition risks, we distinguish between structural and short-term (acute) risks on the one hand, and indirect vs direct impact channels on the other. The main transmission channels are as follows:

- Acute physical risks:
    - Floods and wildfires can reduce homeowners' capacity to pay back their mortgages, while negatively affecting banks´ collateral values and risk weights, exhibiting both direct and indirect elements.
    - Floods and wildfires can disrupt firms' value chains and production processes, reducing their ability to service loans and increasing banks´ risk weights, exhibiting both direct and indirect elements.
- Chronic and acute physical risks can lead to negative economic consequences, lower growth, and further impact both firms and households. This impact will be transmitted indirectly.
- Transition risk: A significant increase of the carbon tax could weaken banks' solvency profiles in carbon-intensive sectors, associated with defaults (direct impact) and lower GDP growth (indirect impact).
- Public policies: We capture public policies through the NGFS scenarios and the calibrated GDP elasticities for the banks solvency parameters, consisted with past practices during financial crises.

All structural risks, ie chronic and changes in "average" acute physical risks and transition risks, are inferred from the GDP trajectories projected by the NGFS scenarios, ie modelled through the indirect channel. These projections provide a range of potential scenario severities, depending on modelling assumptions, resulting in lower or higher GDP losses. In the tool, we provide users with the option to simulate the full range of scenarios, while our reported results are limited to general patterns and tendencies.

For the short-term scenarios, we use a combination of heuristics inferred from the projected GDP growth paths (ie the indirect channel) and realised outcomes for natural disasters (direct channel), consistent with the exposure of the different countries to physical risks. The calibration used for these scenarios is only meant to be indicative and will be refined as more studies become available. We provide users of the tool with options to change the calibration based on their own calibrations. For transition risks, we allow for a simulation of an abrupt increase in carbon prices.

Complementary information is provided in Annex 3.

Comparison of different climate scenario analysis frameworks[13] Table 1

Element	*NGFS (2021): Cross-country overview*	*BdF/ACPR (2021)*	*IMF Mexico FSAP (2022)*	*BoE/PRA (2021)*	*"Best practice" (ECB 2022)*	*ECB (2023)*	*IMF (2024)*	*Our framework*
Integration of solvency and climate risk	Depends	Credit risk and market risk, but not solvency risk	Yes	No	Yes	Credit risk and market risk, but not solvency risk	Credit risk	Yes, and also including cross-border spillover risks
Outcome (Impact ratio)	Capital ratios and/or losses	Loss provisions scaled by total exposures; Changes in fair value of trading book	Capital adequacy ratio	Projected credit losses	Expected credit losses	Expected credit losses on loan and bond portfolios	Potential loan losses from acute physical risks; Share of loans at risk (transition risk)[14]	All bank solvency components on capital ratios, focus on credit losses and capital ratios
Approach	Mix of top-down and bottom-up	Top-down	Top-down	Top-down	Bottom-up	Top-down	Top-down	Top-down
Time horizon	1 to 30 years (30 years most common)	30 years	5 years	30 years	Also use scenarios with longer time horizons	Short-to-Medium term (until 2-23-30)	10 year intervals (2030-2050)	5 year period, up to 2100
Scope of climate scenario analysis	Majority: macroeconomic, some sectoral analysis, Specific countries: counterparty level	All portfolios that are materially impacted	Credit portfolio of banks	All bank portfolios that are materially impacted	All portfolios that are materially impacted by climate risk	Loan and bond portfolio	Loan portfolio	Aggregate approach, ie no differentiation by asset type

[13] We also note that the Federal Reserve has conducted a pilot climate scenario analysis exercise for the six largest US banks, simulating physical risks (like a major hurricane hitting the northeast U.S.) and transition risks under different economic scenarios. These results will not affect capital adequacy assessments yet, but will refine future scenario assumptions.

[14] Loans at risk is defined as loans extended to borrowers that may not be able to service outstanding debt obligations due to deteriorating earnings. The study uses interest coverage ratio (EBIT/interest expenses) and classifies borrowers with ICR<1 as firms-at-risk.

	NGFS (2021): Cross-country overview	*BdF/ACPR (2021)*	*IMF Mexico FSAP (2022)*	*BoE/PRA (2021)*	*"Best practice" (ECB 2022)*	*ECB (2023)*	*IMF (2024)*	*Our framework*
Climate scenario specification	Varies, NGFS scenarios important benchmark		Five-year scenarios drawn from long-term NGFS scenarios	NGFS scenarios	In line with scientific climate change pathways	Short-to-medium term scenarios compatible with long-term temperature targets	Medium-to-long term scenarios (2030-40-50)	All NGFS scenarios
Number of scenarios		Three for transition risk, one for physical risk	Two for transition risk, multiple physical risk scenarios	Three	At least two for transition risk and one for physical risk	Three	One for physical risk, Two for transition risk	Integrated scenarios for all risk types; specific modelling for short-term scenarios
Physical risk	Majority of countries: yes	Yes	Yes (floods and tropical cyclones)	Yes	Scenario relevant for the respective geographical region	Yes	Yes (acute physical risks)	All types (structural risks), short-term scenarios for flooding risk
Transition risk	Majority of countries: yes	Yes	Yes	Yes	More than one transition risk scenario	No	Yes	Structural impact via GDP paths, plus short-term scenario
Static / dynamic balance sheet	Majority: static	Static for five years, re-assessed every five years	Static	Static for five years, re-assessed every five years	Both static and dynamic balance sheet	Static	Static	Static, reflecting today´s situation, to allow for comparisons and due to limited asset maturities

Sources: Authors based on Baudino and Svoronos (2021) and other references listed above

As documented in Table 2, the use of the "traditional" scenario analysis framework by Hardy and Schmieder (2013) framework (see Annex 1) is the main element of our framework to derive bank solvency outcomes. Specifically, it allows for a mapping of the manifestations of different combinations of physical and transitional risks as per the NGFS scenarios through 2100 (NGFS, 2023) into bank solvency outcomes through their respective GDP trajectories.

As banking crises have tended to last up to 5 years, we simulate short-term climate risk scenarios with and without a simultaneous occurrence of financial crises, for today´s conditions and vs potential climate risk conditions until 2100 (Table 1).

We establish the potential direct and indirect impact of climate risk events. This encompasses direct financial losses encountered by banks, as well as losses incurred indirectly through macro-financial downturns, into trajectories for banks' credit losses and capital ratios. When considering the indirect impact, our approach operates on the assumption that historically calibrated GDP-elasticities—quantifying the non-linear impact of changes in GDP growth rates—on banks' credit losses and capital ratios during banking crises serve as meaningful predictors for climate-related economic output losses.[15] For assessing the potential short-term direct impact, we use a combination of losses extrapolated from observed disaster events and tail risks inferred from the Network for Greening the Financial System (NGFS) scenarios.

15 Relevant factors for this assumption encompass the extent of policy support provided to mitigate the repercussions of stress, structural characteristics of the economy (e.g., distinguishing between advanced and emerging market economies), and the resilience of the financial system, among others.

Overview of our scenario analysis: climate risk and traditional risks Table 2

	Scenarios	Outcome	Horizon	Bank impact
Climate risk	7 NGFS scenarios (Figure 4), covering structural risks, plus short-term shocks and cross-border impact	(a) Structural impact only, (b) structural impact and short-term impact on credit losses and capital ratios	Forward-looking short-term scenarios, simulating climate risk situation for the forthcoming decades until 2100	Average impact by country
Traditional financial risks	Moderate, adverse and severely adverse scenario observed in past financial crises & user defined scenarios and cross-border impact	Credit losses and capital ratios for banking crises scenarios	Scenarios for 5 years, based on past crises evidence	Average impact observed during past crises

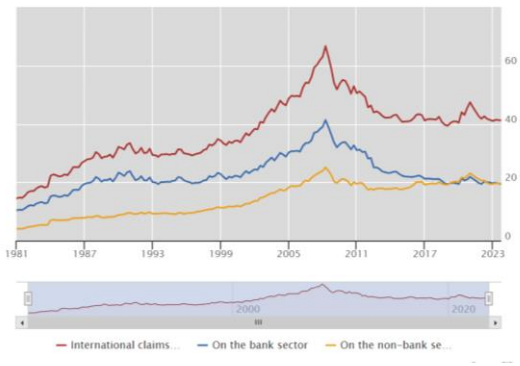
Source: Authors

Existing climate change studies tend to confine their focus to impacts within the same geographical location, ignoring the cross-border impacts of climate shocks, and the same often applies to scenario analysis for "traditional" solvency risks. Besides the conceptual modelling complexity, data accessibility across jurisdictions is another important challenge impairing the analysis of cross-border transmission of climate shocks (FSB-NGFS, 2022). However, not considering international transmission channels (see Box 2) may result in underestimating the financial stability implications of climate change. For instance, some EMDEs that may face the most adverse effects of climate change are dependent on cross-border bank lending (FSB, 2021).

The materiality of cross-border claims between banks and bank lending to non-banking sectors reinforces the case to bring those into the picture: the volume of cross-border claims measured against GDP has more than doubled during the past 40 years (Figure 6, red line in left chart). Much of the increase came from lending to non-banks (yellow line in left graph, right graph), while interbank claims have been at around 20% of GDP on average, after a spike to 40% in 2008.

Figure 6: Evolution of cross-border claims

Total cross-border claims are about 40% of global GDP, half of which are interbank claims and claims to non-bank sectors	The claims to the private non-financial sector are growing proportional to GDP and are equivalent to about 15% of global GDP, ie about 14% of total bank claims, but with a substantial variation across countries



Source: BIS banking statistics

As further outlined in Box 2 and Annex 4, we simulate international scenarios to determine the inward- and outward-spillovers of recession scenarios depending on the intensity of the trade and financial network relationships.

- For the impact of recessions in one country on credit losses and capital ratios in other economies we use the GDP elasticities from Hardy and Schmieder (2013) along with the share of cross-border claims in total credit assets. As documented by Cerutti and Schmieder (2014), cross-border claims can make up a material share of bank assets.
- To mitigate the impact of stress, banks will try to reduce their exposure to countries affected by crises. To gauge this impact, we established econometric results (Annex 4), suggesting that banks have substantially reduced their cross-border claims around crises, especially during severe crises.

Box 2

Modelling of cross-border spillover risk

While cross-border claims can facilitate risk sharing and diversify idiosyncratic risks, they can give rise to systemic risk concerns (Claessens and van Horen, 2014; Bruno and Shin, 2015; Karolyi et al., 2022), amplify losses if shocks occur simultaneously in several countries or are clustered in one geographical region. Interbank claims are a channel through which vulnerabilities of one institution can be rapidly transmitted through the system, as evidently shown during the GFC. Hale et al. (2020), for example, show that non-bank cross-border exposure to simultaneous crises causes significant profitability losses for banks and influences their lending behaviour; banks decrease new business loans and raise interest rates (spreads) on such loans due to crisis-related risks. Higher interconnectedness could also raise challenges to handle the resolution of financial institutions and pitch home and host supervisors against each other.

Given the global nature of climate change, transition and physical shocks can affect multiple countries simultaneously or in quick succession. Such shocks could also be transmitted across borders through the global network of financial claims, triggering global financial stability concerns. These effects could give rise to global contagion that further amplifies the consequences of these shocks through the real and financial channels.

Climate shocks and financial shocks more generally can be transmitted through cross-border claims via the following transmission channels (FSB, 2021):

- Credit Risk: Banks extend credit to borrowers in foreign countries through various instruments like loans, bonds, and derivatives. If the creditworthiness of these borrowers deteriorates due to economic or political shocks, banks may incur losses on their cross-border claims (e.g., higher write-downs on non-performing exposures). These losses can erode the capital of the lending banks, reducing their ability to lend and potentially triggering a broader credit squeeze in the home and host country.

- Market risk: Banks may face valuation losses on securities and, to the extent that these are "held for trading", mark-to-market losses can further affect bank net income and profitability (Hale et al., 2020).

- Liquidity Risk: Shocks can lead to sudden changes in market conditions, making it difficult for banks to access funding or sell assets. If banks have significant cross-border claims that they need to liquidate to raise cash, this can put further downward pressure on asset prices and disrupt financial markets.

- Funding risk: Information contagion, where the market discounts banks that have more cross-border exposures to affected jurisdictions, may face higher funding costs. Prior literature documents how borrower defaults or bankruptcy result in adverse equity market reaction for lending banks and their ability to syndicate loans (Dahiya et al., 2003; Gopalan et al., 2011).

Annex 4 details our modelling approach.

4. Conclusion

This paper introduces an accessible framework to evaluating banks´ climate vulnerabilities using scenario analysis.

During the coming years, the field of climate scenario analysis will likely benefit from conceptual advancements, along with better data, to narrow down potential outcomes for the various scenarios. Work by the FSB (2023/2025), the NGFS (2024) and the BCBS (2024) will be key elements to further both concepts and outcomes. Market-based scenario analysis approaches could also become a useful complement and benchmark for balance-sheet based approaches (Acharya et al 2023), especially for transition risks.

Given the flexibility of our framework, it can be adjusted to reflect the evolving findings of other, more detailed scenario analysis work, with the overarching principle to keep the concept as simple as possible. Adjustments to bank behaviour over time will be a crucial dimension to be captured, ie whether banks continue to lend in areas exposed to climate risk, how they adjust prices in such cases and how competition might affect such trends.

Besides climate risks, banks will face a number of structural changes during the years to come, including socio-economic (aging) and technological change. Using scenario analysis to take a holistic perspective on potential vulnerabilities affecting their business models, associated profitability and risk profiles, will be very important.

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Annexes

Annex 1: Scenario analysis for banks

Scenario analysis for banks and other financial institutions have gained significant prominence in the aftermath of the 2007-2008 global financial crisis. The European Banking Authority's (EBA) stress test and the Dodd-Frank Act Stress Test in the United States (now complemented by the Comprehensive Capital Analysis and Review, CCAR) have played a pivotal role in shaping the evolution of bank stress testing.

It has become a critical tool for regulators, policymakers, and banks themselves to assess the resilience of financial institutions to adverse economic and financial cycle conditions. While the analyses vary in their design (concept, time frame, top-down or bottom-up approach) and scope (risk types, types of scenarios, number of banks), the ultimate objective is the same: to establish an understanding of potential vulnerabilities faced by banks to inform policy work (for authorities) or management decisions (for banks themselves) (see Ong and Jobst 2020, for example).

Our framework relies on Hardy and Schmieder (2013), who have established – based on a wide range of evidence from previous banking crises – GDP elasticities on critical solvency components of banks, including credit losses, pre-impairment income (ie including valuation changes etc), asset growth patterns, risk-weighted assets and overall capital ratios.

The calibration is Hardy and Schmieder (2013) suggests a GDP elasticity of bank capital ratios ranging from 0.1 to 0.5, depending on the severity of the shock (which has a non-linear impact), the type of the economy (advanced vs emerging) and regulatory approach to credit risk (Standardised Approach vs Internal rating-based approach, IRB). For adverse banking crisis (one in 20-40 years), a bank based in advanced economies using the IRB, a scenario with a cumulative deviation of GDP growth by 8.5 percentage points over four years would lead to a reduction in its capital ratio at the trough by about 2.5 percentage points (=8.5 percentage point loss of GDP growth times 0.3 GDP elasticity of capital ratios). Under the same scenario, the bank would have to expect its credit loss rate to peak at 1.5% (=0.3% + 8.5 percentage point loss of GDP growth times -0.15 GDP elasticity of credit loss rates), five times the 0.3% under “normal” conditions.

Annex 2: NGFS Scenarios and modelling framework

Figure A2.1: NGFS scenarios by key assumption

Table 2. Overview of NGFS scenarios by key assumptions. The table maps out key features of the scenario narrative and their macro-financial risk implications stemming from transition or physical risk. Green means "low risk", yellow means "medium risk", red means "high risk".

Category	Scenario	End of century (peak) warming – model average	Policy reaction	Technology change	Carbon dioxide removal -	Regional policy variation +
Orderly	Low Demand **(NEW)**	1.4°C (1.6°C)	Immediate and smooth	Fast change	Medium use	Medium Variation
	Net Zero 2050	1.4°C (1.6°C)	Immediate and smooth	Fast change	Medium-high use	Medium Variation
	Below 2°C	1.7°C (1.8°C)	Immediate and smooth	Moderate change	Medium use	Low variation
Disorderly	Delayed Transition	1.7°C (1.8°C)	Delayed	Slow/ Fast change	Low-medium use	High variation
Hot house world	Nationally Determined Contributions (NDCs)	2.4°C (2.4°C)	NDCs	Slow change	Low-medium use	Medium variation
	Current Policies	2.9°C (2.9°C)	None - current policies	Slow change	Low use	Low variation
Too-little-too-late	Fragmented World **(NEW)**	2.3°C (2.3°C)	Delayed and Fragmented	Slow/ Fragmented change	Low-medium use	High variation

Source: NGFS

Figure A2.2: NGFS suite of models approach

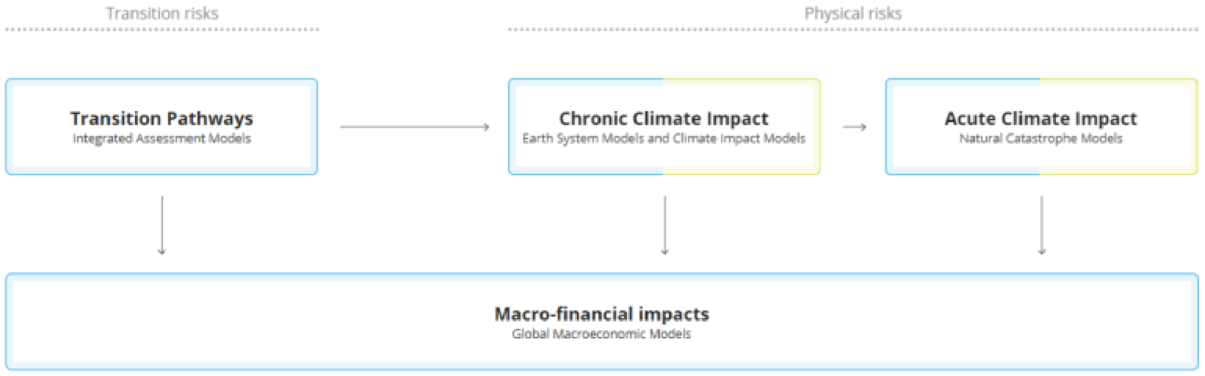


Figure 1. NGFS suite-of-models approach

Source: NGFS

Figure A2.3: Overview of NGFS output variables

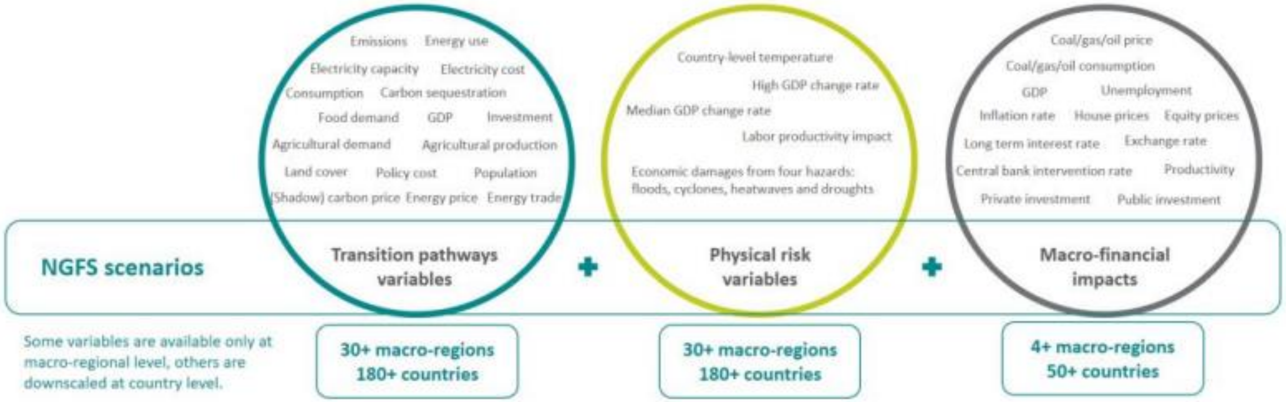


Figure 2. Overview of the range of data provided by NGFS scenarios.
Note: this visual does not contain the full list of variables and is for illustrative purposes only. The names of the variables do not necessarily correspond to the ones used in the databases. The number of countries/regions available varies significantly depending on the variable. Downscaled climate-related and macro-financial variables are available for 180+ and 50+ countries, respectively.

Source: [NGFS]

Figure A2.4: Overview of transmission channels

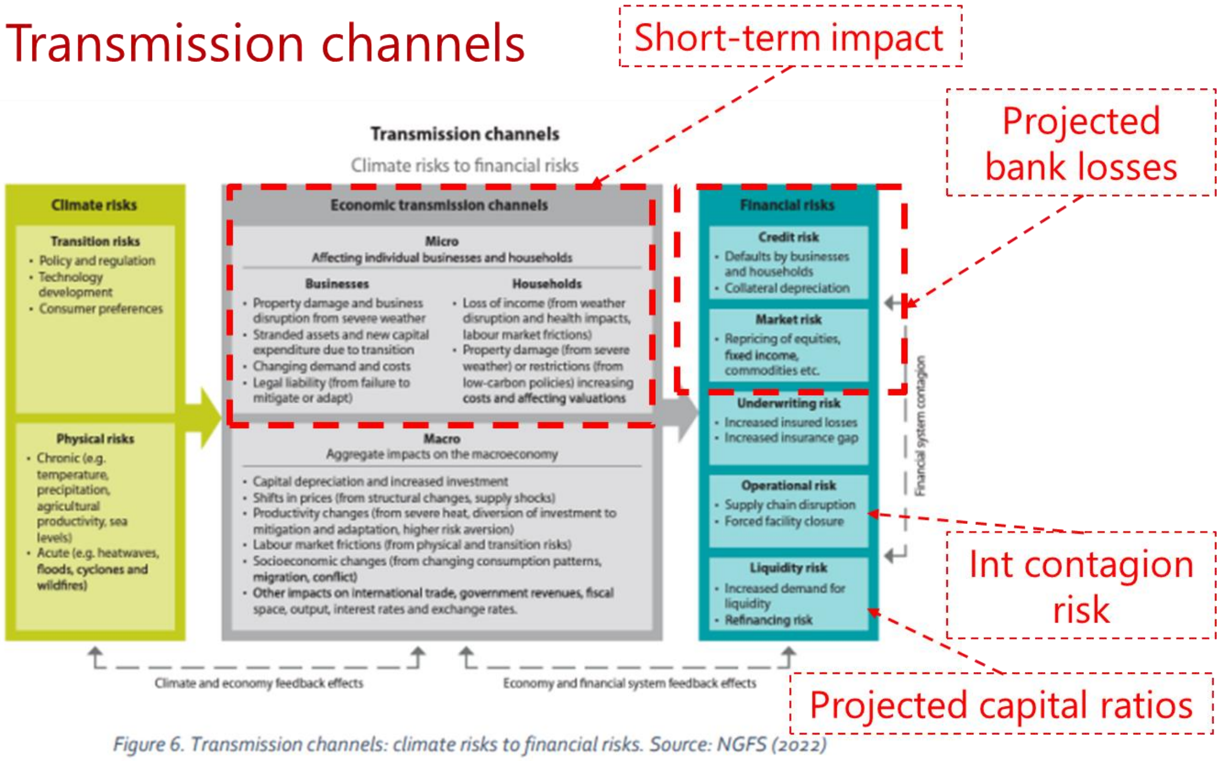
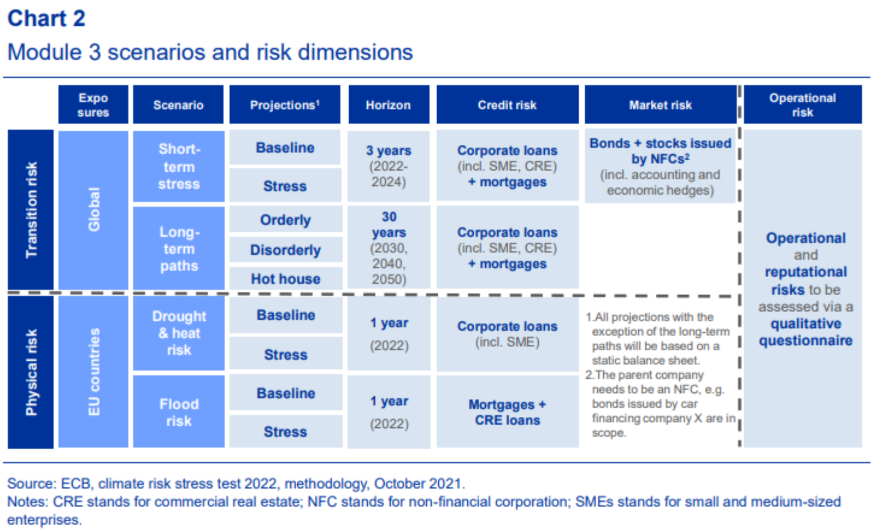


Figure 6. Transmission channels: climate risks to financial risks. Source: NGFS (2022)

Source: [NGFS]

Annex 3: Scenario analysis modelling

Figure A3.1: Climate risk scenarios used by the ECB in their 2022 bottom-up exercise



ECB (2022)

Navigating Climate Vulnerabilities: Scenario Analysis for Banks

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6 May 2024

* The views expressed are those of the presenter and do not necessarily reflect those of the BIS, FSB, or IAIS.

Preview of results

- Attempt to establish forward-looking top-down estimates of climate risk impact on banks until 2100
- Conservative estimates under static balance sheets across countries and over time, for loan pricing and bank capital
- Bird’s view of evolving climate risks in the global banking system and how such risks, when realised, could be transmitted and amplified
- Outcome: Short-term and structural impact of climate shocks growing over time, especially in countries that are more exposed to climate risk

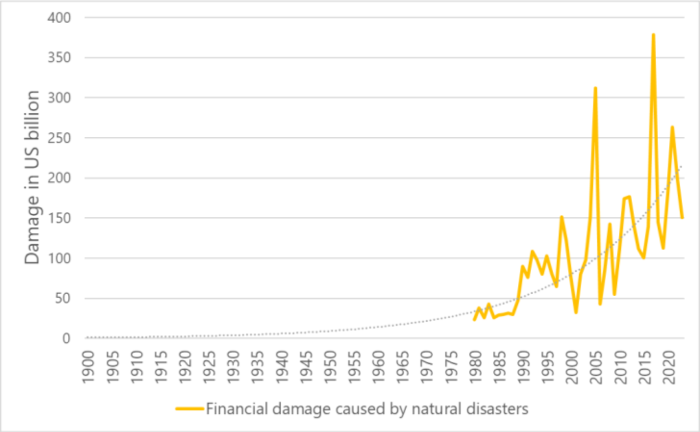
Motivation

- FSB Roadmap for Addressing Financial Risks points to a need for…
  - better data (firm disclosure, aggregate data) and
  - improving conceptual frameworks to assess Financial Stability risks

  … to inform regulatory and supervisory policy work
- Many central banks and IMF are conducting climate scenario analysis
- This work fills a gap
  - Accessible top-down concept to run climate risk scenario analysis for banks at the country level for a wide range of countries
  - Helps understanding transmission channels and illustrates sensitivities of outcomes over time and across countries, including through cross-border channels

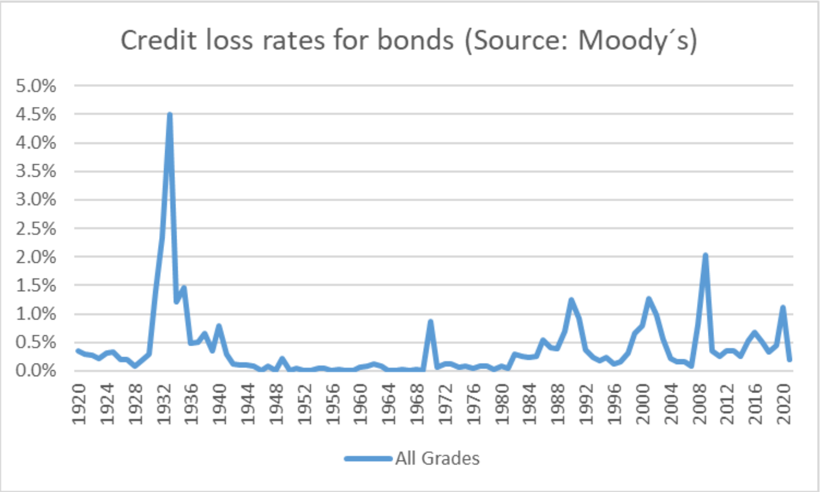
Climate risk vs macro-financial bank solvency risks

- Climate risks are expected to grow over time (→ no historical benchmarks)



Source: EM-DAT

- Bank solvency risks are fairly stationary, all else equal (→ historical benchmarks)



- Similar concept: expected impact vs unexpected tail risk

Concept: Climate risk scenario analysis is much more complex than traditional scenario analysis

Climate risk scenario analysis

Climate pathways
- Mapping of emissions / temperatures into climate impact scenario

→

Macro-financial impact
- Indirect impact: loss of GDP (vs baseline)
- Direct impact: financial losses (lower asset values, bankruptcies)

→

Bank solvency impact
- Credit losses, profitability
- Capital ratios

Traditional solvency scenario analysis

Macro-financial crisis
- Indirect impact: loss of GDP (recession)
- Direct impact: financial losses

→

Bank solvency impact
- Credit losses, profitability
- Capital ratios

Source: Authors

Taken from NGFS

Own contribution

Concept: cross-border transmission

- Climate shocks can have international spillovers due to
  - trade and financial interlinkages and
  - climate event affecting multiple jurisdictions
- We capture cross-border credit risk transmission channel:
  - Indirect and direct impact of climate risk event in host countries on credit losses through cross-border exposures
  - Sensitivity of cross-border bank claims to economic downturn of host countries affected by shock (may mitigate impact)
  - Impact will depend on intensity of economic and financial linkages

Scenarios: Climate risk vs “traditional” risks

	Scenarios	Outcome	Horizon	Bank impact
Climate risk	7 NGFS scenarios, plus short-term shock scenarios (user-defined)	Impact on credit losses and capital ratios	Forward-looking short-term scenarios (5 years), simulating climate risk situation for the forthcoming decades until 2100	Average impact by country
Traditional financial risks	Moderate, adverse and severely adverse & user defined scenarios, calibrated based on past crises evidence	Impact on credit losses and capital ratios	Scenarios for 5 years	Average impact observed during past crises
Combined scenarios	Any combination of the climate risk and traditional financial risk scenario (the marginal impact of the climate risk scenarios increase based on the severity of the underlying macro-financial scenario)			

Source: Authors

Scenarios: Potential bank behaviour

	Potential impact on pricing	Potential impact on bank capital	Caveats
Structural Climate risk	Higher solvency risk (expected loss) of bank customers reflected in higher loan prices	Indirect impact, since tail risk scenarios may get worse, see below	Difficult to model long-term trends; static balance sheet assumption
Short-term tail risk	Banks may disengage from specific sectors or pass on costs for higher capital consumption to their customers	Banks may face direct losses (eg on their collateral) and could decide to allocate more capital, which may increase credit prices and reduce banks' lending capital, which has macroeconomic implications	Difficult to extrapolate tail events; managerial and regulatory developments will play an important role; static balance sheet assumption

Source: Authors

Conclusion and caveats

- Our framework:
  - Accessible approach to establish global perspective of climate risk impact on bank solvency at the country level, both short- and long-term
  - Flexible to modify elements and update parameters using incoming evidence and new concepts (eg BCBS 2024)
- Besides climate risks, banks will face aging risks and technological change

- Assumptions / caveats
  - Static projection (eg balance sheets)
    - Duration of bank assets are short relative to climate risk horizon; adjustment of bank behaviour will matter greatly (upper bound)
  - Use of aggregate data and simplified, but comprehensive modelling
  - Reliance on historical relationship between GDP and solvency
  - Scenarios: Tipping points could have substantial impact on climate outcomes and thus bank solvency