Physical Climate Risk Assessment: Practical Lessons for the Development of Climate Scenarios with Extreme Weather Events from Emerging Markets and Developing Economies

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Central Banks and Supervisors Network for Greening the Financial System

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Abbreviations

CAR	capital adequacy ratio
CBES	Climate Biennial Exploratory Scenario
CLIMADA	CLIMate ADAptation model
EMDE	emerging market and developing economy
GCM	General Circulation Model
GDP	gross domestic product
GVA	gross value added
IPCC	Intergovernmental Panel on Climate Change
LGD	loss given default
MSMEs	micro, small, and medium enterprises
NDC	Nationally Determined Contribution
NGFS	Network for Greening the Financial System
NPL	nonperforming loan
PD	probability of default
RCM	Regional Climate Model
WEO	World Economic Outlook

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1. Executive summary

Emerging markets and developing economies (EMDEs) rank among the most vulnerable to climate change, and they are significantly exposed to both physical and transition risks. Climate risk assessment can provide a structured approach to identify, analyze, and evaluate such risks, and ultimately inform risk management decisions. This note focuses on the assessment of acute physical climate risks associated with extreme weather events. For EMDEs, performing a physical climate risk assessment poses unique challenges that can discourage authorities from engaging in such an exercise. In addition to the diverse climate risk profile and economic status of EMDEs, scarce and poor-quality data coupled with limited local technical capacity make it difficult for EMDEs to apply existing frameworks for climate risk assessments or build on experiences from advanced economies.

Physical climate risk assessments have been conducted in various EMDEs, including the Philippines, Indonesia, Morocco, Tunisia, and countries in Western Africa, by the World Bank and others. The main lesson from these recent experiences is that climate risk assessment methodologies used in developed countries may not be fully replicable in EMDEs, and that such risk assessment should therefore be adjusted to factor in the country's specificities and (data) constraints.

This note aims to complement existing climate risk assessment literature by providing central banks and prudential supervisory authorities in EMDEs with a practical framework for assessing physical climate risks with extreme weather events. This note includes references and links to data sources and tools with good global coverage, which can be very useful for EMDEs. A large majority of data sources and tools used for risk assessment in developed countries have low coverage in some EMDEs or require granular input data sets that are not yet available in EMDEs. Building on a series of case studies in EMDEs, this note proposes a practical framework for assessing physical climate risk and illustrates how to complete a physical climate risk assessment by leveraging existing data and tools.

The proposed practical framework builds on six key steps: (i) define the needs and objectives; (ii) identify available data and resources; (iii) define the scope and approach; (iv) generate the scenarios; (v) estimate the impacts; and (vi) present and interpret the results.

Several key lessons related to the implementation of this practical framework can be drawn:

1. A country-specific approach that is tailored to the needs and objectives identified by local stakeholders should be adopted.
2. There is a wide range of existing data sets and resources (including open source data sets, tools, and models, along with methods to improve data granularity), and it is important to identify which ones can be used to best support the assessment.
3. A staged approach—one that moves from qualitative assessment (e.g., in case of limited data) to a more sophisticated quantitative assessment when data and expertise are available—should be used. The scope and approach of the analysis should be defined based on country specificities, data availability, and local technical capacity.
4. Climate scenarios should (i) be plausible; (ii) explore a range of different options; (iii) enable climate-related macroeconomic and financial risks to be identified and assessed (by considering the geographic distribution of hazard and exposures); and (iv) enable key sensitivities and nonlinearities to be captured.
5. The analysis should capture both direct impacts (physical damages) and, when possible, indirect impacts occurring through the main transmission channels to the economy and the financial sector. When possible, the analysis should also capture short- and long-term effects. The estimation of indirect impacts requires a more sophisticated analysis (including macro modeling) and more granular data.
6. The presentation of results should focus on the order of magnitude and trends, and clearly discuss uncertainties, assumptions, and limitations.

2. Introduction

Emerging markets and developing economies (EMDEs) rank among the most vulnerable to climate change, and they are significantly exposed to both physical and transition risks. Climate change threatens the populations, businesses, and economies of EMDEs and is increasingly impacting the behaviors of investors, financial markets, and financial institutions.

Physical risks from climate change may be driven by both chronic risks associated with gradual changes in climate patterns (e.g., gradual increases in temperatures) and acute risks associated with increased frequency and/or severity of weather events (e.g., tropical cyclones, storms, floods, and droughts).[1] Financial institutions and financial systems are exposed to these risks; central banks and prudential supervisory authorities have a critical role to play in managing them. Physical climate risk assessment provides a structured approach to identify, analyze, and evaluate such risks. It can help improve the resilience of the financial sector and identify opportunities for climate adaptation finance (such as insurance, catastrophe bonds, and other climate-resilient financial instruments).

The Network for Greening the Financial System (NGFS) has produced a series of reports to guide climate risk assessments by central banks and supervisors, including "Guide for Supervisors: Integrating climate-related and environmental risks into prudential supervision,"[2] "Guide on Climate-Related Disclosure for Central Banks"[3] and "Guide to Climate Scenario Analysis for Central Banks and Supervisors."[4] These publications offer useful methodologies and principles to inform climate risk assessment, reporting, and disclosure. Alongside production of these guidance notes, the NGFS and other international bodies have been monitoring the progress of financial authorities in implementing climate risk assessment. For example, the Financial Stability Board[5] and the NGFS[6] both recently presented stocktakes on climate risk assessment exercises. They find that there is considerable variation in the degree to which authorities consider climate-related risks, and that assessments use a wide range of top-down and bottom-up approaches. The reports also flagged the limited number of EMDEs committed to performing climate assessments. Indeed, such an assessment in EMDEs can be challenging because of scarce and poor-quality data coupled with limited local expertise. The impact of data and methodological gaps on climate risk assessments was one of the issues highlighted in the NGFS "Progress Report on Bridging Data Gaps."[7]

This note aims to complement existing NGFS publications with some evidence-based guidance for central banks and financial sector authorities in emerging markets, drawing from recent experiences in EMDEs.

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[1] European Bank for Reconstruction and Development and Global Centre of Excellence on Climate Adaptation, "Advancing TCFD Guidance on Physical Climate Risks and Opportunities," December 2018, http://427mt.com/wp-content/uploads/2018/05/EBRD-GCECA_final_report.pdf.
[2] NGFS, "Guide for Supervisors: Integrating climate-related and environmental risks into prudential supervision,"2020, https://www.ngfs.net/sites/default/files/medias/documents/ngfs_guide_for_supervisors.pdf.
[3] NGFS, "Guide on Climate-Related Disclosure for Central Banks," 2021, https://www.ngfs.net/sites/default/files/medias/documents/guide_on_climate-related_disclosure_for_central_banks.pdf.
[4] NGFS, "Guide to Climate Scenario Analysis for Central Banks and Supervisors," 2020, https://www.ngfs.net/sites/default/files/medias/documents/ngfs_guide_scenario_analysis_final.pdf.
[5] Financial Stability Board, "Stocktake of Financial Authorities' Experience in Including Physical and Transition Climate Risks as Part of Their Financial Stability Monitoring," 2020, https://www.fsb.org/wp-content/uploads/P220720.pdf.
[6] NGFS, "Scenarios in Action: A Progress Report on Global Supervisory and Central Bank Climate Scenario Exercises," 2021, https://www.ngfs.net/en/scenarios-action-progress-report-global-supervisory-and-central-bank-climate-scenario-exercises; NGFS, "Progress Report on the Guide for Supervisors," 2021, https://www.ngfs.net/sites/default/files/progress_report_on_the_guide_for_supervisors_0.pdf.
[7] NGFS, "Progress Report on Bridging Data Gaps," 2021, https://www.ngfs.net/sites/default/files/medias/documents/progress_report_on_bridging_data_gaps.pdf.

It may take time for most EMDEs to meet their need for more and/or better data; but there is room to better leverage existing data and approaches,[8] including using proxies and modeled data, considering qualitative approaches, and building capacity and skills within financial institutions in EMDEs.

A range of existing publications outline approaches to acute physical climate risk assessment. For example, the UN Environment Programme Finance Initiative has authored several useful overviews of methodologies.[9] The 2019 report by the Cambridge Institute for Sustainability Leadership[10] outlines a physical risk framework targeted at investors and lenders and demonstrating how climate models can be used in combination with catastrophe models to assess physical risks.

These existing publications are of great value, but they do not fully capture the diverse needs and challenges among EMDEs for climate assessment. For example, some tools reviewed in these publications have low data coverage in some regions, including regions associated with EMDEs. Furthermore, many of the tools require granular input data sets that may not yet be available in some EMDEs. Existing publications tend to emphasize sophisticated quantitative methodologies, with case studies drawn from countries that do not face the same data or technical-capacity constraints as EMDEs. While often-cited examples from the Netherlands,[11] France,[12] and the United Kingdom[13] provide excellent insight into the sophisticated assessment methods used in a number of developed economies, they may not always be replicable in EMDEs given their specific objectives and challenges.

This note focuses specifically on the assessment of acute physical climate risks associated with extreme weather events. It complements existing literature by providing a simple and practical methodological framework for extreme physical climate risk assessment aimed at central banks and supervisors in EMDEs. It draws some practical lessons for physical climate risk assessment in EMDEs, with a specific focus on extreme weather events associated with acute physical climate risk. The framework is designed to be flexible, recognizing that there is no one-size-fits-all approach; rather, unique needs, objectives, and data and resource availability should be considered. The note highlights publicly available data sets and resources that can be leveraged for the risk assessment. As those involved in the risk assessment become more familiar with the process, and as additional data and resources become available, future iterations may add further sophistication and generate additional insights.

The note includes several case studies in EMDEs and illustrates how to complete a climate risk assessment to inform the authorities and stakeholders even when operating in data- and resource-constrained environments. The country case studies also illustrate the wide variety of risk metrics, outputs, and applications.

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[8] Ibid.

[9] UN Environment Programme Finance Initiative, "Charting a New Climate: State-of-the-Art Tools and Data for Banks to Assess Credit Risks and Opportunities from Physical Climate Change Impacts," 2020, https://www.unepfi.org/publications/banking-publications/charting-a-new-climate/; UN Environment Programme Finance Initiative, "The Climate Risk Landscape: Mapping Climate-Related Financial Risk Assessment Methodologies," 2021, https://www.unepfi.org/publications/banking-publications/the-climate-risk-landscape/; UN Environment Programme Finance Initiative, "The Climate Risk Landscape: 2022 Supplement," 2022, https://www.unepfi.org/publications/the-climate-risk-tool-landscape-2022-supplement/.

[10] Cambridge Institute for Sustainability Leadership, "Physical Risk Framework: Understanding the Impacts of Climate Change on Real Estate Lending and Investment Portfolios," 2019, https://www.cisl.cam.ac.uk/system/files/documents/cisl-climatewise-physical-risk-framework-report.pdf.

[11] De Nederlandsche Bank, "Waterproof? An Exploration of Climate-Related Risks for the Dutch Financial Sector," 2017, https://www.unepfi.org/psi/waterproof-an-exploration-of-climate-related-risks-for-the-dutch-financial-sector/.

[12] ACPR, "Climate Change: Which Risks for Banks and Insurers: No. 101: French Banking Groups Facing Climate Change-Related Risks," 2019, https://acpr.banque-france.fr/sites/default/files/medias/documents/as_101_climate_risk_banks_en.pdf.

[13] Bank of England, "The 2021 Biennial Exploratory Scenario on Financial Risks from Climate Change," 2019, https://www.bankofengland.co.uk/-/media/boe/files/paper/2019/the-2021-biennial-exploratory-scenario-on-the-financial-risks-from-climate-change.pdf?la=en&hash=73D06B913C73472D0DF21F18DB71C2F454148C80.

While the note is mainly targeted at central banks and supervisors, the decision-useful analysis inherent in the note's climate risk assessment methodology might also prove useful to the wider financial community. Through forward-looking assessment of acute climate shocks and their socioeconomic impacts, the proposed framework can support better-informed decision-making for a broad range of potential applications, including the management of climate-related public contingent liabilities, central banks' climate stress-testing, and climate-resilient financial product development (Figure 1).

Source: World Bank.

Figure 1. Some applications of physical climate risk assessment

3. Physical climate risk assessment concept

Climate risks fall into two categories: (i) transition risks related to the transition to a low-carbon economy, and (ii) physical risks related to the physical impacts of a changing climate, including the risk of destruction of assets and/or disruption of operations, trade routes, supply chains, and markets. Physical climate risks can be further categorized into (i) chronic physical climate risks related to slowly evolving phenomena like sea-level rise and gradual shifts in temperature and precipitation patterns; and (ii) acute physical climate risks related to extreme events such as floods, extreme drought, heat waves, wildfires, and hurricanes, whose frequency and severity are being affected by climate change.

Several key factors contribute to acute physical climate risks: (i) the hazard associated with each peril that a region is exposed to, and the growing influence of climate change on the hazard; (ii) the exposure to these perils, which is highly dependent on the specific geographic location of assets and systems, and which varies based on a range of dynamics, including population and economic growth and migration; (iii) the vulnerability of exposed assets and systems; and (iv) the mechanisms through which the risks manifest at a financial or macroeconomic level (Figure 2).

In order to appropriately capture each of these risk dimensions, physical climate risk assessment requires the combination of technical knowledge spanning climate science, catastrophe modeling, macroeconomic modeling, and financial modeling.

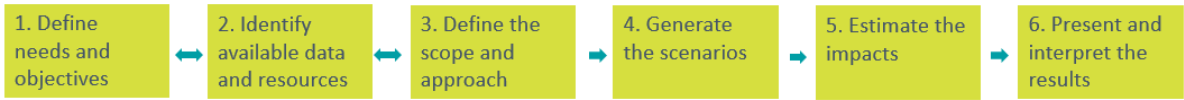
Acute physical climate risk			
Hazard • Hazard associated with each peril to which a region is exposed • Influenced by climate change and other environmental dynamics	Exposure • Exposure to perils based on geographic location of assets and systems • Influenced by dynamics such as population and economic growth and migration	Vulnerability • Translation of hazard intensity into expected damage or loss for exposed assets and systems • Influenced by factors such as construction quality, building codes, and other socioeconomic vulnerability factors	Financial, social, and macroeconomic • Mechanisms through which direct and indirect losses manifest at financial or macroeconomic level • Influenced by macroeconomic variables and structure of financial system, and moderated by various transmission channels

Source: World Bank.

Figure 2. Key factors contributing to acute physical climate risk

4. Step-by-step process for physical climate risk assessment

The proposed physical climate risk assessment methodology covers six key steps (Figure 3). Steps 1 and 2 define the needs of stakeholders, objectives of the risk assessment, and the available data and resources. These steps are particularly important in the context of EMDEs, given their diverse needs and sometimes limited resources. Several iterations of Step 1 may be required, for example if the data and resources identified in Step 2 are insufficient to meet the objectives initially defined in Step 1. The output of these initial steps should be used to define the scope and approach of the assessment (Step 3), which may in turn inform additional iterations of Step 2 to narrow the identified data and resources. The next steps are to establish appropriate climate scenarios to be analyzed (Step 4) and impacts to be calculated (Step 5). The interpretation and presentation of results (Step 6) is a critical part of the process to ensure that the assessment can be used to inform decisions, while also communicating key limitations of the analysis.



Source: World Bank.

Figure 3. Overview of acute physical climate risk assessment process

4.1. Define needs and objectives

It is important to understand the unique context of a given risk assessment exercise. To ensure that the scope and objectives of the assessment are appropriately defined and prioritized, it is helpful to have a clear understanding of the country context, the reasons underlying the decision to conduct the assessment, the needs of stakeholders, and the information gaps that the assessment should address. For example, awareness-raising objectives will imply qualitative assessments focusing on orders of magnitude. Similarly, data-poor environments will constrain the level of sophistication of each modeling building block, and will also inform the level of effort to be invested overall and over each step of the process. As such, several iterations of Step 1 may be required, for example if the data and resources identified in Step 2 are insufficient to meet the objectives initially defined in Step 1. This step ultimately supports the definition of potential outputs and outcomes, aids the identification of appropriate methodologies and adequate data and resource requirements, and helps with managing the expectations of stakeholders and participating institutions.

Interviews with experts and relevant actors can be useful when defining needs and objectives. A questionnaire addressed to key actors (e.g., central bank and ministry of finance) can be of particular interest to identify perils, regions, sectors, and investment or credit portfolios of particular concern; to understand any existing risk management frameworks, public funding arrangements, and insurance penetration; and to identify any existing data and resources. An example of such a questionnaire is shown in Annex 1.

Relevant actors should be consulted and involved early in the process, as their input may influence key decisions impacting the entire risk assessment. Furthermore, early involvement of stakeholders and experts supports transparency, helps identify any misalignments of expectations, and can provide validation for key decisions. The objectives and priorities of stakeholders may be different (e.g., full risk assessment, stress testing of extreme events) and this consultation process should help prioritize such objectives.

Review of the literature, including publicly available risk indices, can help identify which perils are the most important for the assessment. Publicly available risk indices may be useful as a general indicator of a country's vulnerability to physical climate risks and may shed light on how this risk compares with that of other countries. Key examples are the Notre Dame GAIN Index,[14] the Global Climate Risk Index,[15] and the INFORM Risk Index.[16] These indicators cannot, however, provide a reliable estimate of the financial materiality of risks, as they are typically poorly correlated with—and largely insufficient to model the materiality and severity of—potential future acute events. In addition, these indicators typically present average national risk estimates, which might not be relevant when assessing exposures at a regional level.

4.2. Identify available data and resources

Statistical approaches informed by reports of historical damages, generally available at country or regional level, have been used to assess climate risks. Historical damage data can be regarded as the actual past damages resulting from the overall combination of hazard, exposure, and vulnerability for a given event. When country resources are limited or historical damages are not available, a decision may be made to rely on historical damage data from publicly available historical loss databases such as EM-DAT[17] and DesInventar.[18]

Historical damage data may be insufficient or even irrelevant for generating a risk assessment that reflects the current or future risk reality. Furthermore, such data may be unavailable in some EMDEs. With changes in hazard (e.g., due to climate change), exposure (e.g., due to population and economic growth and migration resulting in changes in the location of assets), and vulnerability (e.g., due to more resilient structures, infrastructure, and business plans), this historical approach using damage data may not generate a risk assessment that is reflective of the current or future risk reality. Instead, physical climate risk assessments now increasingly use data sets that can individually characterize hazard, exposure, and vulnerability, and tools such as catastrophe risk models and financial impact and macroeconomic models to combine these data sets and analyze risk. To inform the most appropriate scope and approach for the risk assessment, it is important to identify the availability of such data sets and tools for the area of interest.

The data and resource needs for acute physical climate risk assessment may vary depending on the sophistication and granularity of the analysis. Several key factors should be considered when determining the suitability of a data set for a given risk assessment exercise: (i) whether it covers the relevant variables; (ii) what the temporal, spatial, and/or sectoral coverage is, and how granular the data are; and (iii) whether there are any biases or other anomalies in the data set. Identifying the availability of suitable data will help determine how sophisticated an analysis can be conducted. In some cases, where such data are not available, or where resources are limited, a decision may be made to rely on historical damage data with simple assumptions applied to capture potential climate change impacts. This approach may be useful for an initial risk assessment, which will be refined with more detailed hazard, exposure, and vulnerability data when available.

There are several publicly available data sets and tools that can be used for the physical climate risk assessment. These resources provide useful information on hazards, exposure, and vulnerability, as detailed below.

4.2.1. Hazard data, tools, and resources

There are several publicly available hazard data platforms. Some of them use the same underlying hazard data sets and models but may provide different aggregations for the end-user (e.g., both Aqueduct Floods and ThinkHazard use the same storm surge data set).[19] In addition, while some platforms provide data for existing

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[14] Notre Dame GAIN Index, https://gain.nd.edu/our-work/country-index/.
[15] Global Climate Risk Index, https://www.germanwatch.org/en/cri.
[16] INFORM Risk Index, https://drmkc.jrc.ec.europa.eu/inform-index/INFORM-Risk/Country-Risk-Profile.
[17] EM-DAT—The International Disaster Database, https://public.emdat.be/.
[18] DesInventar, http://desinventar.cimafoundation.org/index.html.
[19] The data set is from Muis et al. 2016. S. Muis, M. Verlaan, H. C. Winsemius, J. C. J. H. Aerts, and P. J. Ward, "A Global Reanalysis of Storm Surge and Extreme Sea Levels," *Nature Communication* 7 (11969): 1– 11. doi:10.1038/ncomms11969.

hazard (e.g., INFORM), others include a forward-looking view of future hazards given climate change (e.g., Climate Impact Explorer and Aqueduct Floods). Different resources may also express hazard using different metrics for the same peril (e.g., for wildfire, Climate Impact Explorer quantifies land fraction annually exposed to wildfires whereas ThinkHazard reports a category based on fire weather index thresholds), which may be used and interpreted differently in an assessment exercise. These platforms generally have global coverage, enabling them to be used for analysis in EMDEs. Table 1 provides an overview of some of these open-source data sets and tools for climate-related perils.

Academic literature and in-country expertise can also provide additional insights into the impacts of climate change on hazards. For example, Bloemendaal et al. (2022)[20] provide a detailed analysis of potential changes in tropical cyclone wind speed probabilities for globally consistent local-scale assessment of changes in future risk. Some of the academic literature may not yet be available in the aforementioned data platforms and may not be easily identified or used by the authorities. Local universities engaged in climate risk research can act as knowledge brokers to support authorities' efforts to identify and understand available research for climate risk assessments and to build local technical capacities.

Proprietary hazard data sets are also available. For example, Fathom[21] and JBA[22] have developed flood depth maps for a range of return periods. The spatial resolution and availability of these data sets vary by region. Other catastrophe modelling firms (such as RMS[23], Verisk[24], and Aon's Impact Forecasting[25]) have also developed hazard data sets for a range of perils that are integrated into their catastrophe models. These firms have also created forward-looking climate-conditioned hazard data sets, but they are very dependent on geography and often subscription-based and not available for EMDEs.

Tools with a forward-looking view of climate variables based on the impacts of climate change are publicly accessible. In addition to the tools that characterize hazard associated with specific perils, tools such as the Intergovernmental Panel on Climate Change (IPCC) Atlas[26] and the World Bank Climate Change Knowledge Portal[27] provide easily accessible data for a range of climate change scenarios for temperature and precipitation variables; these can provide useful insights into potential hazard changes for various climate-related perils. These data sets, along with aforementioned climate-conditioned data sets for specific perils, typically rely on climate models. Climate models are computer simulations of the climate system that can be used to understand past climates or predict future climate under various scenarios of global warming.

Global climate models typically do not offer sufficiently granular spatial resolution and need to be downscaled or complemented by local observational data. While global climate models (general circulation models, GCMs) can provide several key climate variables of interest for risk modeling, their data may not be suited for risk assessment due to the relatively coarse spatial resolution at which these models are typically run. Important climate processes that govern some extreme weather events occur at spatial scales smaller than the GCM resolution, and parameterizations used to represent these sub-grid-scale processes introduce uncertainty and

[20] Bloemendaal, N., de Moel, H., Martinez, A.B., Muis, S., Haigh, I.D., van der Wiel, K., Haarsma, R.J., Ward, P.J., Roberts, M.J., Dullaart, J.C. and Aerts, J.C., 2022. A globally consistent local-scale assessment of future tropical cyclone risk. Science advances, 8(17), p.eabm8438.
[21] Fathom, https://www.fathom.global/.
[22] JBA Risk Management, https://www.jbarisk.com/flood-services/catastrophe-models/flood-models/.
[23] RMS, https://www.rms.com/.
[24] Verisk, https://www.air-worldwide.com/.
[25] Aon Impact Forecasting, https://www.aon.com/reinsurance/impact-forecasting.
[26] Intergovernmental Panel on Climate Change, "IPCC WGI Interactive Atlas," https://interactive-atlas.ipcc.ch/.
[27] Climate Change Knowledge Portal, https://climateknowledgeportal.worldbank.org/.

bias.[28] Most parameterizations broadly focus on average conditions, meaning that natural variability and extremes important for acute climate risk assessment are not well captured. Downscaling techniques such as regional climate modelling (RCM) are used to obtain finer spatial resolution data. However, given that RCMs are typically nested within the GCMs, biases in the GCMs can impact the RCM outputs. Local observational data can also provide granular insights for the region of interest.

Table 1. Global open-source hazard data sets and tools for acute physical climate risk assessment

Data set / tool	Peril	Climate change scenarios	Spatial resolution	Example metrics	Underlying input data sources and models
INFORM[a]	River flood	Current risk only	National (and subnational for some countries)	Average annual population exposed	GAR 2015 flood hazard maps
	Cyclone			Average annual population exposed	GAR 2015 cyclone wind intensity maps
	Storm surge			Average annual population exposed	GAR 2015 storm surge hazard maps
	Drought			Average annual population affected; frequency of drought events	EM-DAT database; FAO GIEWS Agriculture Stress Index
Climate Impact Explorer[b]	River flood	NGFS current policies; NGFS delayed 2°C; NGFS net-zero 2050; RCP2.6; RCP4.5; RCP6.0; RCP8.5; Climate Action Tracker current policies for 2015–2100	National; subnational; country maps (varying resolution; approx. 50km grid)	Land fraction annually exposed to river floods; river flood depth	Flood maps from global hydrological models participating in ISIMIP2b
	Wildfire			Land fraction annually exposed to wildfires; fraction of population annually exposed to wildfires	n/a
	Heat wave			Land fraction annually exposed to heat waves; fraction of population annually exposed to heat waves	n/a
Aqueduct Floods[c]	River flood	"Business as Usual" (RCP8.5, SSP2), "Optimistic" (RCP 4.5, SSP2), "Pessimistic" (RCP 8.5, SSP3) for 2010 (baseline), 2030, 2050, and 2080	10km grid	Inundation depth for floods with a return period of 5, 10, 25, 50, 100, 250, 500, and 1,000 years	GLOFRIS model
	Coastal flood				GTSR data set (Muis et al. 2016)[h]

[28] Verisk, "Climate Models in a Catastrophe Modeling Context: Opportunities and Challenges," 2020, https://www.air-worldwide.com/publications/air-currents/2020/climate-models-in-a-catastrophe-modeling-context/.

Notre Dame GAIN Index[d]	Flood	Baseline (1960–1990) and RCP4.5 (2040–2070)	National	Projected change of monthly maximum consecutive 5-day precipitation	Sillmann et al. 2013[i]
ThinkHazard[e]	River flood	Current risk, with comments on potential climate change impacts	National and subnational (and higher-resolution maps of some underlying data if publicly available)	Category based on inundation depth thresholds	Fathom
	Urban flood			Category based on inundation depth thresholds	Fathom
	Coastal flood			Category based on inundation depth thresholds	GTSR data set (Muis et al. 2016)[h]
	Cyclone			Category based on wind speed thresholds	Impact forecasting
	Wildfire			Category based on fire weather index thresholds	CSIRO 30-year fire weather climatology
	Extreme heat			Category based on wet bulb globe temperature thresholds	Wet Bulb Globe Temperature data set
	Landslide			n/a	Global Landslide Hazard Map
	Water scarcity			Category based on water availability thresholds	IVM Water Crowding Index
FAO GIEWS Earth Observation[f]	Drought	Risk based on 1984–2020 observations only	1km grid	Historical frequency of severe droughts (as defined based on agricultural stress index)	European Space Agency Metop AVHRR satellite data
UNCCD Drought Risk Assessment Visualization Tool[g]	Drought	Risk for 2000–2018	Approx. 10km grid	Category based on probability of exceedance of the median of global severe precipitation deficits for a historical reference period	Carrão et al. 2016[j]; underlying hazard data from GPCC Full Data Reanalysis Version 6.0

Source: World Bank.

Note: AVHRR = Advanced Very High Resolution Radiometer; CSIRO = Commonwealth Scientific and Industrial Research Organisation; FAO GIEWS = Food and Agriculture Organization of the United Nations – Global Information and Early Warning System; GAR = Global Assessment Report on Disaster Risk Reduction; GPCC = Global Precipitation Climatology Centre; ISIMIP2B = Inter-Sectoral Impact Model Intercomparison Project; IVM = Vrije Universiteit Amsterdam Institute for Environmental Studies; RCP = Representative Concentration Pathway; SSP = Shared Socioeconomic Pathway; n/a = description not available; UNCCD = United Nations Convention to Combat Desertification.

a. INFORM considers hazard and exposure in combination, as reflected by the metrics. INFORM, "INFORM Risk", https://drmkc.jrc.ec.europa.eu/inform-index/INFORM-Risk.

b. Climate Analytics, "Climate impact explorer", https://climate-impact-explorer.climateanalytics.org.

c. World Resources Institute, "Aqueduct Floods", https://www.wri.org/applications/aqueduct/floods.

d. University of Notre Dame, "ND-GAIN Country Index", https://gain.nd.edu/our-work/country-index.

e. World Bank, ThinkHazard!, https://thinkhazard.org.

f. Food and Agriculture Organization of the United Nations, “GIEWS Earth Observation”, https://www.fao.org/giews/earthobservation/index.jsp.
g. United Nations Convention to Combat Desertification, “Drought Risk Assessment Visualization Tool”, https://knowledge.unccd.int/drought-toolbox-action/drought-risk-assessment-visualization-tool.
h. Muis, S., Verlaan, M., Winsemius, H.C., Aerts, J.C. and Ward, P.J., “A global reanalysis of storm surges and extreme sea levels,” *Nature communications*, 7 (1): 1-12, https://www.nature.com/articles/ncomms11969.
i. Sillmann, Jana, et al. "Climate extremes indices in the CMIP5 multimodel ensemble: Part 2. Future climate projections." *Journal of Geophysical Research: Atmospheres* 118.6 (2013): 2473-2493, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/jgrd.50188.
j. Carrão, Hugo, Gustavo Naumann, and Paulo Barbosa. "Mapping global patterns of drought risk: An empirical framework based on sub-national estimates of hazard, exposure and vulnerability." *Global Environmental Change* 39 (2016): 108-124, https://www.sciencedirect.com/science/article/pii/S0959378016300565.

4.2.2. Exposure data and resources

Several types of exposure data may be used depending on the objectives of the climate risk assessment. Exposure data are needed to determine whether any assets are at risk from a given hazard. Sectoral exposure data for banks can be helpful to identify which banks and other financial institutions have credit exposures to sectors directly exposed to physical risks (such as agriculture) and to sectors indirectly exposed (such as tourism, construction, or mortgages). In addition to the sectoral data, spatial data can also be useful to assess exposure to physical risks.

The resolution of the spatial data is important. While regional-level data may be sufficient for an initial analysis of exposure to drought risk, more granular spatial data are needed to estimate exposure to localized risks (such as flood risks) given that hazard can vary substantially within several meters. Obtaining precise spatial location data may be challenging. Even in developed countries, some banks have difficulty obtaining a precise view of the geographical location of their real estate and corporate exposures.[29]

Where high-resolution spatial data are not available, various methods can be used to disaggregate data to a finer spatial resolution. For example, capital stock and spatial gross domestic product (GDP) data can be disaggregated by using granular land cover and population data. Various data sets may be useful for these purposes, including the Global Human Settlement Layer Global Population Grid[30] used in INFORM,[31] the History Database of the Global Environment population data set used for the gridded GDP data set in the Climate Impact Explorer,[32] Lit Population[33] asset value data derived from nightlight intensity and population data and available through CLIMADA (CLIMate ADAptation),[34] the German Aerospace Center’s Global Urban Footprint database,[35] and various satellite imagery data sets. Such data sets can be coupled with innovative modeling techniques based on artificial intelligence to significantly increase the granularity of the available exposure data (see for example Box 1). However, these data sets and techniques may require specific technical expertise.

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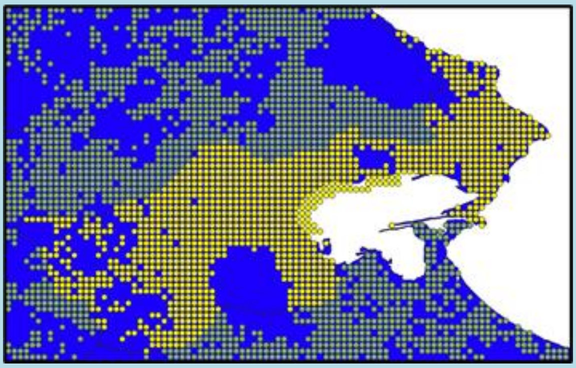
[29] ACPR, “A First Assessment of Financial Risks Stemming from Climate Change: The Main Results of the 2020 Climate Pilot Exercise,” Analyses et syntheses 122-2021, https://acpr.banque-france.fr/sites/default/files/medias/documents/20210602_as_exercice_pilote_english.pdf.
[30] S. Freire and M. Pesaresi, “GHS Population Grid, Derived from GPW4, Multitemporal (1975, 1990, 2000, 2015),” European Commission, Joint Research Centre, 2015, https://data.europa.eu/data/datasets/jrc-ghsl-ghs_pop_gpw4_globe_r2015a?locale=en.
[31] M. Marin-Ferrer, L. Vernaccini, and K. Poljansek, “INFORM Index for Risk Management: Concept and Methodology Report – Version 2017,” EUR 28655 EN, 2017, https://drmkc.jrc.ec.europa.eu/inform-index/Portals/0/InfoRM/INFORM%20Concept%20and%20Methodology%20Version%202017%20Pdf%20FINAL.pdf.
[32] Climate Impact Explorer, “Methodology,” July 27, 2021, https://climate-impact-explorer.climateanalytics.org/methodology/.
[33] Eberenz, Samuel, et al. "Asset exposure data for global physical risk assessment." *Earth System Science Data* 12.2 (2020): 817-833, https://essd.copernicus.org/articles/12/817/2020/.
[34] ETHZürich, “CLIMADA: Economics of Climate Adaptation,” https://wcr.ethz.ch/research/climada.html.
[35] DLR, “GUF Data and Access,” https://www.dlr.de/eoc/en/desktopdefault.aspx/tabid-11725/20508_read-47944/.

Box 1. Bridging the gap with space technology and analytics to improve the quality and granularity of available exposure information in Tunisia

Granular exposure data were necessary to inform a national disaster risk financing strategy and an actuarial model for catastrophe insurance in Tunisia. While exposure data were originally available only at the governorate (district) level, a more granular data set was created by ImageCat by linking development patterns from satellite earth observation, roughly consistent with land use classes (figure a), with assumptions of structure type and building density. Exposure values were disaggregated onto grids using earth observation data sets such that the resultant exposure data set (figure b) had sufficient spatial granularity to be useful for modeling flood risk.

(a) Example earth observation data used to identify development patterns

(b) Example granular gridded exposure data set produced by ImageCat



Lesson learned: Remote sensing data and innovative modelling techniques can be leveraged to improve the granularity of data with reduced time and costs, even in cases where granular exposure data are not readily available.

Source: World Bank, Tunisia Risk Analysis Project Summary Report, unpublished, 2022.

4.2.3. Vulnerability data and resources

Vulnerability information and resources vary by peril. Vulnerability or damage functions are used to calculate the damage that can be expected for a given hazard severity. The choice of vulnerability functions depends on the perils, sectors, and region of interest. For tropical cyclone, the functions of Eberenz et al.[36] that relate wind speed to property damage have been calibrated for different regions, recognizing differences in building vulnerabilities across the globe. For flood, the European Commission Joint Research Centre's flood depth-damage functions[37] relate flood depth to damage per asset or land use class. Such curves can be applied per sector, including industrial, commercial, agricultural, and transportation sectors. For drought, global data sets from FAOSTAT[38] can be used to define the vulnerability of agricultural capital stock, but it is important to note that national-level yield and

[36] Eberenz, Samuel, Samuel Lüthi, and David N. Bresch. "Regional tropical cyclone impact functions for globally consistent risk assessments." Natural Hazards and Earth System Sciences 21.1 (2021): 393-415, https://nhess.copernicus.org/articles/21/393/2021/.

[37] Joint Research Centre, "Global Flood Depth-Damage Functions: Methodology and the Database with Guidelines," 2017, https://publications.jrc.ec.europa.eu/repository/handle/JRC105688.

[38] Food and Agriculture Organization of the United Nations, "Food and Agriculture Data," https://www.fao.org/faostat/en/.

rainfall data sets are also often available (and collected from institutional agencies or ministries). Given the sensitivity of catastrophe risk models to vulnerability functions, it is critical that selected vulnerability curves are appropriate for the specific country context, and that they are adjusted if required.

4.2.4. Risk metrics

Some risk metric data sets combining hazard, exposure, and vulnerability are publicly available, but these pre-computed data typically do not accommodate user-defined inputs and may not be validated at the country level. In addition to resources that provide hazard, exposure, and vulnerability data individually, there are several opensource tools that provide risk metrics based on a combination of hazard, exposure, and vulnerability. These resources can provide easy-to-access views of country or regional risk and may be useful for validating the order of magnitude and trends of results of more in-depth analysis. However, they do not easily allow other data sets to be used as inputs (e.g., granular bank exposure data), and results should be interpreted with caution, particularly if the data have not been validated at a country level. Some examples of publicly available risk metric data sets are shown in Table 2.

Table 2. Publicly available physical climate risk metric data sets and tools

Data set / tool	Peril	Climate change scenarios	Spatial resolution	Example metrics
Aqueduct Water Risk Atlas[a]	Drought	No forward-looking climate change scenarios	5 x 5 arc minute grid cells	Category based on drought risk indicator combining hazard, exposure of population and assets, and vulnerability from Carrão et al. (2016)[d]
	River flood		30 x 30 arc minute grid cells	Category based on average annual affected population
	Coastal flood		30 x 30 arc minute grid cells	Category based on average annual affected population
Aqueduct Floods[b]	River flood	"Business as Usual" (RCP8.5, SSP2), "Optimistic" (RCP4.5, SSP2), "Pessimistic" (RCP8.5, SSP3) for 2010 (baseline), 2030, 2050, and 2080	Country; state; river basin	Urban damage; affected population; affected GDP, with option to vary flood protection level
	Coastal flood			
Climate Impact Explorer[c]	Tropical cyclone	NGFS current policies; NGFS delayed 2°C; NGFS net-zero 2050; RCP2.6; RCP4.5; RCP6.0; RCP8.5; Climate Action Tracker current policies for 2015–2100	National; subnational; country maps (varying resolution; 50km grid)	Annual expected damage from tropical cyclones; 1-in-100-year expected damage from tropical cyclones
	River flood			Annual expected damage from river flood
	Heat stress			Labor productivity due to heat stress

Source:

Note: RCP = Representative Concentration Pathway; SSP = Shared Socioeconomic Pathway.

a. World Resources Institute, "Aqueduct Water Risk Atlas", https://www.wri.org/applications/aqueduct/water-risk-atlas.

b. World Resources Institute, "Aqueduct Floods", https://www.wri.org/applications/aqueduct/floods.

c. Climate Analytics, "Climate impact explorer", https://climate-impact-explorer.climateanalytics.org.

d. Carrão, Hugo, Gustavo Naumann, and Paulo Barbosa. "Mapping global patterns of drought risk: An empirical framework based on sub-national estimates of hazard, exposure and vulnerability." *Global Environmental Change* 39 (2016): 108-124, https://www.sciencedirect.com/science/article/pii/S0959378016300565.

Catastrophe models can be used to estimate risk using user-defined input data. Catastrophe models combine science, engineering, and finance to simulate, in probabilistic terms, the potential financial impacts of disasters to a given portfolio. Models are typically flexible to accommodate user-defined input data, particularly for exposure. There are many types of catastrophe risk models, from the simplest probabilistic models based upon historical losses and exposure analysis, to more complex and spatially resolved models that use the latest high-resolution climate models to simulate large catalogs of realistic events in probabilistic terms and overlay with detailed exposure data and vulnerability functions.

Although the availability of catastrophe models is limited in many EMDEs, various open access catastrophe risk models are now being developed. Proprietary catastrophe models developed by specialist firms have historically been unavailable in EMDEs for most, if not all, perils. Where such models do not exist or where it is not feasible to build such models, it is common to develop risk profiles using public empirical data on natural hazard and disaster risk as well as loss databases. However, various open access catastrophe risk models are now becoming available and could play an important and growing role in coming years. For example, CLIMADA[39] is an open source catastrophe risk modeling framework used by Climate Impact Explorer (Box 2), and Oasis Loss Modelling Framework is an open source modeling platform with increasing coverage for a range of perils around the world. Proprietary catastrophe model providers may also provide analytical consulting services using insights drawn from other countries, in cases where they do not have a full catastrophe model available for the country and perils of interest.

[39] ETHZürich, "CLIMADA: Economics of Climate Adaptation," https://wcr.ethz.ch/research/climada.html.

Box 2. Open source catastrophe risk modeling using CLIMADA

CLIMADA[a] (CLIMate ADAptation) is an open source natural catastrophe risk modeling model. It provides global coverage for several climate-related perils, including tropical cyclones, river floods, agricultural droughts, and wildfires. Both historical and probabilistic event sets are available, with future climate change scenarios also included for some perils. CLIMADA integrates hazard, exposure, and vulnerability modules for risk assessment and socioeconomic impact quantification. The platform enables globally consistent analysis at varying levels of spatial resolution, depending on the purpose. Example applications of CLIMADA include a global assessment of tropical cyclone risk considering regional differences in vulnerability,[b] a study of the impacts of floods on human displacement,[c] and an assessment of the impacts of climate on flood damage trends.[d] CLIMADA is also used to derive the indicators quantifying economic damages shown in the Climate Impact Explorer.[e] At a country/regional level, CLIMADA has been used to assess flood risk in Nigeria and Uganda,[f] drought risk in Ethiopia,[g] and hurricane risk in Mexico[h] and the Antilles;[i] however, such applications typically require specific training and expertise to utilize the CLIMADA software and to tailor the analysis to the country context.

Lesson learned: Open source catastrophe modeling tools such as CLIMADA are available and can be used to assess a range of climate-related perils across the globe. However, such tools may need further validation, and some technical expertise is required to apply these tools and tailor them to the country context to inform decision-making.

a. ETHZürich, "CLIMADA: Economics of Climate Adaptation," https://wcr.ethz.ch/research/climada.html.

b. S. Eberenz, S. Lüthi, and D. N. Bresch, "Regional Tropical Cyclone Impact Functions for Globally Consistent Risk Assessments," *Natural Hazards and Earth System Sciences* 21, 1 (2021): 393–415, https://nhess.copernicus.org/articles/21/393/2021/.

c. P. M. Kam, G. Aznar-Siguan, J. Schewe, L. Milano, J. Ginnetti, S. Willner, J. W. McCaughey, and D. N. Bresch, "Global Warming and Population Change Both Heighten Future Risk of Human Displacement Due to River Floods," *Environmental Research Letters* 16, 4 (2021): 044026, https://iopscience.iop.org/article/10.1088/1748-9326/abd26c/pdf.

d. I. J. Sauer, R. Reese, C. Otto, T. Geiger, S. N. Willner, B. P. Guillod, D. N. Bresch, and K. Frieler, "Climate Signals In River Flood Damages Emerge under Sound Regional Disaggregation," *Nature Communications* 12, 1 (2021): 1–11, https://www.nature.com/articles/s41467-021-22153-9.

e. Climate Impact Explorer, "Methodology," July 27, 2021, https://climate-impact-explorer.climateanalytics.org/methodology/.

f. InsuResilience Solutions Fund, "CLIMADA Climate Risk Analysis: Urban Flood Resilience against Riverine Floods in Uganda and Nigeria," June 2021, https://www.insuresilience-solutions-fund.org/content/1-our-work/1-climate-risk-analysis/climate-risk-analysis_uga-nga_5-pager_final.pdf.

g. Economics of Climate Adaptation, "Executive Summary: Ethiopia Drought Risk," August 2021, https://eca-network.org/wp-content/uploads/2021/11/ExSummary_ECA_ETHIOPIA_FINAL.pdf.

h. G. Bressan, A. Duranovic, I. Monasterolo, and S. Battiston, "Asset-level climate physical risk assessment and cascading financial losses," *SSRN*, 2022, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4062275.

i. David N. Bresch and Gabriela Aznar-Siguan, "CLIMADA v1.4.1: Towards a Globally Consistent Adaptation Options Appraisal Tool," *Geoscientific Model Development*, 2020, https://gmd.copernicus.org/preprints/gmd-2020-151/gmd-2020-151.pdf.

4.2.5. Data and resources for analyzing financial sector and economic impact

The analysis of the impact of climate events on the economy or the financial sector requires financial and economic data sets. To translate estimated damages from catastrophe models into estimates of financial or macroeconomic losses, additional financial and economic data sets are needed. When assessing macroeconomic impacts, data sets should include national accounts, stock and depreciation of physical capital, household consumption, labor/unemployment, trade flow, and productivity data. Other data sets that can support the analysis include government spending and revenue, consumer price index, interest rate, policy rate, informal sector, and regional and sectoral GDP/gross value added (GVA) data. Key data sets required to assess financial sector risk include balance-sheet data for systemically important banks, corresponding to each of the CAMELS rating dimensions (capital adequacy, assets and liabilities, management, earnings, liquidity, and sensitivity to risk). Table 3 contains some examples of the types of data relevant when assessing the impacts on the economy and the financial sector.

Depending on the objective and design of the assessment exercise, data sets should be available for several periods and broken down by sectors, regions, or categories. For example, when assessing physical climate impacts on the banking sector, quarterly commercial bank loan and nonperforming loan (NPL) data should ideally be available for a period covering at least 20 years (or should be sufficiently broad to allow robust results). These loan and NPL data should be broken down by purpose (working capital, investment, or consumption), size (MSME [micro, small, and medium enterprise] or not), category (corporate loans, mortgages, commercial real estate loans, household loans, other), sector (including both productive and nonproductive sectors, and possibly subsectors such as for agriculture), and geography (ideally at sub-provincial level). Similarly, data for other asset classes (in addition to commercial bank loans) should ideally be integrated in the analysis and broken down by sectors, regions and categories.

Table 3. Financial and macroeconomic data variables for risk assessment

Balance sheet data

Capital adequacy	• Primary capital • Total capital • Total loans and credit growth
Assets and liabilities	• Adjusted assets • Total assets • Gross assets • Nonperforming loans • Non-interest-accruing assets • Restructured loans • Charged-off loans • International asset position by countries or by regions
Management	• Construction loans • Agricultural loans • Loans past due • Loans to bank insiders • Management overhead
Earnings	• Net interest income • Returns
Liquidity	• Liquidity coverage ratio • Net loans
Sensitivity to risk	• Total income from interest rates • Change in interest rate income • Change in total assets

National macroeconomic data

National accounts	• Current accounts • Financial accounts • Capital accounts • Balance sheets
Physical capital	• Stock of physical capital (in value and in volume, i.e., in current price and constant price) • Physical capital depreciation rate
Household consumption	• Household final consumption by sector
Informal sector	• Contribution of informal sector to GDP • Number of households working in the informal sector
Regional GDP/GVA	• Regional GDP/GVA(including sector breakdown)
Labor and productivity	• Mean/median wage, by sector and region • Mean/median hours worked, by sector and region • Employment rate by sector • Number of jobs by sector
Trade flow	• Import/export tables by sector (in value and in volume)
Government spending and revenue	• Aggregate public investment • Total assistance and transfer to households • Tax revenue by source (income, capital gains, sales/consumption, tariffs/duties) • Bond issuance (volume)

Source: World Bank.

4.3. Define the scope and approach

The scope and the approach need to be tailored. Once the key needs and objectives have been defined (Step 1) and available data and resources have been identified (Step 2), the scope and approach of the risk assessment can be defined, and a practical approach for risk assessment can be designed. There is no one-size-fits-all approach; any approach needs to be tailored to meet country-specific needs and the availability of data and resources. This step sets the scope of analysis (e.g., key perils, regions, and sectors) and determines whether a qualitative or quantitative approach is most appropriate; it also establishes the level of sophistication of analysis and the granularity of results. In countries with limited data, a qualitative assessment may be appropriate to raise awareness of climate risk among financial decision-makers, build an expert network, and identify information gaps (see Box 3). The definition of the scope and assessment approach also needs to consider how to tailor the scenarios for the specific risk assessment exercise. This tailoring includes choices related to the perils to be covered, the number of scenarios, the time horizon (e.g., 2030 or 2050), and the specific outputs that will be needed, including the level of detail of results. These decisions will have an important bearing on the generation of scenarios (Step 4) and the impact measurements to be evaluated (Step 5).

In some cases, approaches need to be peril- or sector-specific. Analysis that is peril- and sector-specific enables appropriate methodologies to be used for each peril/sector combination. Recent experience shows that a generic data science–based approach for all perils and sectors together is not always ideal, and that in some cases it may be more appropriate to develop specific methodologies—for example, lending to small and medium enterprises exposed to urban flooding, or agriculture lending exposed to droughts. Each of these sources of exposure to banks and other financial institutions will require different approaches, assumptions, data sets, and resolutions and will come with very different levels of reliability.

Systemic impacts, distributional impacts, and compound impacts should also be considered within the scope of the assessment when appropriate. It may be relevant to consider systemic impacts (large-scale disruptions of entire economic sectors or systems), distributional impacts (the uneven distribution of national-level losses across sectors, geographies, economic agents, banks), and/or compounding effects (such as the nonlinear sum of various shocks, including political and climate, or recession and climate, but also the interplay between physical and transition risks).

Box 3. Qualitative climate risk assessment for member states of the West African Economic and Monetary Union

A primarily qualitative approach was used to analyze acute physical climate risks to the financial sector in member states of the West African Economic and Monetary Union. The objective of the study was to identify the physical climate risks faced by the financial system and to better understand the transmission channels, based on publicly available data. The structure of the financial sector was first analyzed, including the composition of loan portfolios by sector. This analysis showed that agricultural sector loans represent only 3 percent of loans declared to the central credit registers. Historical climate-related losses are mainly related to banks' exposure to the agricultural sector, and hence agricultural banks may be the most vulnerable to physical climate risk. Key transmission channels were explored to understand the means through which drought and flood risk may impact the financial sector, including direct physical losses, indirect impacts due to effects on electricity, water, transportation, and supply chains, and indirect impacts via macroeconomic channels. Various extreme climate scenarios were identified, highlighting a substantial exposure of credit portfolios to severe droughts, a weaker impact of a heat wave scenario, and a medium impact of a flood scenario. The qualitative analysis helped to highlight key physical climate risks faced by the financial sector.

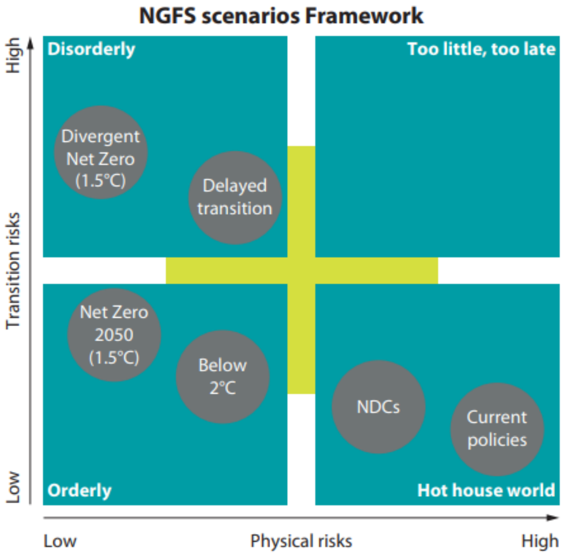
The exercise brought together experts from both member countries and international organizations, including the World Bank and International Monetary Fund. The recommendations of the study, which point to the need to collect quantitative climate risk data and to raise the awareness of financial institutions, may help facilitate future climate risk assessments.

Lesson learned: When data are insufficient to conduct a quantitative risk assessment, an initial qualitative risk assessment may be useful to increase awareness of climate-related financial risks among financial decision-makers, build an expert network, and identify data that should be collected to support future quantitative risk assessments.

Source: World Bank, "Union Economique et Monetaire Ouest Africaine Programme d'Evaluation due Secteur Financier – Note Technique", 2022.

4.4. Generate climate scenarios

Climate scenarios are an important component of the physical climate risk assessment methodology. Climate scenarios can be defined as plausible representations of future climate corresponding to potential future realizations of climate change. The NGFS defines a range of scenarios that can be considered as a common starting point to analyze climate risks to the economy and financial system. NGFS scenarios consider both transition risks (dependent on the transition pathway) and physical risks (dependent on whether climate targets are met) (Figure 4). Along the physical risk dimension, scenarios cover 1.5°C warming; below 2°C warming; a scenario based on full implementation of pledged Nationally Determined Contributions (NDCs), corresponding to ~2.5°C of warming; and a "current policies" scenario, corresponding to 3°C+ of warming.



Source: NGFS, "NGFS Climate Scenarios Database: Technical Documentation V2.2," June 2021, https://www.ngfs.net/sites/default/files/ngfs_climate_scenarios_technical_documentation__phase2_june2021.pdf.

Figure 4. NGFS climate scenarios framework

Climate scenarios need to be translated into peril-specific scenarios for the country and/or region in order to analyze acute physical climate risks. Scenarios should be designed to be plausible (i.e., represent possible and realistic potential futures), distinctive (i.e., explore a range of different permutations), consistent (i.e., have strong internal logic), relevant (i.e., contribute insights related to the objectives of the assessment), and challenging (i.e., explore futures that may result in outcomes significantly different from the current state).[40] See Box 4 for an

[40] Task Force on Climate-Related Financial Disclosures, "The Use of Scenario Analysis in Disclosure of Climate-Related Risks and Opportunities," https://www.tcfdhub.org/scenario-analysis/.

overview of the Bank of England 2021 Climate Biennial Exploratory Scenario exercise. Several recent international comparisons also provide a good overview of the design and application of climate scenarios.[41]

Box 4. Scenario generation: Bank of England 2021 Climate Biennial Exploratory Scenario

The stress-testing exercise carried out by the Bank of England 2021 Climate Biennial Exploratory Scenario (CBES) was designed to explore the resilience of the UK financial system to transition and physical risks, including acute physical climate risks. Participants included UK banks and building societies, life insurers, and general insurers. A key desired outcome of the exercise was better understanding of vulnerability to climate change and enhanced ability to manage climate-related financial risks among participants.

The generation of scenarios for CBES provides a useful example of how scenarios can be designed for a climate risk assessment exercise such that they are distinctive, plausible, challenging, consistent, and relevant. CBES considers three distinctive scenarios: "Early Action," "Late Action," and "No Additional Action," which are designed based on the NGFS scenarios. The Early Action scenario and Late Action scenario primarily explore transition risks from climate change. The No Additional Action scenario (mapped to the NGFS "current policies" scenario) primarily explores physical risks and represents a scenario of 3.3°C of global warming relative to pre-industrial levels. Such levels of warming, while plausible, would be likely to occur only later in the century. However, the Bank of England decided to calibrate the scenario based on the level of risks that could be prevalent in the period 2050–2080 (i.e., the risks for this period are front-loaded to the period 2020–2050 used for the other CBES scenarios). This front-loading is done to enable the impact of more extreme risks to be explored, ensuring that the scenario is sufficiently challenging, while also maintaining consistency with the 30-year time horizon used for other scenarios in the CBES analysis.

The Bank of England included a table of perils/territories with material climate signal by year 2080 under a 3.3°C global warming level to enable participants to select relevant climate-related perils for analysis based on the impact of climate change on each peril and the geographic location of their exposures. The table was based on a literature review and industry consultation. To characterize peril-specific scenarios, the Bank of England provided benchmark data for a series of hazard indicators, including for tropical cyclones (e.g., change in frequency, intensity, and precipitation rates), wildfires (change in land area exposed), heat waves (change in land area exposed), and rainfall. These data, covering the UK and several "material geographies" (e.g., Canada, China, France, Germany, Japan, and the US), were provided by a range of sources, including the NGFS, Oasis Hub, the UK Met Office, and academic literature. In addition, participants were provided with "optional climate data," including gridded NGFS data sets. However, recognizing that there is a range of tools that could be used to analyze climate risks, participants were also allowed to use their own climate data, provided that these were consistent with the warming levels and benchmark data specified by CBES. Publication of the CBES exercise results is expected in May 2022.

Lesson learned: Scenarios can be designed such that they are plausible, distinctive, consistent, relevant, and challenging. Characterization of peril-specific scenarios may leverage data from multiple sources, but consistency should be maintained. The availability of granular data and good disclosure and reporting practices in developed countries (e.g., UK) allows the financial sector authorities to probe the resilience of the financial system via scenarios exploring a wide range of risks and helps financial sector actors understand their vulnerability to climate change.

[41] NGFS, "Scenarios in Action: A Progress Report on Global Supervisory and Central Bank Climate Scenario Exercises," 2021, https://www.ngfs.net/en/scenarios-action-progress-report-global-supervisory-and-central-bank-climate-scenario-exercises; Financial Stability Board, "Supervisory and Regulatory Approaches to Climate-related Risks: Interim Report," 2022, https://www.fsb.org/wp-content/uploads/P290422.pdf; P. Baudino and J. Svoronos, "Stress-testing banks for climate change – a comparison of practices," Bank for International Settlements Financial Stability Institute, 2021, https://www.bis.org/fsi/publ/insights34.pdf.

Sources: Bank of England, presentation for the NGFS, April 2022; Bank of England, "Guidance for Participants of the 2021 Biennial Exploratory Scenario: Financial Risks from Climate Change," June 2021, https://www.bankofengland.co.uk/-/media/boe/files/stress-testing/2021/the-2021-biennial-exploratory-scenario-on-the-financial-risks-from-climate-change.pdf.

When designing the scenarios, one should explore a range of different permutations to capture the nonlinear dynamics of risks. For example, scenarios could be developed to cover a range of global warming pathways (e.g., NGFS scenarios of 1.5°C, 2°C, or 3+°C warming; or Representative Concentration Pathway [RCP] scenarios), time horizons (e.g., 2030, 2050, 2100), event return periods (e.g., 1-in-20-year event, 1-in-50-year event, 1-in-100-year event, 1-in-500-year event), and perils. See Box 5.

Box 5. Definition of a range of scenarios covering several RCPs, time horizons, event return periods, and perils for climate risk assessment in Morocco

Scenarios for a climate risk assessment in Morocco were designed to cover a range of perils (drought, fluvial flood, and pluvial flood). For each peril, a 1-in-500-year baseline scenario was defined, representing historical/current climate conditions. For example, for drought, a 3-year prolonged nationwide drought event was defined. To analyze potential climate change impacts, corresponding scenarios were also defined representing changed hazard by 2030 based on climate projections. Two Representative Concentration Pathways were explored, an RCP4.5 and an RCP8.5. The sensitivity of modelling results for these scenarios were additionally analyzed for financial impact metrics (e.g., NPLs) for a range of return periods up to 1,000 years. . The inclusion of multiple scenarios was important to enable the sensitivity and nonlinearities of results to be explored. For example, based on the return periods analyzed for the drought scenarios, it was found that the impact of drought on the agricultural sector's capital stock, labor force, and imports increased steeply up to a return period of approximately 100 years, but that the increase is less steep for return periods greater than 100 years.

Lesson learned: The inclusion of a range of climate scenarios in the climate risk assessment can help identify and quantify key sensitive parameters and nonlinearities.

Source: Bank Al Maghreb, presentation for the NGFS, February 2022.

A minimum of two scenarios should be designed in order to allow for a comparison of risks. The scenarios should include a baseline or reference scenario representing current conditions, and at least one alternative scenario representing a plausible future that integrates climate change. See Box 6. The baseline scenario may be based on a historical event adjusted for current exposures to analyze the potential risk associated with a similar event occurring today, or it may be based on modeled events corresponding to current conditions. The alternative scenarios are typically selected to capture a range of potential future events, varying the time horizon and potential climate trajectories. The climate change–related hazard data sets and resources identified in Step 2 can be helpful to generate estimates of climate change impacts on hazard when specifying the alternative scenarios. See Box 6.

Box 6. Definition of baseline and climate change urban flood scenarios in Indonesia

A physical climate risk assessment for Indonesia considered severe but plausible scenarios for two perils that could pose risks for the Indonesian financial sector: pluvial floods and sea-level rise. These scenarios were designed for Java Island and, more specifically, Jakarta, as this region was found to have both high credit exposures and high flood risk (based on modeled average annual flood losses).

Three urban flood scenarios were defined for Java Island (see table below). The baseline scenario was based on a 2007 flood event that impacted Jakarta. This event was estimated as equivalent to a 1-in-50-year flood event for the region, and it affected approximately 750,000 people. To explore the potential impacts of climate change on urban flood risk, two alternative scenarios were developed for the potential risk associated with an increase in the duration and volume of rainwater based on IPCC projections. While there is considerable uncertainty associated with rainfall projections, and how rainfall increases may translate into increased flood severity, these scenarios nonetheless are a useful means to explore potential futures and their implications for risk.

Three urban flood scenarios for Java Island

Scenario	**2007 flood (baseline)**	**More wet days**	**More rain volume**
Main characteristics	Duration: 3 days 15% of house value impacted	Duration: 5 days 15% of house value impacted	Duration: 3 days 25% of house value impacted
Population affected	Up to 750,000 people	Up to 1.2 million people	Up to 990,000 people

Lessons learned: Even without sophisticated climate and peril modelling, climate scenarios can be designed with historical events and publicly available climate projections and financial sector data, acknowledging the uncertainties and limitations associated with this approach. Scenarios should be tailored to capture key risks to the financial system, including the geographic distribution of hazard and exposures.

Source: World Bank, internal technical note for the Country Climate and Development Report on Indonesia, 2021.

Compounding shocks, beyond climate change, should be considered in physical climate risk assessments.[42] Given recent experiences of multiple concurrent or closely successive shocks (including COVID-19), it is important to consider compound risk scenarios that recognize that different natural peril events and other shocks often occur simultaneously or at short intervals (see for example Box 7). Economic and financial risks, climate change, environmental damage and biodiversity loss, and public health emergencies are all interconnected in compound events, which can generate nonlinear amplification effects on the risks facing vulnerable communities, financial systems, and economies. The compound impacts can be larger than the sum of the impacts of the individual shocks. Risks may be linked through a range of transmissions channels (see Step 5). Disregarding these interlinkages and their compounding effects can result in an underestimation of risk and limit effective financial risk management.

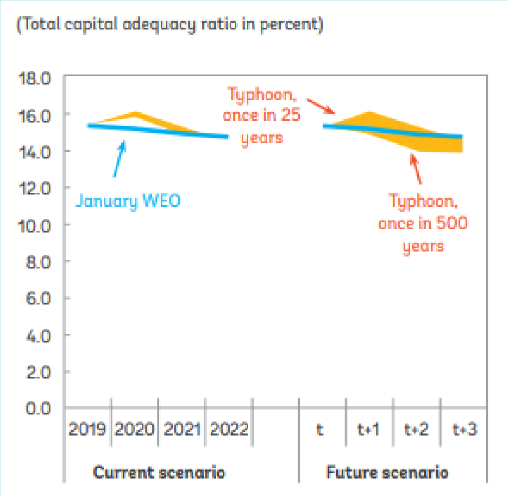
Box 7. Compound risk assessment for joint typhoon and pandemic shocks in the Philippines

The 2021 International Monetary Fund (IMF) and World Bank Financial Sector Assessment Program for the Philippines developed a new approach to analyze the compound risk associated with a joint shock from a typhoon and a pandemic in the Philippines. The analysis modeled typhoon events with return periods ranging from 25 to 500 years and considered the impacts of a pandemic by comparing World Economic Outlook (WEO) data from January 2020 (to capture conditions without the COVID-19 pandemic) and October 2020 (with the COVID-19 pandemic). In the figures below, the shaded orange area shows the impact of shocks on the total capital adequacy ratio. Comparing the impacts of a typhoon for two scenarios—one during a period without a pandemic (figure a) and one during a period with a pandemic (figure b) is instructive: although the destruction from a typhoon alone does not necessarily pose a systemic risk to the financial system (except if extreme tail

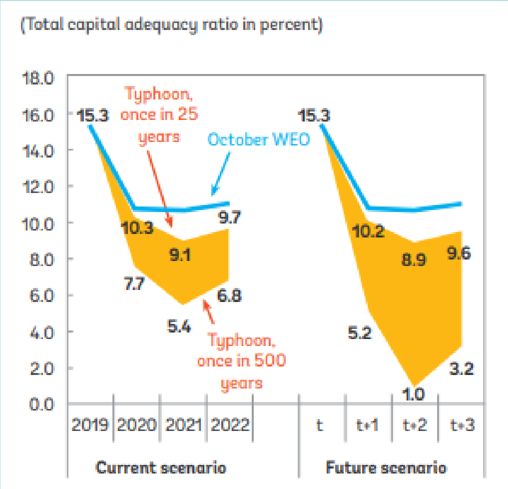
[42] N. Ranger, O. Mahul, and I. Monasterolo, *Assessing Financial Risks from Physical Climate Shocks: A Framework for Scenario Generation* (Washington, DC: World Bank, 2022), https://openknowledge.worldbank.org/handle/10986/37041.

events materialize), it is apparent that a joint shock with a pandemic is likely to result in much more intense effects, beyond just the sum of the effects of individual shocks. The risk is further worsened when the effects of future climate change are considered.

(a) Impact of typhoon on bank capital (during time without pandemic, using January 2020 WEO data)



(b) Impact of typhoon and pandemic on bank capital (using October 2020 WEO data)



Lesson learned: Compound shocks, such as climate shocks and pandemic shocks, can have potential multiplier effects on the economy and the financial sector.

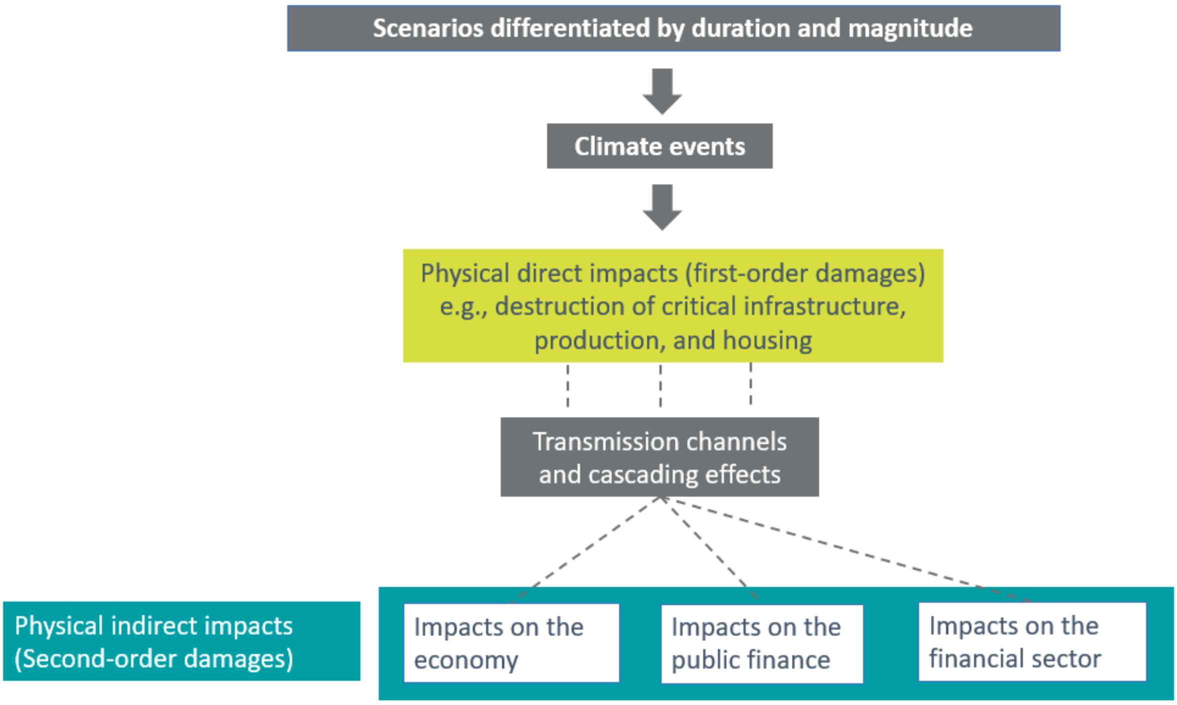
Source: International Monetary Fund, "Philippines: Financial System Stability Assessment: Press Release and Statement by the Executive Director for the Philippines," Country Report No. 2021/074, 2021, https://www.imf.org/en/Publications/CR/Issues/2021/04/08/Philippines-Financial-System-Stability-Assessment-Press-Release-and-Statement-by-the-50347.

4.5. Estimate the impacts

Once the climate scenarios have been defined, the impacts associated with each of these scenarios can be estimated. The impact measurements to be estimated may relate to both direct and indirect impacts (Figure 5).

Direct damages or first-order damages are the most visible consequences of disasters and include physical destruction of housing, critical infrastructure, and means of production. Direct damages are usually assessed through catastrophe risk modeling techniques overlaying hazard, exposure, and vulnerability components and integrating future modeled impacts of climate change. Estimation of first-order damages, those directly resulting from a catastrophic event, lies at the heart of catastrophe modeling, and is especially important from the microeconomic perspective of individuals, businesses, and insurers impacted by these adverse events. Direct flood damage, for example, is commonly determined using depth-damage curves, which denote the flood damage that would occur at specific water depths per exposed capital or per land use class. Drought damages are usually assessed as reduced productivity (e.g., of crops and/or livestock) and increased costs (e.g., irrigation costs), both of which can be further worsened given the cascading effects of drought impacts.

Large-scale catastrophes also have indirect impacts (second-order damages) that go far beyond the direct damages in both space and time. In the wake of a disaster, various disruptions may occur that potentially cause additional economic losses; these include disruptions to productive activities arising from the destruction of critical network infrastructure for transport, electricity, and water; other interruptions and production outages; and sudden redirection of public and private investments. The shock caused by the catastrophe enters the economy by hitting capital stock in several sectors of economic activities (in agriculture, for example, these include livestock, crops, and food processing) that are localized in the area hit by the disaster. The shock can propagate within the economy through different transmission channels. Cascading effects may include significant impacts on the economy (e.g., employment, production, and investment), heavy tolls on public finances (e.g., fiscal revenues and debt sustainability), and the country's financial sector (e.g., credit, market and operational risks and financial stability indicators). Indirect impacts on the financial sector can be significant. Knowing the total scope of damages, including second-order economic effects, is essential to effective financial risk management.



Source: World Bank.

Figure 5. Direct and indirect impacts of extreme events

Macroeconomic models capture the interplay between risks and highlight transmission channels through which indirect impacts are propagated. Multiple macroeconomic models have been designed to replicate the operation of an individual country's economy or the global economy to examine the dynamics of important economic indicators such as output, inflation and unemployment.

In recent years, macroeconomic models are being increasingly leveraged in physical climate risk assessments (see for example Box 8). Usually, input shocks or direct damages, conditioned to the scenario and estimated by catastrophe models as described above, exogenously impact the macro model. Long-term indirect impacts are estimated by the macroeconomic model through endogenous reactions of sectoral and macroeconomic variables over time. The dynamics of macroeconomic models require adaptations to capture countries' socioeconomic specificities and reflect key transmission channels. Examples of models include, the National Institute Global Econometric Model (NiGEM), the University of Venice's EIRIN model, and the Organization for Economic Co-operation and Development's Dynamic Stochastic General Equilibrium model (CatDSGE). The World Bank is currently incorporating climate change and climate shocks in its macro-economic and fiscal model (MFMoD). Among others, MFMod provides projections for greenhouse gas emissions, productivity changes due to global warming, and adaptation needs to climate change.

The choice of macroeconomic models should be driven by the outcomes of interest to policymakers. Some models focus on partial equilibria, others on a full macro adjustment. Some models seek to project, others seek to explain the economic shock transmission. Also, some models are better suited to provide guidance on macro critical issues, while others are better suited to provide information on sector specificities. In Morocco, the World Bank, the Ministry of Finance and Bank Al-Maghrib jointly explored the results from two different macroeconomic models as part of an integrated acute physical risk assessment. A CatDGSE model was used to assess the impacts on the economy (e.g., on GDP, employment, household consumption, and government spending) of climate shocks and policies, and to analyze the costs and benefits of different options for post-hazard government support. An EIRIN model was used to examine the sectoral impact of current and future climate scenarios (e.g., impacts on agricultural, industry and services sectors alongside impacts on financial metrics such as NPLS and CAR), and to analyze the effects of compounding shocks (e.g., a pandemic and flood scenario). Both models allowed a better understanding of the economic shock transmission channels. More detailed explanations of the different macroeconomic approaches, and their relative benefits and limitations, are available in the literature.[43]

Macroeconomic models can capture nonlinear dynamics of risks and some distributional effects. Measurement of impacts on the financial system may not be linearly related to direct damages to physical assets. Depending on the scenario modeled, the indirect impacts on the economy and the financial system may be substantially greater than the direct impacts. Macro models can also help refine the analysis in some focus areas. It is important to note, however, that they generally do not address the geographic dimension, so that results from these models erase some of the granularity included in upstream modeling phases (e.g., catastrophe models) and limit the granularity of downstream modeling phases. It is therefore critical to use these in a manner that preserves as much of the geographic impact information as possible (e.g., by disaggregating their outputs down to subnational level based on a financial exposure footprint or hazard map, depending on country contexts).[44]

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[43] A. Burns, C. Jooste, G. Schwerhoff, "Climate Modeling for Macroeconomic Policy: A Case Study for Pakistan," Policy Research Working Paper No. 9780. (2021) World Bank, https://openknowledge.worldbank.org/handle/10986/36307.; The Coalition of Finance Ministers for Climate Action, "How to Scope the Fiscal Impacts of Long-Term Climate Strategies: A Review of Current Methods and Processes," 2022, https://www.financeministersforclimate.org/sites/cape/files/inline-files/How%20to%20Scope%20the%20Fiscal%20Impacts%20of%20Long-Term%20Climate%20Strategies.pdf.

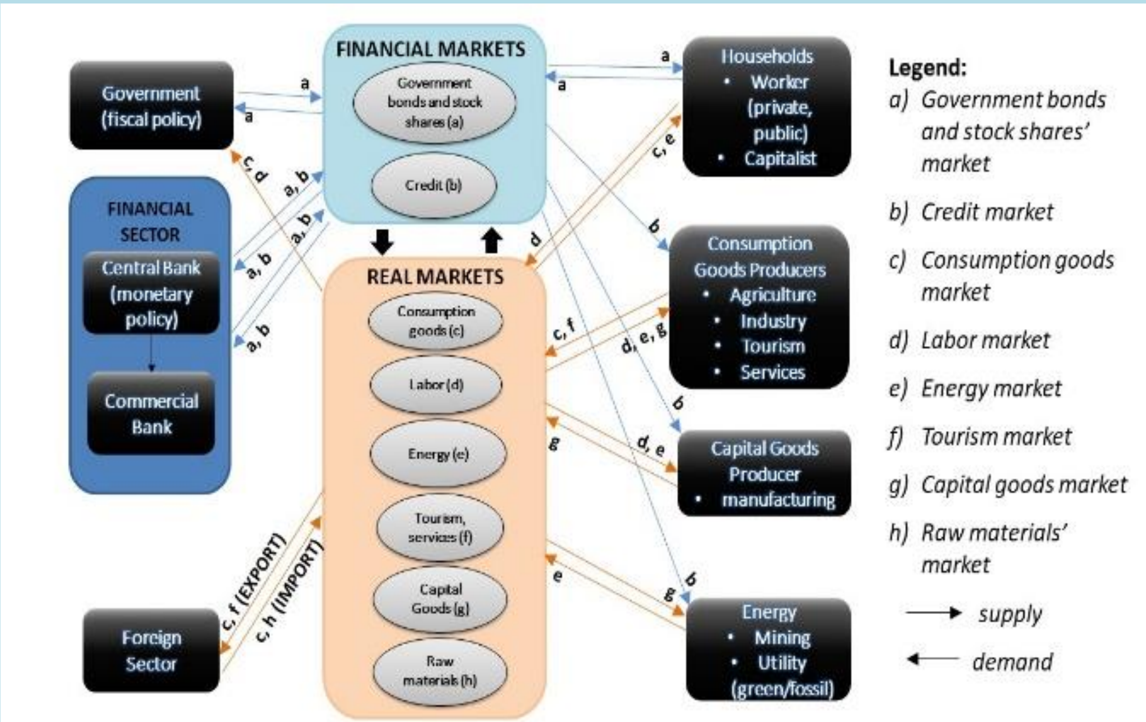
[44] There are some alternatives to the macroeconomic modelling approaches described in this note, which consider credit and market portfolios at a granular counterparty level using geolocated firm data to first model impacts of climate shocks on individual non-financial firms, then relate these micro impacts to bank financial impact metrics. For example, the Bank of England used Moody's Analytics' Public Expected Default Frequency

As with the catastrophe modelling approaches used to estimate direct damages, the macroeconomic modelling approaches used to estimate indirect damages come with limitations and a degree of uncertainty. Macroeconomic models aim, to some extent, to replicate the economy and provide stylized representations of how an economy or a sector will respond to shocks, including climate shocks. The underlining assumptions and economic theories can differ substantially between macroeconomic models, leading to substantial variability in results. Also, results may vary depending on data quality and granularity. In the case of Morocco, the results from the two macroeconomic models, developed as part of an integrated acute physical risk assessment, show that most vulnerable sectors and transmission channels identified were overall consistent across the models, but the magnitude of loss estimates varied to a large extent (e.g., when considering the indirect to direct loss ratio) illustrating the need for cross-model comparison when possible, alongside well-informed interpretation and usage of the outputs of such complex, multivariable analyses.

Box 8. Macroeconomic modelling and transmission channels (EIRIN model)

EIRIN is an agent-based stock-flow consistent model of an open economy composed of agents, sectors and markets, represented as a network of interconnected balance sheets items (figure a). Agents and sectors follow behavioral rules informed by literature, heuristics, and the real world. The choice of this modeling approach is based on its ability to capture the characteristics of complex systems, allowing users (i) to assess in a realistic way the macro-financial impacts, including compounding impacts, of climate change, pandemics, or other shocks; and (ii) to test the impact of fiscal, monetary, and financial mitigation policies.

(a) Agents, sectors and markets of the EIRIN economic model.



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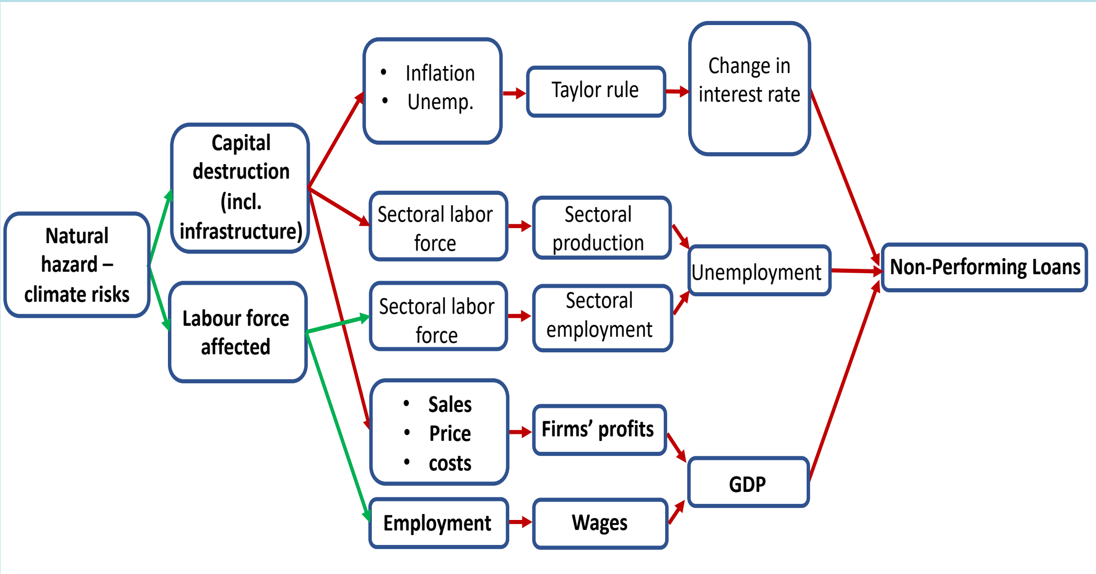
structural credit risk model to convert scenario-specific, firm-level estimates of climate damages to implied probabilities of default.; Bank of England, "The Bank of England's climate-related financial disclosure 2021" (2021), https://www.bankofengland.co.uk/prudential-regulation/publication/2021/june/climate-related-financial-disclosure-2020-21.

Source: A. Hrast Essenfelder, A. Mazzocchetti, R. Gourdel, and I. Monasterolo, "Compound Risk Assessment for DRF: Focus on Climate Physical Risks and the Banking Sector," unpublished methodological note developed for the World Bank Disaster Risk Financing and Insurance Program, April 2021.

In the context of the EIRIN model and its modeling solutions, financial risk metrics are rooted in the state-of-the-art literature and the practice followed by leading financial authorities, including central banks and financial regulators. The inclusion of the NPL affects the composition of the balance sheet of both the banking sector and borrowers in the credit market. In sectors that rely on credit for investment and liquidity purposes, loans are accounted in the liability side. However, these sectors may no longer be able to meet part of their contractual obligations because their economic and/or financial conditions have deteriorated after a shock. Figure b shows the main EIRIN variables through which a natural hazard shock impacts nonperforming loans, including determinants (i.e., change in interest rate, unemployment, and GDP), and the sectoral and macro-financial variables that affect the determinants.

(b) Natural hazards transmission channels to NPLs



Source: A. Hrast Essenfelder, A. Mazzocchetti, R. Gourdel, and I. Monasterolo, "Compound Risk Assessment for DRF: Focus on Climate Physical Risks and the Banking Sector," unpublished methodological note developed for the World Bank Disaster Risk Financing and Insurance Program, April 2021.

Sources: N. Dunz, A.H. Essenfelder, A. Mazzocchetti, I. Monasterolo, and M. Raberto, "Compounding COVID-19 and climate risks: the interplay of banks' lending and government's policy in the shock recovery," *Journal of Banking & Finance*, 106306 (2021), https://www.sciencedirect.com/science/article/pii/S0378426621002582; A. Hrast Essenfelder, A. Mazzocchetti, R. Gourdel, and I. Monasterolo, "Compound Risk Assessment for DRF: Focus on Climate Physical Risks and the Banking Sector," unpublished methodological note developed for the World Bank Disaster Risk Financing and Insurance Program, April 2021.

4.6. Present and interpret the results

Acute physical climate risk assessment should be viewed as an ongoing exercise that provides insightful information but comes with complexities and uncertainties. Such exercises are relatively new, and only recently have the risk modeling community and the financial sector joined forces to articulate a risk assessment framework combining different expertise, data sources, and models.

Presentation and interpretation of the results should emphasize both the quantitative and qualitative components of the analysis. The added value of such assessments lies as much in the approach itself as in the estimated impacts. Intermediary results (e.g., critical transmission channels, exposure hot spots) and qualitative results (e.g., most exposed sectors and geographies, critical perils) are as valuable and important as loss numbers and quantified results per say. This value alone justifies the level of investment involved in putting together a robust modeling methodology, which will also pave the way to future activities and applications as more data and better understanding become available.

A focus on the order of magnitude and trends rather than specific quantitative results is generally advisable, given the substantial uncertainties typically associated with the risk assessment, particularly in countries that may have limited data to support the analysis. This is particularly relevant for financial supervisors when considering to what extent the results can be used to assess probabilities of default and losses given default of particular exposures, or capital requirements. A sensitivity analysis of the results is critical to confirm that the order of magnitude and trends are consistent.

Uncertainties, assumptions, limitations, and caveats need to be clearly communicated to the stakeholders. Issues related to the following may be discussed:

- Limited data availability and granularity and the necessary use of proxies and assumptions (e.g., when estimating regional or sectoral impacts). Finer sectoral and regional data would help capture the distributional aspects and improve the accuracy of results in that respect.
- The potential for different data sources, tools, and models to generate different results when estimating the direct impacts of physical climate risks. In some cases, the limited explanation of methodologies and underlying data may reduce stakeholders' ability to understand the results that would otherwise inform decision-making.
- The design of the macroeconomic modeling used to estimate indirect impacts, which cannot capture all the dynamics and interactions between sectors and agents. Different modeling frameworks calibrated for a country can facilitate validation of the approach and results to increase confidence in the orders of magnitude of results and trends observed.

The presentation of results may initially focus on key stakeholders in the financial sector, but results may also be relevant to a wider audience. Understanding the full extent of direct and indirect impacts of climate risks, and how they permeate through the financial system, has a wide range of applications, not only for financial sector risk management but also for broader public financial management. For example, a large proportion of banks are owned by the state in many EMDEs. The state may thus be exposed to climate risks through contingent liabilities associated with the banking sector. These contingent liabilities come in addition to other climate risk–related contingent liabilities faced by the state, including physical damages to public assets and infrastructure. Recent crises (e.g., global financial crisis of 2007-2008, the COVID-19 pandemic) show that governments are particularly exposed to tail risks, even more so in many EMDEs where insurance penetration is low and households and businesses rely on governments for shock-responsive financial assistance.

5. Summary of key lessons learned and recommendations

Acute physical climate risk assessment is a new topic, and even more so in EMDEs. Nevertheless, several key lessons can already be drawn from recent work in EMDEs.

The main overarching lesson is that climate risk assessment methodologies currently used in developed economies may not be easily replicated in EMDEs due to multiple constraints and limitations (including data); the risk assessment should be adjusted to fit with the country context. The practical framework proposed in this note aims to be flexible enough to be used by EMDEs.

The framework relies on six key steps: (i) define the needs and objectives; (ii) identify available data and resources; (iii) define the scope and approach; (iv) generate the scenarios; (v) estimate the impacts; and (vi) present and interpret the results.

The implementation of this practical framework in EMDEs is still work in progress, but some preliminary lessons can be drawn from these experiences, which can inform central banks and supervisors:

1. A country-specific approach should be tailored to the needs and objectives identified by the local stakeholders. A questionnaire and interviews with experts and relevant actors can help define the needs and objectives of local stakeholders, and identify perils, regions, sectors, and investment or credit portfolios of particular concern (**Step 1**). See Annex 1.
2. There is a wide range of existing data sets and resources, including open sources data sets, tools, and catastrophe models. However, they can present different results, and caution should be used when interpreting outputs from global data sets that may not have been validated at the country level. It is important to identify which ones can be used to best support the country assessment (**Step 2**). In cases where granular data are not readily available, innovative methods relying on satellite data and artificial intelligence may be used to improve the granularity of data.
3. The scope and approach of the analysis should be defined based on country specificities, data availability, and local technical capacity (**Step 3**). In case of limited data, an initial qualitative risk assessment may be useful to increase awareness of climate risk among stakeholders, build an expert network and local capacity, and identify data that should be collected to support future risk assessments. A staged approach—one that moves from a qualitative assessment to a more sophisticated quantitative assessment when data and expertise are available—can be used. The methodology should be designed to allow for future improvements.
4. Scenarios should be plausible and should explore a range of different options (**Step 4**). Even in the absence of sophisticated climate risk modeling, scenarios can be defined based on historical events, adjusted from publicly available climate projections and acknowledging the uncertainties and limitations associated with the approach. Scenarios should be tailored to capture key climate-related financial risks and the geographic distribution of hazard and exposures. The inclusion of a range of scenarios in a climate risk assessment can help identify key sensitivities and nonlinearities (e.g., due to compounding shocks).
5. Qualitative analysis generally focuses on direct impacts (physical damages) and identifies key transmission channels. Quantitative analysis should capture both indirect and direct impacts, as well as short- and longer-term effects on the economy and sectors (**Step 5**).
6. The presentation of results should focus on the order of magnitude and trends, and discuss uncertainties, assumptions, and limitations (**Step 6)**.

The complexity and cross-disciplinary nature of the assessment requires broad expertise. Highly specialized institutions and partners can be useful in designing a methodology, identifying key sources of information, and possibly supporting EMDEs through the risk assessment itself.

This practical framework is a first attempt to adjust climate risk assessment to the needs and specificities of the EMDEs through a first set of country cases. It is meant to be further refined as more EMDEs perform climate risk assessment.

Appendix: Questionnaire for financial authorities related to physical climate risk assessment

The purpose of this questionnaire is to collect initial baseline information on the financial sector in a specific country or region. This questionnaire **focuses on the assessment of physical climate risks**.

A. Governance

1. Are there climate-related risk management frameworks or processes in place at the Central Bank or within private banks?
2. If so, please describe your environmental and climate risk management strategy, including how it has evolved over the years.
3. Are there other public bodies (national or regional) that have a role related to climate risks? Are there arrangements for coordination between these bodies?
4. Have you initiated or participated in collaborations with other institutions (e.g., ministries, financial institutions, other supervisory entities, universities, etc.) in any climate risk assessment initiative for the financial sector? Please specify the format and expected deliverables of these collaborations.

B. Risk identification

5. Please give a prioritized list of climate risks (e.g., droughts, floods, tropical cyclones, etc.) that you have identified or are most concerned about in terms of their potential impact on the financial sector. Please specify in your response the following:
   - The transmission channels that you consider may impact the banking sector
   - The type(s) of financial risks involved (credit risk, market risk, liquidity risk, operational risk, business model risk, liability risk, and reputational risk)
6. What are the time horizons (e.g., 2030, 2040, or beyond) you are considering for identifying these risks, and how do you expect these risks to evolve over time?
7. Which geographic regions do you consider to be particularly exposed to climate risks? Please specify in your answer for each geographical region the peril(s) you are considering.
8. Which sectors (e.g., agriculture, fisheries, tourism) do you consider to be particularly exposed to climate risks? Please specify in your answer for each sector the peril(s) considered. In the case of drought, which crop failure would the financial sector be most exposed to?
9. Are there any financial institutions that you consider to be particularly exposed to climate risks based on their location, activities, and clientele? Are some of them systemic?
10. Which asset classes or portfolios (banking and nonbanking) do you consider particularly exposed to climate risks?

C. Scenario's definition and impact quantification

11. Are there examples of past events in which these risks have materialized? If so, please list the key historical events that have had the most impact, and please provide details on the impact of these events on the banking industry. Can you give some insights into how the impacts were estimated and which metrics were analyzed (e.g., NPLs)?
12. Has your organization undertaken any quantitative analysis of the impacts of climate risks on the financial sector, particularly on assets related to sectors, regions, and clients that are particularly vulnerable to climate-related events such as storms, floods, or drought? If so, please provide additional information (the peril assessed, climate risk models used, outputs/ results, etc.).
13. In the absence of a quantitative financial impact analysis, do you have estimates of the values at risk (e.g., in terms of credit portfolio in sectors or geographies that you believe are particularly exposed to climate risk)? Please provide estimates if available (ideally by type of peril).
14. Have you identified climate risk scenarios that are particularly relevant to the financial sector? If so, please describe the scenarios that you believe are most relevant. Are they based on historical events or projected climate change scenarios?
15. Among the possible climate change scenarios, is there any type of risk (e.g., drought, flood, tropical cyclones), type of investment or credit, type of sector (e.g., agribusiness, tourism), type of subsector or product (e.g., agricultural crops), or geographic area that you believe are more important in terms of financial risk to your organization and hence warrant further analysis?

16. For the assessment of physical risk on the banking exposures, please indicate the area(s) where you feel that information is lacking:
    - Physical hazard (characterization of future drought or flood scenarios, for example).
    - Financial exposure (granularity of the available data on portfolio exposures by geographic area and by sector of activity).
    - Financial vulnerability of banking exposures (characterization of the financial impact in terms of credit risks, for example). In this regard, please share any information on firm indebtedness by sector.
17. How does the microfinance sector manage the impact of climate-related risks?

D. Government interventions (to be completed by the Ministry of Finance)

18. Please provide detailed information on government compensation related to climate disasters (e.g., floods, droughts, and forest fires).
19. If possible, please provide estimates of the percentage of total disaster damages covered by public sources.
20. Are there any credit guarantee mechanisms in place? What are the targeted sectors and beneficiaries? What is the share of the guaranteed banking portfolio?

E. Climate-related physical risks for the insurance sector (to be completed by the insurance authority)

21. Does the insurance and reinsurance sector have strategies or policies for managing climate risk as a whole? Does it have methods or tools for estimating the risk—at least qualitatively—on its exposure portfolios (assets or liabilities)?
22. Are there estimates of industry values at risk (e.g., in terms of aggregate policy limits) to climate risk (e.g., drought or flood)? Do some insurers have such indications for their own portfolio?
23. What types of products, policies, or geographic areas do you consider to be most exposed to physical climate risk?
24. Is climate risk considered in the risk underwriting process (e.g., in terms of selection, exclusion, or pricing)?
25. Are there any subsidy/compensation mechanisms or dedicated support funds from governments to (re)insurers in case of a default situation following an extreme loss scenario that could include weather events?
26. Please specify what insurance products are available in the financial sector to cover climate-related damages. Is flood insurance available? To what extent is drought, and in particular, its impact on agriculture, insured? Please specify market size, coverage, and residual protection gap.
27. What is the availability of relevant insurance products related to climate damage? Do you have any indication of the premium breakdown for the most important insurance products?
28. To what extent is the lack of a mature insurance market for policies covering climate damages considered a barrier to bank lending to areas/sectors vulnerable to climate risks?