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UNEP 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

TCFD Banking Pilot Project Phase II

September 2020

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Acknowledgments

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Executive Summary

Context

Three years on from the publication of the Task Force on Climate-related Financial Disclosures (TCFD) recommendations, the financial sector's attention is firmly focused on climate-related risks and opportunities. The TCFD recommendations aimed to promote forward-looking scenario-based assessments of climate change by financial institutions and corporates, and for the findings to be incorporated into their strategic decisions. Since then, the Network for Greening the Financial System (NGFS), a grouping of central banks and supervisors, has been established and its membership has grown at a fast pace. The NGFS aims to contribute to the development of environment and climate risk management in the financial sector, and to mobilize mainstream finance to support the transition toward a sustainable economy. Its members have collectively pledged support for the TCFD recommendations. In another major development, the Principles for Responsible Banking (PRB) were established by UNEP FI and member banks in 2019. Signatory banks to the PRB (more than 180 by August 2020), have committed to align their strategy and practice with the vision that society has set out for its future in the Sustainable Development Goals and the Paris Climate Agreement. UNEP FI has run pilot projects on implementing the TCFD recommendations for over 90 banks, investors, and insurers. Many other processes and organizations aim to tackle climate risk and opportunity in the financial sector.

This new focus on climate-related risks and opportunities sits within a context of intensifying climate change impacts. The Intergovernmental Panel on Climate Change (IPCC) Special Report on global warming of 1.5°C estimates that human activities have already caused about 1°C of global warming above pre-industrial levels.[1] If global GHG emissions continue to increase at the current rate, warming is likely to reach 1.5°C by around 2040 and up to 4°C by the end of the century. Yet the world will face severe climate impacts even with 1.5°C of warming. Physical risks – which result from climate variability, extreme events and longer-term shifts in climate patterns – are already being experienced and are set to intensify in the future.

This report describes the outputs of the UN Environment Programme Finance Initiative (UNEP FI) Phase II banking pilot which lays out state-of-the-art tools and data for assessment of physical climate-related risks and opportunities by banks. The Phase II pilot, involving 39 UNEP FI member banks from six continents, focused on addressing key methodological challenges highlighted in its predecessor Phase I report, 'Navigating a New Climate'.[2] As the climate policy context evolves, banks are more focused on meeting the emerging expectations of financial industry regulators. While the emphasis at present is on assessing risks, banks have a key role to play – and an enormous business opportunity to realize – in providing finance for governments, businesses and consumers to invest in adaptation measures.

This Phase II report provides rich technical guidance and information on the resources available to support forward-looking scenario-based assessments of physical risks and opportunities. The tools and data to support banks' physical risk and opportunity assessments must be grounded in robust scientific evidence, be usable within the context of banks' other data, tools and systems, and facilitate comparability between banks. While these needs are not yet fully met, significant advances have been made.

Phase II pilot project activities and outputs

The Phase II pilot activities were structured as a set of five modules:

- **Module 1: Extreme events data and portals – reviewed examples of climate and climate-related extreme events data and portals from both public (free to use) and commercial data providers.** While there are many portals providing data on projected future incremental changes in temperature and precipitation, the Phase I pilot identified a lack of data on future changes in extreme events. The examples included in the review were purposefully selected to cover a wide range of extreme event types of relevance to banks' loan portfolios. The review applied an analytical framework which covered: whether the provider gives observed and/or future data; spatial resolution and spatial coverage of the datasets; the output formats; and data accessibility.

  Piloting banks also provided their views on how the data and portals can be strengthened to better meet their needs for undertaking portfolio physical risk assessments. The banks identified trade-offs between 'one stop shop' data portals which bring together multiple hazard types and thus facilitate comparison between hazards at the same location, versus providers who specialize in one or two hazards at high quality (e.g. high spatial resolution, wide range of return period statistics). Banks were enthusiastic about using data portals which allowed for hazard data to be downloaded and integrated into their own systems, as client data confidentiality can constrain them from uploading data to external analytics platforms.

- **Module 2: Portfolio physical risk heatmapping – recognized the benefits of examining total portfolio exposure and identifying where higher physical risks may lie before moving on to 'deep-dive' assessments of at-risk portfolio segments.** The module explained the wide range of impact channels through which physical risks can affect counterparties' performance across their entire value chains, encompassing operations, physical assets, supply chains and markets. It described the three components of risk that can be evaluated in heatmapping, using the IPCC's risk definition – vulnerability, hazards and exposure.

  The module also summarized a collective activity by Phase II pilot banks who worked towards reaching a shared view on key areas of vulnerability and relevant hazards for six sectors of interest. While banks' views differed, their key sector-based findings on vulnerabilities were:

  - **Agriculture, forestry and fisheries** are highly vulnerable due to their reliance on climate-sensitive natural resources (water, land) and labor health and productivity, where outdoor workers can be exposed to extreme events.
  - **Metals and mining** activities depend on water availability, while competition with other water users are often key issues for mining operations. More frequent heatwaves can also impact labor productivity and operating hours at mine sites.
  - **Power and energy** sector vulnerabilities vary between sub-sectors. Hydropower and thermal power generation are highly dependent on water for operation. In comparison, solar and wind generation were considered less vulnerable to climate-related factors.
  - Within **oil and gas**, extraction of crude petroleum and natural gas are vulnerable due to their dependence on natural resources and outdoor workers (who are also often working in extreme environments). Further, changes in seasonal demand for fuels for heating and cooling can be expected.
  - **Manufacturing** needs large quantities of water and land for operation of the sector's fixed assets.
  - **Real estate** is vulnerable to changes in market demand driven by physical risk, as experience of extreme events, particularly when coupled with insurance concerns could make some real estate locations less desirable, while opening up investment opportunities in others.

- **Module 3: Tools for physical risk assessment of financial risk – aimed to improve banks' understanding of commercially-available tools and analytics, as well as training the Phase II banks to utilize the Phase I Excel-based methodologies**.[a] The module examined commercial tools and analytics using a framework which considers their coverage of climate scenarios, time horizons and hazards; their approach to analyzing physical risks; the required user inputs; and the outputs provided. The tools and analytics are differentiated according to their level of analysis (ranging from portfolio-wide assessments through to analysis of individual assets); the impact channels covered; and their methodologies for impact assessment.

  Several piloting banks provided case studies on their experience of applying and further developing the Phase I methodologies to provide initial physical risk assessments for specific sectors, whereas others engaged in direct discussions with commercial providers to evaluate their tools and analytics. Some piloting banks identified parts of their real estate portfolios which could experience future depreciation in property values due to extreme events, and potential increases in the probability of default (PD) for energy and oil & gas companies. The banks highlighted some benefits from trialing the physical risk tools, including bringing together teams of experts from across the bank to look at climate change risk, and developing their understanding of potential risks to segments of their portfolios. They also identified challenges faced during the piloting process, including collation and processing of bank-held data and insufficient granularity or lack of data on counterparties.

- **Module 4: Physical risk correlation analysis of FI portfolios – was developed as banks recognized the value of having a deeper understanding of observed relationships between loan performance metrics and climate-related events.** Some banks have reported that borrowers are already being affected by climate and weather events, and these effects provide early signals of a changing climate, and empirical evidence which may help to calibrate forward-looking physical climate risk assessments. The module provided a step-by-step process for banks to undertake correlation analysis with a worked example using actual property values for an anonymized coastal city and its neighborhoods in the US. The results revealed neighborhoods and types of house experiencing 'climate gentrification' – a term used to describe increases in real estate values in neighborhoods that are more resilient to climate-related threats.[3] The module also summarized recent developments in scientific research on correlation analysis and more sophisticated statistical techniques, based on a review of more than 50 studies investigating flood, drought and wildfire risks within the real estate and agriculture sectors. A pilot bank applied correlation analysis to begin to evaluate how a major wildfire in South Africa may have affected the value of nearby properties. Their results showed a deceleration in price increases after a major fire event for properties located close to the wildfire.

- **Module 5: Analysis of opportunities driven by physical climate risk – aimed to provide insights into the climatic, business, policy and market-led drivers of physical risk-related opportunities.** The scale of investment needed for adaptation over the next 10 years is enormous and cannot be met by public budgets alone – both public and private finance are needed to meet this challenge. Opportunities for banks to support the adaptation needs of their clients were found to vary depending on the region, market and industry in which a bank operates. Understanding the changes taking place in business sectors and with clients as they are impacted by a changing climate, being aware of the adaptation responses they need to make, and recognizing the challenges presented by the Paris Agreement and a green recovery from COVID-19 were found to be critical. The module reiterated the opportunities framework developed in the Phase I pilot, which helps banks identify where to focus their adaptation and resilience financing efforts. The framework was designed to provide a strategic market assessment within the context of a bank's institutional capacity and market positioning. Application of the framework can show where a bank is best-placed to assist its clients. Piloting banks summarized actions they were taking and planning, to help clients adapt and build resilience to physical climate risk. In turn, these actions provide business opportunities to the bank in sectors including agriculture, water-intensive industries, real estate, urban development and infrastructure.

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a The methodologies are detailed in the Phase I report, 'Navigating a New Climate'.

The five modules are shown in the numbered rings in Figure 1, mapped on to the cause-effect chains linking climate hazards to risks and opportunities for banks. Some of the modules target several elements in the cause-effect chains, e.g. Module 5 supports analysis of client adaptation needs, solution provider opportunities, and associated opportunities for banks. Furthermore, analysis of some elements in the cause-effect chains is supported by more than one module, e.g. Modules 2, 3 and 4 all help with assessment of risk to banks' loan portfolios.

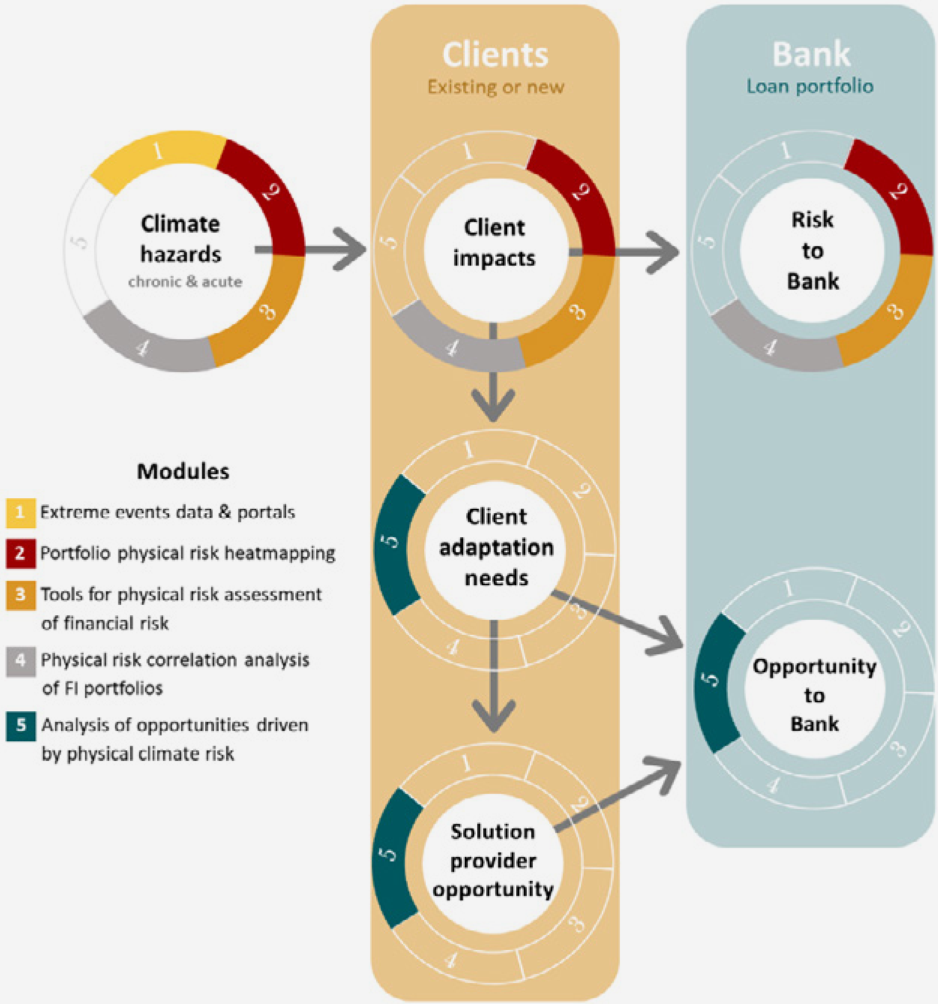

Figure 1: The Phase II pilot modules map on to the cause-effect chains linking climate hazards to risks and opportunities for banks

Looking forward

The imperatives for banks to assess and act on physical climate-related risks and opportunities have never been greater – nor have their needs for robust tools and data to support their assessments. The modules developed through the Phase II pilot have charted out state-of-the-art tools and data to help them on this journey. Nevertheless, challenges remain, and the Phase II pilot has shed light on the very real practical constraints that banks face in making strides forward.

Evaluating physical climate-related risks and opportunities in loan portfolios requires data which translate climate science into impacts on clients and the wider economy, and onwards to financial metrics used by banks. It requires knowledge of how physical risk can affect the entire value chains of banks' counterparties – not only their physical assets and operations, but also their supply chains and markets, and their environmental and social performance. It requires an understanding of how well-prepared counterparties are for the risks that lie ahead, of their adaptation

plans, and of the risk mitigation that will be provided by insurers and governments. Evaluating all these factors within loan portfolios is no mean feat, and the data collection and analysis effort can appear daunting.

While more work lies ahead, the pilot has shown that the Phase II tools and data can provide real help to banks in charting their way forward:

- Heatmapping proved to be an efficient approach which helped to focus attention on portfolio segments meriting deeper analysis. The collaborative sector vulnerability exercise by piloting banks identified many cause-effect chains through which climate change can affect indicators of investment performance. It demonstrated the richness and complexity of physical climate risk, and also revealed differences of opinion among the banks on the degree of vulnerabilities facing sectors and subsectors.
- The commercially-available tools and analytics for physical risk assessment enable banks to begin evaluating credit impacts. The range of tools / analytics shows that providers have made significant advances in facilitating physical risk analysis across counterparties' value chains. Yet they still lack depth and data on some key aspects of counterparty physical risk. Piloting banks also identified challenges in corralling together in-house datasets and in assessing risks for SME clients.
- Correlation analysis and more advanced statistical techniques for analyzing relationships between loan performance metrics and climate-related events show great potential and should be further explored. The pilot has identified a large body of research on these techniques applied to real estate and agriculture, which can be built upon by banks to develop their own analyses, grounded in empirical data specific to their portfolios.

Even this is not enough to fully grasp the systemic nature of climate change and its interactions with other risk factors. This report is published in the wake of the COVID-19 pandemic which has demonstrated the implications of failing to understand and manage systemic risks. Like COVID-19, climate change can lead to systemic risk, and requires models capable of appraising multiple hazards and system interdependencies. COVID-19 has demonstrated the limits to current risk management practices which are invariably focused on fragmented appraisal of risk. Management of systemic risk must improve if a robust response to climate change is to be achieved.

Banks have not yet understood and realized their potential opportunities to support clients' investments in adaptation. The banking sector has a critical role to play in implementation of the Paris Agreement by mobilizing financial flows to deliver adaptation and climate resilience. The Principles for Responsible Banking provide a driver for banks to assess and report on their climate resilient investment/lending opportunities, as signatories to its framework are committed to aligning with the Paris Agreement and to conducting impact assessments and target setting around positive impacts alongside negative impacts. Banks must recognize their pivotal role in financing economies and societies that are prepared for the unavoidable physical risks that lie ahead.

1. **Introduction:** Helping banks respond to an evolving climate landscape

1.1. Context

The publication of the voluntary recommendations of the FSB Task Force on Climate-related Financial Disclosures (TCFD) in June 2017 proved to be a game-changer for focusing the financial sector's attention on climate-related risks and opportunities. Just three years later around 1,400 organizations have signed up as TCFD supporters, and a lot else has changed. December 2017 saw the establishment of the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) by eight central banks and supervisors. Since then, NGFS membership has grown rapidly, reaching 69 members and 13 observers by July 2020. In 2018, the Intergovernmental Panel on Climate Change (IPCC) Special Report on global warming of 1.5°C[4] showed that the world will face severe climate impacts even with 1.5°C of warming above pre-industrial levels, and the effects are significantly worse at 2°C. The Principles for Responsible Banking (PRB) were established by UNEP FI in 2019. Signatory banks to the PRB, numbering more than 180 in August 2020, have committed to aligning their strategy and practice with the vision that society has set out for its future in the Sustainable Development Goals and the Paris Climate Agreement.[5] UNEP FI has run pilot projects on implementing the TCFD recommendations for over 90 banks, investors, and insurers.[b] Other financial sector initiatives are focused on mainstreaming frameworks for the management of climate-related risks and opportunities, developing new approaches and creating new guidance and tools.[c]

Regardless of the success and rate at which global greenhouse gas (GHG) emissions are controlled, some anthropogenic climate change is already locked into the earth's climate system over coming decades and centuries. According to the IPCC Special Report on global warming of 1.5°C, human activities are estimated to have already caused about 1°C of global warming above pre-industrial levels. If global GHG emissions continue to increase at the current rate, global warming is likely to reach 1.5°C by around 2040 and up to 4°C by the end of the century. Physical risks—those risks resulting from climate variability, extreme events and longer-term shifts in climate patterns—are already being experienced and are set to intensify in the future.

A dramatic transformation across economies is required over the next 10 years to transfer to a sustainable development pathway, consistent with achieving net zero by 2050 at the latest and managing unavoidable physical risks. This will require radical actions by all stakeholders. Governments for example will have to effect change through enacting targeted policies and regulations to ensure public services, infrastructure and natural environments are resilient to climate change. Business will need to direct more investment toward adaptive technologies, while the changing priorities of environmentally-conscious consumers will be critical in driving more responsible spending behaviors. All of these actions will need to be underpinned by a finance and banking sector which provides the required funding. Radical action is not only confined to the delivery of the transition agenda; it is also required in adapting to changes in the climate. Stabilizing the global climate at temperature increases of 1.5°C or 2°C above pre-industrial levels, in line with the Paris Agreement, still represents a severely adverse outcome for both natural and human systems. Both levels will have 'baked in' catastrophic impacts in many parts of the world, in developing and developed countries. For example, stabilizing at 2°C leaves 37% of the global population exposed to severe heat at least once in every five years, a 7% reduction in maize harvests in the tropics, and a 99% loss of coral reefs.[6]

b See https://www.unepfi.org/climate-change/tcfd/

c See examples provided in: https://www.mainstreamingclimate.org/connecting-the-dots/. [Last accessed 14 August 2020]

Box 1.1: The Network for Greening the Financial System and the Principles for Responsible Banking

Network for Greening the Financial System

The NGFS, a network of central banks and supervisors, is a global initiative which contributes to the development of environmental and climate risk management in the financial sector. Its purpose is to help strengthen the global response required to meet the goals of the Paris Agreement and to enhance the role of the financial system in managing risks and mobilizing capital for green and low-carbon investments in the broader context of environmentally sustainable development. NGFS members represent five continents, around 60% of global greenhouse gas emissions and the supervision of over three-quarters of the global systemically important banks and two-thirds of global systemically important insurers.[7] The network shares best practices and works to mobilize mainstream finance to support the transition toward a sustainable economy.

Supported by the network, central banks and supervisors around the world will evolve their climate-related risk and opportunity disclosure expectations and policies. A recent NGFS guidance report, for example, sets out recommendations for NGFS members as well as the broader community of banking and insurance supervisors to integrate climate-related and environmental risks into their supervision, including guidance on engaging with the financial institutions they supervise[8]. Other recent NGFS publications include its guide to climate scenario analysis for central banks and supervisors[9].

The Principles for Responsible Banking

The Principles provide the framework for a sustainable banking system, and help the industry to demonstrate how it makes a positive contribution to society. The six principles embed sustainability at the strategic, portfolio and transactional levels, and across all business areas. Signatory banks commit to taking three key steps which enable them to continuously improve their impact and contribution to society:

1. Analyze their current impact on people and planet,
2. Based on this analysis, set targets where they have the most significant impact, and implement them,
3. Publicly report on progress.

1.2. The UNEP FI Phase II banking pilot for physical climate risks and opportunities

The UNEP FI Phase II banking pilot commenced in 2019 within this changing landscape and aimed to build upon the outcomes and findings of Phase I. The Phase I pilot involved 16 commercial banks and developed initial methodologies for undertaking forward-looking scenario-based assessments of climate risks and opportunities in loan portfolios, in line with the TCFD recommendations. For physical risks and opportunities, it culminated in the 2018 publication of the report, 'Navigating a New Climate'.[10] A larger cohort of UNEP FI member banks, 39 in total, from six continents, have engaged in Phase II.

1.2.1. Purpose of this Phase II pilot

Banks need analytical tools and data to support them in assessing physical climate risks and opportunities, so they can evaluate and manage the potential financial and strategic impacts on their portfolios and strategies, and produce effective disclosures. As the climate policy context evolves, banks are increasingly focused on alignment with emerging expectations of financial industry regulators. The tools and data to support them must be grounded in robust scientific evidence, and usable within the context of other data, tools and systems used by, or available to, banks. While these needs are not yet fully met, advances are rapidly being made.

The Phase II pilot aimed to provide active guidance to banks on some of the pressing challenges in assessing physical risks and opportunities, focused on key methodological issues highlighted in Phase I. It took as its starting point the 'future directions' identified in the final chapter of the Phase I report,[d] which identified key challenges and proposed ways forward to begin to address them. It aimed to deepen and improve upon the Phase I methodologies. This Phase II report therefore provides richer technical guidance, and more information on resources available to assess physical risks and opportunities, than its Phase I forerunner.

The Phase II pilot activities were structured as a set of modules, which map on to the cause-effect chains linking climate hazards to risks and opportunities for banks. As shown in Figure 1.1, the cause-effect chains start with changes in chronic and acute climate hazards. These in turn can adversely impact banks' clients through lower earnings or higher costs and ultimately lead to lower credit quality portfolios driven by physical risk-adjusted probabilities of default. Clients may adapt to these impacts by investing in measures to minimize them (such as technologies to reduce water use in areas facing greater water stress due to climate change). Providers of adaptation solutions (e.g. water efficiency technology providers) may thus have opportunities to grow their markets. Banks then have the potential to realize opportunities to increase lending to clients with adaptation needs, as well as to adaptation solutions providers requiring investment for growth.

The Phase II modules are briefly introduced in Table 1.1 and are shown in the numbered rings in Figure 1.1. As the figure shows, some of the modules help to tackle several elements in the cause-effect chains, e.g. Module 5 supports analysis of client adaptation needs, solution provider opportunities, and associated opportunities for banks. Furthermore, analysis of some elements in the cause-effect chains is supported by more than one module, e.g. Modules 2, 3 and 4 all help with assessment of risk to banks' portfolios.

d Set out in Chapter 5 of 'Navigating a New Climate' entitled 'Future directions: Towards the next generation of physical risk and opportunities analysis'.

Table 1.1: Overview of the Phase II pilot modules for physical climate risk and opportunity

No.	Module	Scope
1	Extreme events data & portals	Reviews available data portals for present-day and future extreme events Identifies their key features and summarizes piloting banks' views on how they can be strengthened
2	Portfolio physical risk heatmapping	Explains concept of heatmapping as part of physical risk assessment Identifies range of impact channels through which physical risks can manifest, and interlinkages between vulnerability, hazards and investment performance Summarizes views among piloting banks on key areas of vulnerability and related climate hazards for selected sectors
3	Tools for physical risk assessment of financial risk	Reviews commercially available tools and analytics for physical risk assessment of banks' loan portfolios Summarizes data gaps and areas of improvement identified by piloting banks
4	Physical risk correlation analysis of FI portfolios	Provides a workflow for correlation analysis and shows how this can be applied using data on observed extreme events and financial metrics in the real estate and agriculture sectors Summarizes recent developments in scientific research on correlation analysis applied to flood, drought and wildfire risks Signposts more sophisticated statistical techniques for analyzing indicators of physical risks in financial data
5	Analysis of opportunities driven by physical climate risk	Defines opportunities for banks in the context of physical risk Sets out climatic, business, policy and market-led drivers of physical risk-related opportunities Summarizes a framework for banks to assess opportunities

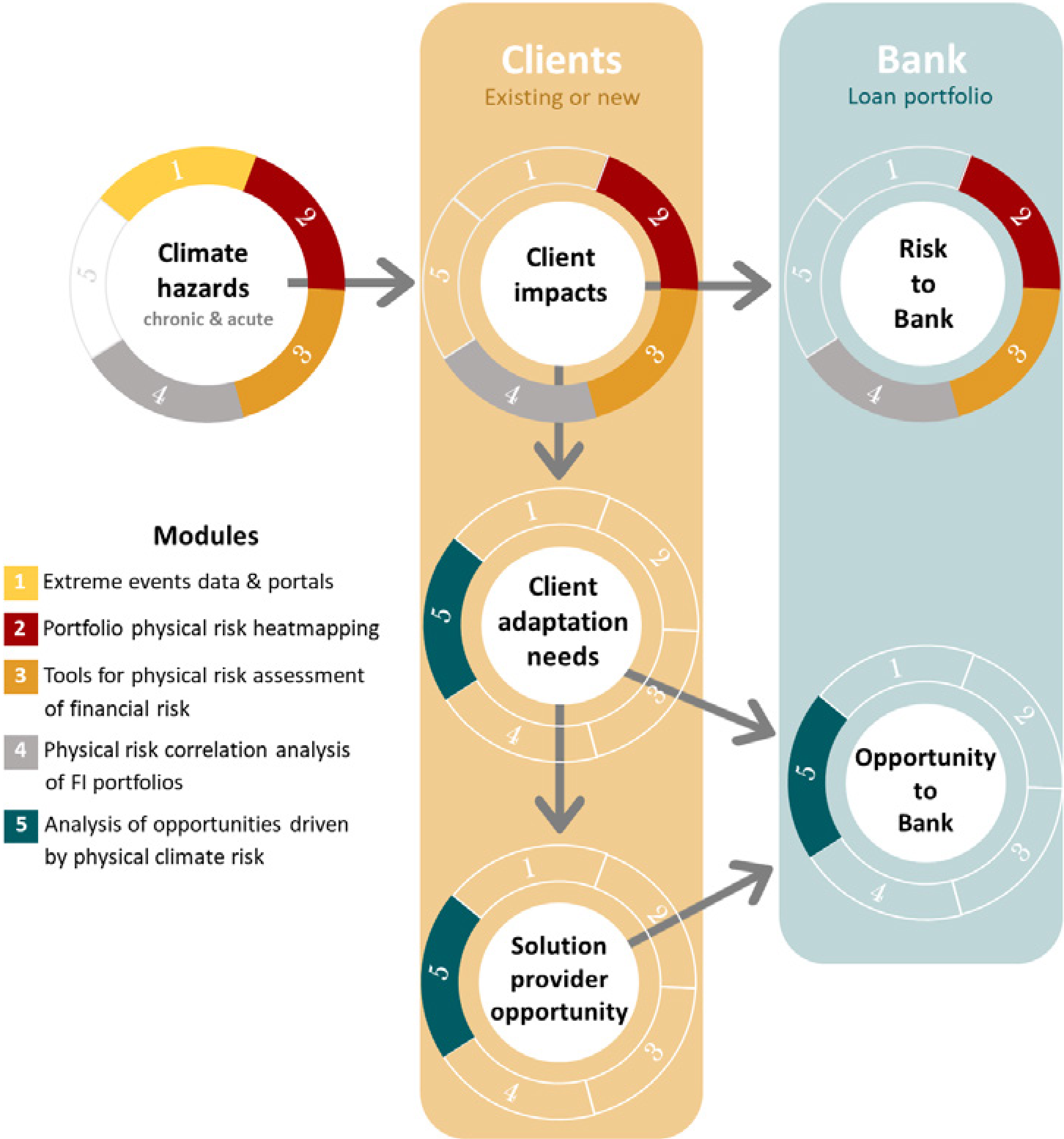

Figure 1.1: The Phase II pilot modules mapped on to the cause-effect chains linking climate hazards to risks and opportunities for banks

1.2.2. Structure of this Phase II report by module, including experiences of piloting banks

This Phase II report presents each module in turn and includes the experiences of piloting banks who contributed to the development of the modules. The chapters for each module address the scope outlined in Table 1.1. In detailing the experiences and learnings of the participating banks in these modules, this report ties together the work undertaken during the year-long Phase II TCFD program. Additionally, each module addresses a specific component of physical risk and opportunity assessment that provides a blueprint for industry participants in assessing these topics. The Module 1 chapter incorporates reflections of piloting banks who trialled extreme events data and portals. The Module 2 chapter summarizes the outputs of an exercise by piloting banks which aimed to reach a collective view on key areas of vulnerability and related climate hazards for selected sectors. The chapters for Modules 3, 4 and 5 include stand-alone case studies from banks who piloted these modules, to provide practical experience and insights into the challenges and benefits of applying them. The final chapter provides concluding remarks on what lies ahead to further progress physical risk and opportunities assessments, recognizing the pivotal role that banks play in financing climate-resilient economies.

2. Extreme events data and portals

Extreme events such as floods, droughts and tropical storms already cause damage to fixed assets, lead to changes in output and asset values, and disrupt supply chains. They can affect banks' borrowers and have the potential to create risks for banks' loan portfolios. As the climate is changing, extreme events are becoming more frequent and more severe. Their importance varies across geographies and time horizons, between different industry sectors and individual borrowers. Data on future changes in extreme events (along with data on projected future incremental changes in variables such as temperature and precipitation) are therefore some of the layers of data and information that banks need to bring together to analyze physical climate risks in their portfolios.

This chapter reviews climate and climate-related extreme events data and portals (to access the data), identifying their key features and how they could be strengthened to improve their applicability for portfolio physical risk assessments undertaken by banks. The physical risk methodologies developed in the UNEP FI TCFD banking pilot Phase I called for the use of extreme events data, alongside data on incremental climate change impacts, to assess how banks' loan books could be affected under future climate scenarios. While there are many portals providing data on projected future changes in average temperature and precipitation, (incremental changes) there is a lack of data on future changes in extreme events. Thus, Phase I found that banks need more guidance on how to access data on future changes in extreme events. Other important lessons relating to extreme events data and portals were learned from Phase I. These include aspects related to data usability by banks, available extreme events statistics and forward-looking data for scenario analysis:

- Many banks do not currently have internal capacities to undertake spatial climate risk analyses using geographic information systems (GIS)[e] and are more accustomed to using spreadsheet-based tools. At the same time, physical climate risk is spatially variable.
- Online spatial risk analysis tools and data portals may not allow users to download data. Banks may not be able to upload portfolio data into portals for online analysis, either due to data confidentiality concerns or because the portal does not provide the functionality to do so.
- Many data portals provide only a sample of extreme event statistics. Datasets that provide wider distributions of extreme events would be valuable for banks' analysis of the impacts of these events on their loan portfolios.
- Data portals are required which provide spatial data on future changes in extreme events under climate change scenarios. Many publicly available portals provide historic or present-day data only.
- There are scientific challenges in providing robust data on future changes in extreme events at localized scales relevant for banks. It is beneficial for banks to understand recent scientific developments, and the limits of what the science can currently tell us.

e A geographic information system (GIS) is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. By relating seemingly unrelated data, GIS can help individuals and organizations better understand spatial patterns and relationships. (Source: National Geographic).

2.1. Objectives

The Phase II pilot aimed to improve the banks' understanding of, and access to, data on climate and climate-related extreme events. It aimed to engender discussion between banks and data providers so that:

1. Banks understand available data portals for present-day and future extreme events.
2. Banks understand how they can interact with and use the data portals to conduct physical climate risk analysis on their portfolios.
3. Banks understand some of the key recent developments in scientific research on present-day and future extreme events.
4. Data providers and climate scientists better understand banks' needs for improved and more accessible data on extreme events.

This module evaluated the key features of some data portals covering extreme events, from both public (free to use) and commercial data providers. While it is by no means exhaustive in its coverage of the available portals, it aims to demonstrate how these features play out in the context of banks undertaking physical risk assessments. Numerous other extreme event datasets are available (see Section 2.5).

2.2. Framework for review

Extreme events data types, organized according to hazard type, are mapped in Table 2.1. The table also lists some associated data providers, along with features of their datasets including:

- whether the provider gives observed and/or future data,
- spatial resolution,
- spatial coverage,
- output / data format, and
- access (or the extent to which the datasets are open access).

The range of examples were purposefully selected to cover a wide range of extreme hazard types of relevance to banks' loan portfolios. Data sources that cover only incremental (chronic) changes in climate (e.g. in temperature or precipitation) were not included in this review. That is not to diminish their importance, but data on future incremental changes are more readily available. Portals which require a higher degree of specialist knowledge to use appropriately were also excluded, e.g. data portals aimed at researchers or specialist advisory firms.

2.3. Extreme event types

Extreme events of interest for banks will depend on what and where they have exposure to. However, a general list of extreme events hazards which banks can consider includes:

- Coastal flood (exacerbated by sea level rise)
- Flood
- Tropical cyclone (hurricane and typhoon)
- Extreme heat
- Extreme precipitation
- Landslide
- Drought
- Water scarcity and stress
- Wildfire

Extreme event data are available for these hazards, as shown in the examples in Table 2.1. Datasets and portals mapping floods are most commonly available, covering various flood sources, e.g. coastal, riverine or surface water. This reflects the experience of flooding and the threat it poses to life, property and economic activity. As the table shows, there is lower data availability for some other hazards, particularly data on future changes in tropical cyclones, landslides and wildfires. This is because it is scientifically challenging to evaluate how these hazards will change in the future.

Public data sources often cover a wide range of hazards, whereas commercial providers tend to specialize in the provision of data on one or two hazard types. For example, the Royal Netherlands Meteorological Institute (KNMI) Climate Explorer, the Global Facility for Disaster Reduction and Recovery (GFDRR) ThinkHazard! platform, and the Partnership for Resilience and Preparedness PREPdata portal all provide data on a wide range of extreme variables. The ThinkHazard! platform, for example, offers data for all the hazards listed in Table 2.1 except drought. Multi-hazard platforms help users to understand when a location is exposed to multiple extreme events. However, generalist portals may not have the highest quality data on individual hazards, compared to providers who specialize in one hazard. For instance, specialist providers, such as Climate Central (who have both free-to-use and paid-for products), JBA Risk Management and others focus on providing detailed data on flooding, reflecting their deep modeling expertise in this area.

Box 2.1: Bank feedback on hazard coverage in portals and data products

One piloting bank expressed a strong preference for hazard platforms and data products that bring together multiple hazard types. The bank suggested that the more hazard types providers can include within the same portal, the easier it would be for banks to choose a data provider rather than "shopping around" for several different providers, with the risk of these not being directly comparable due to differing assumptions about future projections.

It was suggested this is why **ThinkHazard!** is useful – it enables comparison between diverse physical hazard data at the same location. **ThinkHazard!** categorizes hazard as low, medium or high probability of occurrence in the next 10 years, drawing on different data sources depending on the hazard type and country.

It should be noted that a "one-stop-shop" provider may not have data at the finest spatial scale compared to providers who specialize in one hazard. This is particularly relevant for flooding, which is highly spatially variable and where specialist providers typically have more granular data.

2.4. Review of extreme events data and portals

Table 2.1 provides a non-exhaustive sample of extreme event data and portals, mapping their key characteristics. Inclusion in this chapter does not necessarily represent an endorsement of any data or tool.

Key:

✓ = covered

blank = not covered

* = providers who discussed portals with the banks during Phase II

Table 2.1: Extreme event data and portals (non-exhaustive)

Hazard	Provider – portal / product name	Observed/ Historical	Time periods			Future scenarios			Spatial resolution	Spatial coverage	Outputs		Licensing and cost
			2020/ 2030	2040/ 2050	2100	<2°C	2°C	>4°C			Data	Map	
Coastal flood (exacerbated by sea level rise)	*Climate Central - Coastal Risk Screening Tool[11]		✓	✓	✓	✓	✓	✓	5 m U.S. 30 m excl. U.S.	Global	✓	✓	Free-to-use
	*Climate Central - Surging Seas Risk Finder[12]		✓	✓	✓	✓	✓	✓	5 m	U.S. and Caribbean	✓	✓	Free-to-use
	*Climate Central - Portfolio Analysis Tool (PAT)[13]	✓	✓	✓	✓				Property level	Global	✓	✓	Chargeable
	GFDRR - ThinkHazard![14]	✓	✓						~1 km	Global		✓	Free-to-use
	Jupiter - FloodScore™[15]		✓	✓	✓	✓	✓	✓	3 m	Global	✓	✓	Chargeable
	PREP - PREPdata[16]			✓	✓		✓	✓	2 km	Global	✓	✓	Free-to-use
	WRI - Aqueduct Floods[17]	✓	✓	✓	✓	✓	✓	✓	1 km	Global	✓	✓	Data: chargeable Map: free-to-use
Flood	GFDRR - ThinkHazard![14]	✓	✓						1 km	Global		✓	Free-to-use
	* JBA Risk Management - Flood Maps[18]	✓	✓	✓	✓	✓	✓	✓	5–30 m	Global	✓	✓	Chargeable
	Swiss Re - CatNet®[19]	✓							30 m	Global	✓	✓	Chargeable, free to Swiss Re clients
	UNEP / UNISDR - Global Risk Data Platform[20]	✓ (1999–2007)							200 m (flood outline only; not flood depth)	Global	✓	✓	Free-to-use
	WRI - Aqueduct Floods[21]	✓	✓	✓	✓	✓	✓	✓	1 km	Global	✓	✓	Data: chargeable Map: free-to-use

Hazard	Provider – portal / product name	Observed/ Historical	Time periods			Future scenarios			Spatial resolution	Spatial coverage	Outputs		Licensing and cost
			2020/ 2030	2040/ 2050	2100	<2°C	2°C	>4°C			Data	Map	
Tropical cyclone (hurricane & typhoon)	GFDRR - ThinkHazard![22]	✓	✓						30 km	Global		✓	Free-to-use
	NOAA - Historical hurricane tracks[23]	✓ (1842–2019)							3.5 km	Global	✓	✓	Free-to-use
	Swiss Re - CatNet®[19]	✓ (1891–2008)	✓							Global	✓	✓	Chargeable, free to Swiss Re clients
Extreme heat	GFDRR - ThinkHazard![22]	✓	✓						~5–10 km	Global		✓	Free-to-use
	Jupiter - HeatScore™[24]		✓	✓			✓	✓	30 m – 1 km	Global		✓	Chargeable
	KNMI - Climate Explorer[25]	✓ (1901–2017)	✓	✓	✓	✓	✓	✓	5 km	Global	✓	✓	Free-to-use
	PREP - PREPdata[16]	✓ (1950–2005)	✓	✓	✓	✓		✓	25 km	Global	✓	✓	Free-to-use
	World Bank - Climate Change Knowledge Portal[26]	✓ (1901–2016)	✓	✓	✓	✓	✓	✓	1 km	Global	✓	✓	Free-to-use
Extreme precipitation	KNMI - Climate Explorer[25]	✓ (1901–2010)	✓	✓	✓	✓	✓	✓	5 km	Global	✓	✓	Free-to-use
	World Bank - Climate Change Knowledge Portal[26]	✓ (1901–2016)	✓	✓	✓	✓	✓	✓	1 km	Global	✓	✓	Free-to-use

Hazard	Provider – portal / product name	Observed/ Historical	Time periods			Future scenarios			Spatial resolution	Spatial coverage	Outputs		Licensing and cost
			2020/ 2030	2040/ 2050	2100	<2°C	2°C	>4°C			Data	Map	
Landslide[f]	GFDRR - ThinkHazard![22]	✓	✓						~500 m	Global		✓	Free-to-use
	PREP - PREPdata[16]	✓ (2007–2018)	✓						1 km	Global	✓	✓	Free-to-use
	UNEP / UNISDR - Global Risk Data Platform[20]	✓							~0.75 – 1 km	Global	✓	✓	Free-to-use
Drought	*PCA - Global Drought Risk platform[27]	✓ (1950–2016)	✓	✓			✓	✓	25 km	Global		✓	Free-to-use
	UNEP / UNISDR - Global Risk Data Platform[20]	✓ (1980–2001)							~50 km	Global	✓	✓	Free-to-use
	World Bank - Climate Change Knowledge Portal[26]	✓ (1980–2001)	✓	✓	✓	✓	✓	✓	1 km	Global	✓	✓	Free-to-use
Water scarcity and stress	GFDRR - ThinkHazard![22]	✓	✓						1 km	Global		✓	Free-to-use
	PREP - PREPdata[16]	✓ (as per WRI)	✓	✓			✓	✓	1 km	Global	✓	✓	Free-to-use
	*WRI - Aqueduct Water Risk Atlas[28]	✓ (1960–2014)	✓	✓			✓	✓	1 km	Global	✓	✓	Free-to-use
Wildfire	GFDRR - ThinkHazard![22]	✓	✓						~50 km	Global		✓	Free-to-use
	PREP - PREPdata[16]	✓ (past week)							1 km	Global	✓	✓	Free-to-use
	Swiss Re - CatNet®[19]	✓								Global	✓	✓	Chargeable, free to Swiss Re clients
	UNEP / UNISDR - Global Risk Data Platform[20]	✓ (1995–2011)							~10 km	Global	✓	✓	Free-to-use

f Landslide susceptibility information on the PREPdata portal is based on the possibility of landslides occurring in the past and incorporates the most up-to-date data from 2017. Landslide information on the UNEP/ UNISDR platform is based on a global risk index for landslides triggered by precipitation.

2.4.1. Time horizons

Most of the providers offer both observed data and future projections. Observational data is that which is collected by instruments either on the Earth's surface (weather stations) or from space (Earth Observation instruments such as satellites). It typically consists of historical data recorded over a number of years, though it can be current or real-time. Future climate projection data is based on simulations from climate models (e.g. general circulation models, GCMs and regional climate models, RCMs).

Hazard data can be observed and / or modeled. For example, flood data can include the spatial extent of past flood events, or flood zones from hydrological modeling, expressed in the form of return periods. This can form the basis for modeling of future flood zones under various return periods, by incorporating data on changes in driving climate variables from climate models. The time periods of the historical data vary by provider and range from the mid-19th century to the present day.

The time horizon for future projections data varies by provider and hazard. Future flood projections are available for coastal flood and/or sea level rise from several providers, such as Climate Central and PREP for both 2°C and 4°C climate scenarios. Climate Central, for instance, offers coastal flood data from the 2020s through to 2100 and their recent research has improved the accuracy of future coastal flood risk data. A 2019 study[29] by Climate Central tripled estimates of sea level rise vulnerability by using new data on land elevation.

Data on extreme heat, extreme precipitation, and water scarcity and stress are available based on observed records and for future projections from most providers, for 2°C and 4°C climate scenarios. Extreme temperature and precipitation projections are available from the 2020s through to 2100, whereas, for instance, water scarcity data from WRI's Aqueduct Water Risk Atlas is available for the 2020s to 2040s.

2.4.2. Spatial resolution and coverage

Generally, flood data are available at very high spatial resolution (granularity), as is necessary for flood risk assessments, given the very localized nature of flood risk, e.g. coastal flooding data from Climate Central's Surging Seas Risk Finder is available at 5 m scale and Jupiter FloodScore™ provides data at 3 m scale. JBA Risk Management's Flood Maps also offer 5–30 m spatial resolution. Drought, extreme heat and extreme precipitation hazard data are typically provided at lower spatial granularity. These data can range from 1–25 km spatial scale.[g]

There can be tradeoffs between data granularity, geographical coverage and data costs. Ultra-high resolution flood data are often chargeable or may be limited in geographical coverage. Climate Central's Surging Seas Risk Finder, for example, is limited to the US and the Caribbean. JBA Risk Management's Flood Maps cover the UK, Ireland, parts of Europe and the US at 5 m resolution, though data for the rest of the globe is at 30 m. These and other providers of fine-scale data, e.g. Jupiter, charge for their data. PREPdata, on the other hand, offers data free of charge, though global data is available at 2 km resolution.

The extreme event data providers outlined in Table 2.1 mainly offer datasets with global coverage, with a few providers (noted above) offering higher resolution datasets. In addition to these, there is a variety of spatial data portals available, not listed in Table 2.1, that offer extreme event data only for specific countries.

g For reference, the resolution of Coupled Model Intercomparison Project 5 (CMIP5) climate models range from 5–400 km in the atmosphere. The Coupled Model Intercomparison Project brings together climate modeling groups from across the world to promote a standard set of climate model simulations. CMIP5 is the fifth phase and provided a framework for coordinated climate change experiments from 2011–2016, and thus includes simulations for assessment in the IPCC's Fifth Assessment Report (AR5) as well as others that extend beyond the AR5. For more information see: https://pcmdi.llnl.gov/mips/cmip5

Box 2.2: Bank feedback on spatial resolution of extreme events data and portals

Piloting banks found that WRI Aqueduct platform provided accessible data, at spatial scales suitable for a first high-level risk assessment.

Banks found that JBA's flood risk score data at 5 m spatial scale is suitable for assessing risks to mortgage portfolios. The fine spatial scale enables banks to distinguish between individual properties in close proximity facing different levels of risk.

Banks noted that national government agencies (e.g. hydrometeorological agencies, environment agencies, emergency management agencies and geoscience organizations) can also be good sources of country-specific data at high spatial resolution.

2.4.3. Data output format and usability

Tools and portals have been developed to allow users to view, analyze, and download climate-related data through standard web browsers (per examples in Table 2.1). Climate model output data and extreme event data involve many variables, time horizons and scenarios, sometimes on a global grid, and can therefore result in petabytes of climate data. To accommodate this massive data volume, data are often made available as netCDF files, a compressed file format that is easier for scientists to handle. This creates barriers for less technical users who would have to perform significant analysis on the data to make it usable for decision-making. The formats and outputs of some of the more accessible portals are described below.

Floods

Flood datasets are often presented as return periods. For example, the return period of a flood might be 100 years; otherwise expressed as its probability of occurrence in any one year being 1/100, or 1%. This means that, in any given year, there is a 1% chance that a flood event of that magnitude will occur, regardless of when the last flood event was. A range of return periods—typically, five or more return periods up to 1 in 1,000 years—is required to evaluate the distribution of flood outcomes including the tails of the distribution.

JBA Risk Management offer global flood maps which cover river (fluvial), surface water (pluvial) and coastal (storm surge). Their coastal maps are currently limited to the UK, Ireland and the US at 5 m resolution, and Canada at 30 m resolution. These comprise flood extents and depths for six return periods (20, 50, 100, 200, 500 and 1,500 years) globally (including Europe) and up to five return periods for the UK and Ireland (20, 75, 100, 200 and 1,000 year). However, JBA plan to be able to offer any return period required for all three flood types in the near future as their modeling evolves. SwissRe CatNet® flood data also include a range of return periods (50, 100, 200 and 500 years.) Of the free-to-use data portals, UNEP/UNISDR provide the most comprehensive range, offering six return periods for present day flood (20, 50, 100, 200, 500 and 1,000 years). These flood maps enable users to perform analysis against a range of flood severities, from low to extreme, to develop detailed risk profiles.

Sea level

Sea level change data is often shown in units of centimeter above sea levels in the year 2000, and future time horizons are often provided out to the year 2100. A research paper by Kopp *et al.*[30] is widely cited and used in the portals as a source of global projections for a range of future sea level rise scenarios.

Climate Central offer a range of interactive sea level tools[31] which allow users to generate customizable, localized maps of projected sea level rise and coastal flood risks by year, sea level rise model, water level, greenhouse gas scenario and elevation.

Tropical cyclones (hurricanes and typhoons)

Information on tropical cyclones can also be expressed as return periods, or the frequency at which a certain intensity of tropical storm can be expected. For instance, UNEP/UNISDR display cyclone wind for 5 return periods (50,100, 250, 1000 years). In addition, information is available on past tropical cyclone events, including the cyclone path, intensity and frequency. NOAA's Historical Hurricane Tracks is another free interactive mapping tool that allows users to see the paths of historical hurricanes.

Extreme heat and extreme precipitation

Extreme heat and extreme precipitation data are available in a number of different formats. PREP's PREPdata tool shows extreme heat days as the annual average count of days with heat greater than the 99th percentile of the baseline, and extreme precipitation days as the annual average count of days with precipitation above the 99th percentile. The KNMI Climate Explorer offers further options, from the annual maximum value of daily maximum temperature to the percentage of days when daily maximum temperature is greater than the 90th percentile. KNMI also offer a plethora of extreme precipitation indices: annual maximum 1-day precipitation, annual maximum consecutive 5-day precipitation, annual total precipitation from days >95th percentile and annual total precipitation from days >99th percentile (see examples in Figure 2.1).

(a) Changes in annual maximum consecutive 5-day precipitation

(b) Changes in annual total precipitation from days >99th percentile

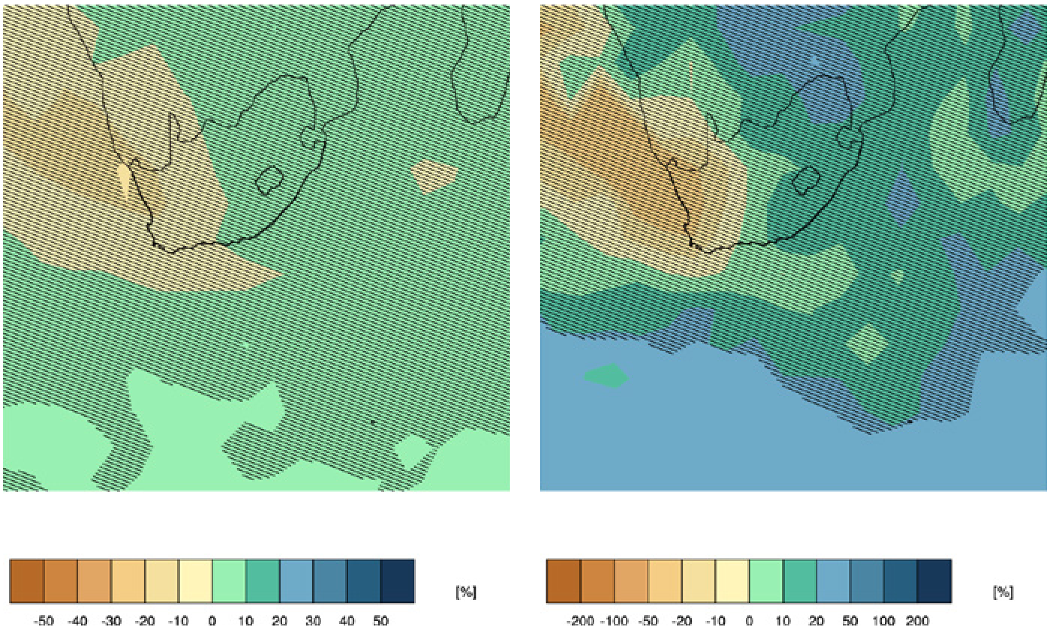

Figure 2.1: Example statistics for future changes in extreme precipitation: (a) Percentage changes in annual maximum consecutive 5-day precipitation, (b) Percentage changes in annual total precipitation from days >99th percentile. Changes are for South Africa by the 2040s compared to the 2000–2019 baseline period, for representative concentration pathway (RCP) 8.5 (which implies approximately 4.3˚C of global warming by 2100, relative to pre-industrial levels). Hatching indicates areas where the magnitude of the change is less than one standard deviation of model-estimated present-day natural variability.[h] Source: KNMI.

Drought, water scarcity and water stress

There are various datasets which describe drought, water scarcity and water stress, and various definitions attached to each of these terms. The terms below are those used by WRI Aqueduct:[32]

- 'Drought risk' measures where droughts are likely to occur, the population and assets exposed, and the vulnerability of the population and assets to adverse effects,
- 'Water stress' measures the ratio of total water withdrawals to available renewable surface and groundwater supplies,
- 'Water scarcity' is measured through water depletion. Water depletion measures the ratio of total water consumption to available renewable water supplies. As WRI highlights, baseline water depletion is similar to baseline water stress, though instead of looking at total water withdrawal (consumptive plus non-consumptive), baseline water depletion is calculated using consumptive withdrawal only.

h The hatching can be interpreted as an indication of the strength of the future changes from present-day climate, when compared to the strength of present-day internal variability. It either means that the change is relatively small or that there is little agreement between models on the sign of the change.

The PCA drought risk product covers both baseline ('historic') and future droughts of various durations (1–3 months, 4–6 months, 7–12 months and 12 months+). The drought maps are presented as either 'return periods' (years) or their inverse, 'annual frequencies' (%).

On water scarcity and water stress, WRI Aqueduct Water Risk Atlas provides both baseline data and future projection data. Baseline water stress is measured by the ratio of total water withdrawals to available renewable surface and groundwater supplies. The global data are presented on a scale of 5 categories, from low (<10%) to extremely high (>80%), as well as showing where there is arid or low water use and no data. Future water stress data are shown as an indicator of competition for water resources and is defined informally as the ratio of demand for water by human society divided by available water. The data are presented on a scale of seven categories, from a 2.8x or greater decrease to a 2.8x or greater increase in water availability in the future, compared to the baseline.

Box 2.3: Bank feedback on extreme events data and portals – output metrics and statistics

Piloting banks found the **Swiss Re** CatNet® tool has a useful range of return periods.

They also found that the **WRI Aqueduct** platform provided a broad spectrum of return periods and appreciated that the data and maps were not limited to flooding but also covered various metrics of water stress, such as water depletion. Banks had mixed views on whether the country rankings available on the WRI Aqueduct platform were useful to them. Some found they were, whereas others noted that the country ranking could not be used directly to quantify risks within their own portfolios. Banks suggested that an improvement would be to include municipality-level data.

Most piloting banks agreed that the **JBA** extreme event statistics were useful. Banks also found their tables of return period equivalence were useful. The large range of flood return periods was found to be a major strength compared to some publicly available, official data, which does not always include such broad ranges. By including numerous flood return periods in the assessment, it becomes less likely that the risk is underestimated.

Piloting banks were in agreement that the **Princeton Climate Analytic**s product had extreme events statistics that were useful for them, in terms of the range of return periods and the data under future climate scenarios.

One bank found that the fact that outputs for different hazards are so different, makes the data hard to interpret for someone who is not a climate specialist. They suggested the data would be easier to understand if they were expressed using a consistent scale across hazards that indicated the extent to which an asset was exposed (e.g. very high, high, moderately, moderately low, low, no exposure), rather than return periods etc. The bank suggested that a similar scale reflecting hazard intensity (or severity) would be useful—as well as a combined rating—as both the frequency and the intensity of a hazard need to be understood.

Banks also noted that, in addition to data on extreme event frequency and intensity, damage functions are needed to evaluate risks. Damage functions relate hazard intensity (e.g. wind speed, water depth, etc.) to damage caused to assets, usually expressed as a damage ratio. Damage functions are integrated into tools for physical climate risk assessment of financial risk, as discussed in Chapter 4.

Wildfire

A 'fire danger rating' is a fire management system that incorporates the aspects of selected fire danger attributes into numerical or qualitative indices. Fire danger rating systems are used to determine the risk level of fire occurrence, and thus provide a scale for managing such crises. These systems are based on historical meteorological parameters to assess fire danger, calculated as numerical indices. Some fire management systems and indices that are commonly used include: the Keetch Byram Drought Index (KBDI), the Canadian Forest Fire Weather Index, and the Fire Danger index (FD).

In the GFDRR ThinkHazard! portal, wildfire hazard data are based on a probabilistic dataset generated from the daily Canadian Fire Weather Index and are provided as frequency-severity data. A specific temperature threshold is defined for each hazard level, at 5, 20, and 100 year return periods, which can also be displayed as a high, medium, or low risk.

Box 2.4: Bank suggestions for improving the usability of extreme events data and portal outputs

The main improvements suggested by banks for the **WRI Aqueduct** tools included the addition of municipality-level data and an increase in map resolution. As the files are currently available as (geo)tiffs, banks noted that GIS shapefiles would be preferable. A more accessible portal to download data for offline integration was also suggested as an improvement, which would allow banks to be able to better embed flood risk analysis within their own risk processes. Banks would also appreciate more guidance on downloading the underlying geospatial data for offline usage and processing.

JBA's standard flood maps indicate the source of flood risk in the coloring of flood-affected areas. Some piloting banks suggested that for ease of analysis, they only wanted to know the additional flood-affected areas (not the source). It should be noted that **JBA** can adapt their data to suit client requirements. Banks also suggested a formula or calculation to move between the **JBA** risk score and return periods could be a beneficial addition to their data. It should be noted, however, that a bank can license return period data with the scores, in one database, in which case there would be no need for a formula or calculation.

Piloting banks suggested that an improvement to the **Climate Central** tools would be the addition of a search function using zip / post codes and latitude and longitude coordinates. It should be noted, however, that the new Coastal Risk Screening Tool allows users to enter latitude and longitude coordinates and zip / postal codes to find a location.

Several banks mentioned that guidance manuals (for various tools) would help them to better use and understand the hazards data. To that end, **Climate Central** have started to make YouTube tutorial videos to help banks and financial institutions gain understanding in applying their tools.[33]

Box 2.5: Bank comments on general usability of extreme events data and portal inputs and outputs

Piloting banks found that **WRI's** interactive web-based maps were intuitive to explore across the different hazard types. One bank appreciated that it was possible to input a single location or import their data, and that open source peer-reviewed data underpins the risk results produced by the tools. A challenge flagged by one bank was that their compliance (security) requirements meant that it might not be possible to input their counterparty data into a third-party application.

Banks found that **JBA's** sample data worked well in their internal GIS tools, and were therefore easy to overlay with banks' internal exposure data. Banks noted that the data provided were easy to use, which made the analysis straightforward to conduct. They appreciated that the **JBA** score can produce a combined score when a property is at risk from more than one type of flooding. Some banks noted that the data could provide a reliable starting point by establishing an accurate baseline, which will allow for more accurate scenario analysis in the future.

Banks found **Climate Central's** products to be useful overall, and one bank stated that the portals were very straightforward and easy to use. One bank felt the inclusion of Google Maps made the portal accessible and familiar to use. Another highlighted the ability to adjust timeframe as a particularly useful feature.

Piloting banks appreciated that the **Princeton Climate Analytics (PCA)** data products allowed information to be downloaded in different formats.

Piloting banks found the **Swiss Re** CatNet® tool was accessible and straightforward to use. Banks found its most useful feature was the ability to upload addresses using Excel.

Several banks underscored the labor-intensity of using some of the extreme events data and portals. For example, as it was not possible to export data from the **ThinkHazard!** portal one bank noted that considerable effort would be needed to use its outputs for portfolio financial risk assessments.

2.4.4. Licensing arrangements

Extreme event hazard datasets and portals have a range of licensing arrangements, though generally, many are free to use for all purposes. Hazard portals or visualization tools are typically open access when developed by non-governmental organizations such as WRI or UN organizations. Some providers only permit free access to datasets and tools for non-commercial purposes (e.g. research) whereas commercial uses are chargeable. For instance, Climate Central's CoastalDEM®, which includes updated land elevation data, is chargeable when used for commercial purposes. Swiss Re offer their CatNet® tool free of charge to clients, though is otherwise chargeable.

Box 2.6: Bank comments on sectors and situations where extreme events data and portal outputs could be useful

Piloting banks suggested they found the **WRI** tools most useful for agribusiness and agriculture, followed by commercial and residential real estate, and water services and wastewater treatment. One bank suggested the **WRI platform** may be better suited to transaction-specific analysis than for portfolio assessment purposes.

Banks noted that using the **JBA** data allowed for a high-quality assessment of current flood risk for mortgage portfolios. Banks also suggested the **JBA** data and tool were useful for assessing risk to the agriculture sector.

Banks piloting the **Climate Central** tools and data suggested that they would be particularly useful for assessing real estate and project finance loan portfolios.

Agribusiness was thought to be the most relevant sector for the application of the **PCA** data product.

Swiss Re CatNet® was noted to be most useful to assess the agriculture, real estate, oil and gas, and energy sectors.

2.5. Additional data sources and scientific programs on extreme events

Numerous other extreme event datasets are available in addition to those discussed above, and this section provides an overview of some key data initiatives, including the Oasis Hub and the Oasis Loss Modeling Framework (LMF). The Oasis Hub acts as a marketplace where many extreme event datasets and tools can be explored, and the Oasis LMF is an open source catastrophe modeling platform. This section also briefly introduces some key climate research programs established under the auspices of the World Climate Research Programme, which aim to improve scientific understanding of extreme events.

2.5.1. Oasis Hub

Box 2.7: Overview of Oasis Hub

Authored by Tracy Irvine, Oasis Hub

Introduction

Oasis Hub is an independent, global aggregator for catastrophe, extreme weather, climate change and environmental risk data, tools and services. We provide services securing data, analytical tools, data aggregation and GIS mapping for companies and commercialisation of new data, tools and services from academia and SMEs. We are at the 'centre' of a collaboration network between those who need data to conduct risk assessment and resilience and adaptation planning, and those who produce data and tools for climate and catastrophe risk management.

Our vision is to build a global community, becoming one of the world's leading providers of data, software, tools, services and models. The community will enable environmental, catastrophe and climate change physical risk assessments and climate adaptation and resilience planning, creating greater resilience against future environmental catastrophes and climate change impacts.

Our focus is to create an open, transparent and educational data and tools platform that helps provide environmental, climate change, catastrophe and risk information to business and the public sector. The platform encourages collaboration, problem solving and understanding around catastrophe and climate change information.

Oasis Hub was formed as a result of a collaboration between academia and the insurance sector. Insurance wanted to see global risk data, tools and services in one location and academia wanted to increase research impact from the data and tools they have created, by improving evidence-based understanding of climate change and natural catastrophes.

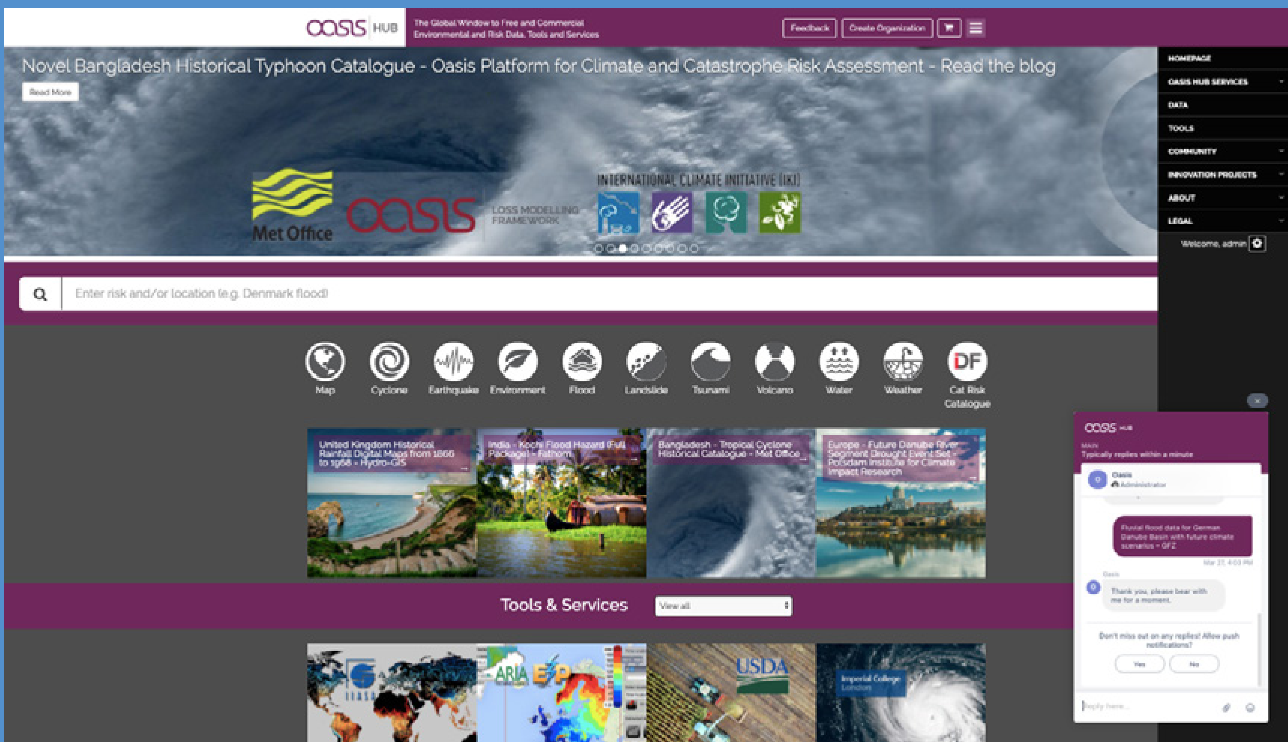

Figure 2.2: Oasis Hub Platform showing the ability to search and ask questions on data and analytical tools on the platform. Source: Oasis Hub.

What hazards and geographies does Oasis Hub cover?

Oasis Hub's platform encompasses natural hazard and climate change risk data, analytical tools, and services.

Over the past few years, we have brought data and tools from around the world together to form a robust web of global, regional and local data sources. We promote greater understanding in using the correct data for specific user tasks or problem analysis. For example, some users may seek to analyze or risk assess at national level, therefore extensive, low resolution data (100 km^2) may be sufficient for their needs. Others may wish to assess a mortgage portfolio at city level where high resolution data (e.g. 5–30 m^2) with flood defense information may be more appropriate. The level of historical and climate change modelled data required may vary dependent on need. Oasis Hub advise customers on the range of the most relevant data, tools and services, linked to their specific needs.

We have identified important global data sources: National Oceanic and Atmospheric Administration (NOAA), National Centers for Environmental Information (NCEI), Copernicus, European Commission Joint Research Centre and are able to help process these large scale data for local needs. Further to this, we have collected open public data from municipalities from across the world, strengthening our coverage, thus including large scale global data, down to local level data. We also work with universities and research institutes to provide access to important catastrophe and climate change data and tools. We check the licensing of each dataset, so business can use it with the knowledge the provenance and quality has been checked. We collect and post data daily.

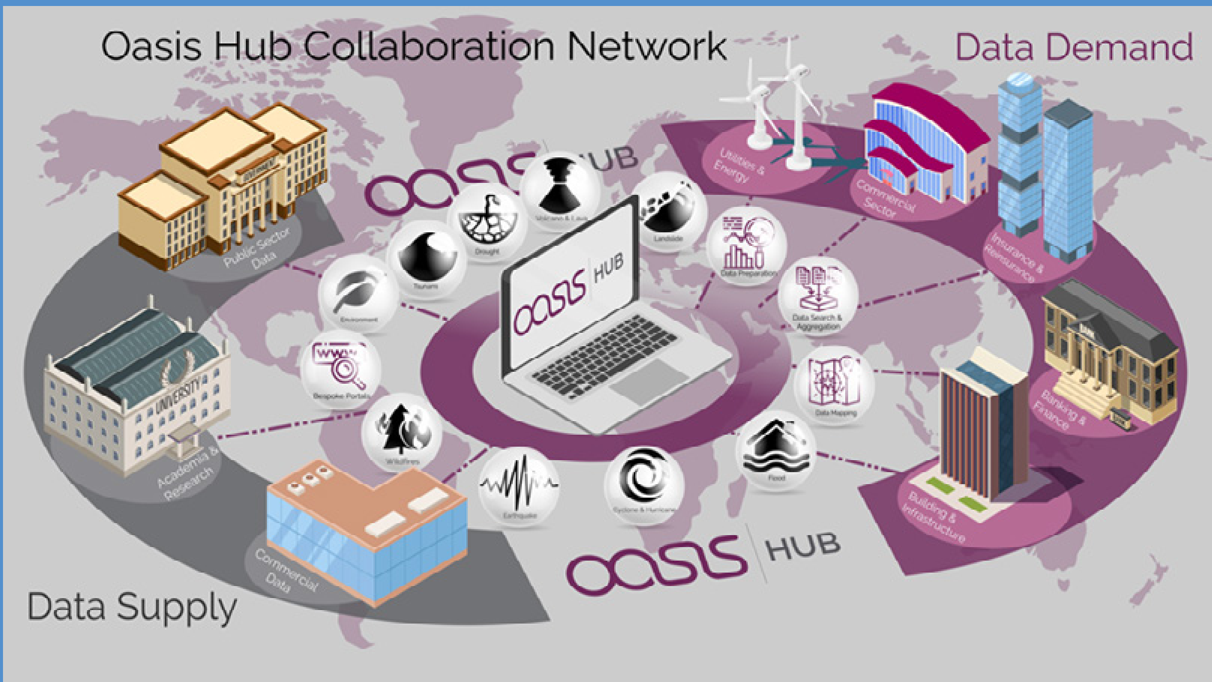

Figure 2.3: Oasis Hub data collaboration ecosystem. Source: Oasis Hub – collaboration ecosystem, 2020.

As well as public sector and open source data, we partner with commercial specialists, who can provide more up-to-date data, expertise and advice around particular problems, e.g. property location and flood mitigation advice. It is important to utilize this specialist expertise to gain a more accurate view on risk, resilience and adaptation options. Oasis Hub acts as an, at cost, reseller for the commercial providers of data, tools and services from our commercial partners. The advantage of working with the Hub is we can provide companies with options analysis on the extent of providers for any particular problem, thus fulfilling procurement obligations.

We are also working with research and academic institutions, such as Imperial College London, Potsdam Institute for Climate Impact Research, Germany, and Technical University of Denmark who are innovating new data and analytical tools, introducing climate change assessments in agriculture, forestry, utilities, property and planning, finance and insurance. We also enable research collaborations between academia and businesses. An example of this can be found in a large insurance, research and SME collaboration – 'Oasis Innovation Hub for Catastrophe and Climate Extremes Risk Assessment'. For more information, visit: https://h2020insurance.oasishub.co/.

Oasis Hub membership

Oasis Hub has provided data for a large range of companies. Currently (as of June 2020), we have a membership of 1500+ professionals with users spanning:

- Insurance and reinsurers
- Banking, finance and investment companies
- Academics from across the world
- ICT and telecom companies
- Not-for-profits
- Media
- Building and development
- Multi-lateral organisations

What is clear from our analytics is organisations are searching for a wide range of global data, in all hazard areas. We have supplied over 3,200 datasets for organisations using them for risk modeling, risk verification and platform development.

Our members also gain access to our newsletter with information on new data and tools coming onto the Hub, as well as access to a range of popular educational webinars on aspects of climate change and natural hazard risk assessment and climate resilience and adaptation.

Oasis Hub has been funded by the European Commission's, H2020 Program, linked to the creation of Climate Services, Innovate UK and endorsed by the Global Innovation Lab for Climate Finance. We also complement our sister, not-for-profit company, Oasis Loss Modeling Framework (Oasis LMF), which offers an open source software used by the insurance sector to understand financial risk from catastrophe events.

Box 2.8: Bank feedback on Oasis Hub

Several banks who surveyed the Oasis Hub found that the way in which it offers a one-stop shop for multiple datasets was particularly useful, as was the variety of providers, and the specific official country information from government portals. Banks felt that the data/portal could help them to make progress on some aspects of a physical risk assessment in their loan portfolios by helping them access relevant datasets.

One suggested improvement was for the portal's search functions. The bank suggested that search results could give more information on spatial coverage and resolution of datasets or a search function for zip / post codes could be added.

2.5.2. Oasis Loss Modeling Framework

The Oasis LMF is an open source catastrophe modeling platform.[i] The framework has been developed by the global (re-)insurance community, though it aims to provide tools that other financial institutions and others can use. It is free and open to use by anyone.

Oasis LMF provides an open source platform for developing, deploying, and executing catastrophe models, using a full simulation. Catastrophe models are packaged in a standard format and the components can be from any source, such as model vendors, academic and research groups. There are currently 19 suppliers, covering 90 models. Specifically, the Oasis LMF platform provides:

- A platform for running catastrophe models, including a web-based user interface and an application programming interface (API) for integration with other systems (Oasis Loss Modeling Framework);
- Core components for executing catastrophe models at scale and standard data formats for hazard and vulnerability (Oasis ktools);
- A toolkit for converting and testing catastrophe models into Oasis (Oasis MDK); and
- A large supplier of commercially available and free models.
- Banks with adequate technical capacity may be able to use the Oasis LMF to conduct hazards analysis for their portfolios including some climate change catastrophe models.

Box 2.9: Bank feedback on Oasis Loss Modeling Framework

Piloting banks found that the Oasis Loss Modeling Framework was accessible, and particularly liked that everything was open on Github. One bank found that having the ability to (re)use code was useful, as was having online open courses to learn how to use the tool. Another bank suggested that an improved user interface would be beneficial for the Framework.

Piloting banks found the Oasis Loss Modeling Framework (and Oasis Hub) to be potentially useful for physical risk assessment in most segments of banks' portfolios.

i See https://oasislmf.org/ for more information.

2.5.3. World Climate Research Programme grand challenges

Clearly, it is useful for banks and other financial institutions to understand how a changing climate will affect the location, frequency and severity of extreme events in the future. However, developing data on future changes in extreme events is scientifically challenging, and some questions which banks would like answered are beyond the limits of current scientific knowledge. Continued dialogue between banks and scientists is needed to help push these frontiers forward.

Key climate science research programs relevant to extreme events have been established under the auspices of the World Climate Research Programme, including its 'Grand Challenges'.[34] The World Climate Research Programme (WCRP) was set up by the World Meteorological Organisation (WMO) and the International Science Council. WCRP contributes to advancing understanding of the multi-scale dynamic interactions between natural and social systems that affect the climate.[35] The WCRP has allowed climate scientists to accurately monitor, simulate and project global climate, and this climate information is used in governance, decision-making and in support of a wide range of practical end-user applications.

The WCRP has determined a set of seven Grand Challenges, which are areas of emphasis in scientific research, modeling, analysis and observations for WCRP and its affiliate projects in the coming decade. Lead researchers from several of the Grand Challenges engaged with the Phase II pilot banks, providing an overview of their current research. These included the Grand Challenges on: Weather and Climate Extremes; Near Team Climate Prediction; and Regional Sea-level Change and Coastal Impacts.

The WCRP Grand Challenge on Weather and Climate Extremes is organized around four overarching themes[36] (Document, Understand, Simulate, Attribute) with a main focus on four core extreme event types (heavy precipitation, heatwave, drought and storm). The themes each have a main question:

- Document: Are existing observations sufficient to underpin the assessment of extremes?
- Understand: What are the relative roles of large-scale, regional and local scale processes, as well as their interactions, for the formation of extremes?
- Simulate: Are models able to reliably simulate extremes and their changes, and how can this be evaluated and improved?
- Attribute: What are the contributors to observed extreme events and to changes in the frequency and intensity of the observed extremes?

The WCRP Grand Challenge on Near Team Climate Prediction supports research and development to improve multi-year to decadal climate predictions and their utility to decision makers.[37] It also supports the development of organizational and technical processes for future routine provision of decadal prediction services that can assist stakeholders and decision-makers. It aims to:

- Improve the quality of initialized decadal climate information and prediction,
- Collect, collate, and synthesize prediction output and tailor information toward services that address stakeholder needs,
- Develop processes to assess and communicate the degree of confidence and uncertainty in the predictions.

The WCRP Grand Challenge on Regional Sea-level Change and Coastal Impacts is an integrated interdisciplinary program on sea level research reaching from global to regional and coastal scales.[38] The program aims for close interaction with coastal stakeholders to make sure that results of the proposed scientific research are most useful for coastal zone management, and climate change impacts and adaptation efforts. Its overarching goals are to:

- Establish a quantitative understanding of the natural and anthropogenic mechanisms of regional to local sea level variability,
- Promote advances in observing systems required for integrated sea level monitoring, and
- Foster the development of sea level predictions and projections that are of increasing benefit for coastal zone management.

Ongoing dialogue between banks and scientists, such as those who are involved in the WCRP Grand Challenges, can help to build shared understanding of banks' data needs on extreme events, and on the progress that the scientific community is making towards meeting these needs.

MUFG case study:
Flood risk assessment of companies in MUFG's loan portfolio

Overview

Physical risk related to river flooding for all companies in MUFG's loan portfolio was assessed globally. The period of suspension of business and the amount of physical damage were estimated based on location information for business partners combined with available hazard maps in each area and so on. The estimation results were reflected in the balance sheet (BS) and Profit and Loss (P&L) for each company, and the impacts on the financial condition in 2020–2050 were estimated from movements in the credit rating. The overall concept is shown in Figure 2.4 and 2.5.

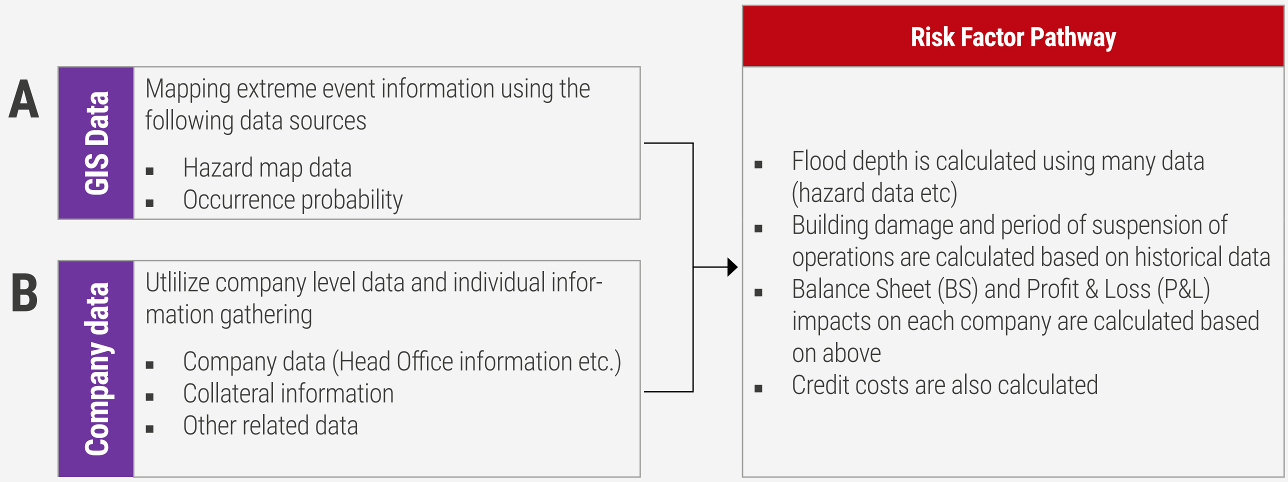

Figure 2.4: Overall concept for assessment of physical risk due to flooding

STEP 1: Obtaining inundation: Calculating longitudes and latitudes from location address of each company

STEP 2: Suspension period of business

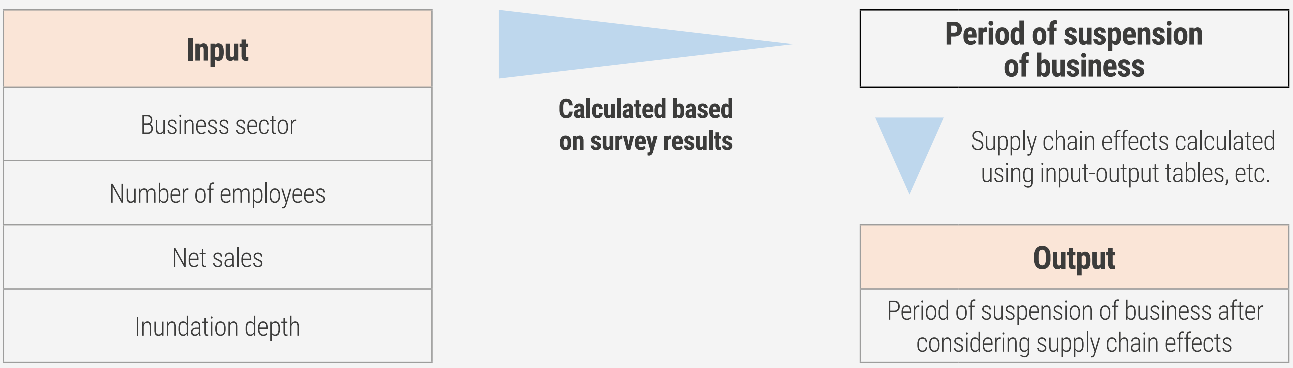

Figure 2.5: Calculation of the period of suspension

Results of the flood risk assessment and key assessment challenges

Findings

Similar to the outcome of past discussions in the Pilot Project and opinions of other banks, no major impact was confirmed in this assessment. However, when considering physical risks more generally, it should be noted that the assessment has only considered river flood risk. It has not included other extreme climate-related events which could affect these companies (e.g. coastal flood risk, tropical cyclones, droughts, heatwaves) and has not assessed incremental (chronic) climate change impacts on the performance of these businesses.

Challenges

The assessment identified several challenges and limitations, which could be taken into account to improve future assessments:

- Depending on the region, the availability of hazard information for each extreme event, and the information on the damage function caused by the extreme events vary. There are no standard scenarios or data on damage caused by extreme events.
- Since the level of information disclosure differs for each company, it is very difficult to make an accurate risk evaluation for a company that has production facilities and business resources across multiple locations. In order to measure the damage caused by supply chain disruption due to an extreme event, more detailed data on trade flows are required.
- To measure the impact of each scenario defined by the IPCC in detail, it is necessary to perform a simulation for each scenario. Therefore, implementation of a global river model, CaMa-Flood Model, is being considered. In addition, we plan to participate in a Flood Risk Panel involving researchers working on flood risks and enterprises.

3. Physical climate risk heatmapping of bank portfolios

This chapter sets out a framework for physical climate risk heatmapping of banks' portfolios, and summarizes a collective effort by the Phase II banks to identify key areas of climate-related vulnerability for specific sectors.

Heatmapping of physical risk offers a quick and efficient way to screen whole portfolios, across sectors, sub-sectors and geographies, in a single analytical exercise. It provides insight into total portfolio exposure to physical risk. In line with good practice in risk assessment, heatmapping can provide an early indication of where higher risks may lie within a portfolio, and brings focus for deep-dive analyses of risk 'hotspots' or client engagement.

3.1. Objectives

The Phase II pilot module on physical climate risk heatmapping aimed to:

1. Improve banks' understanding of the concept of heatmapping as part of physical climate risk analysis,
2. Encourage discussion between the Phase II banks on the range of channels through which physical risks can manifest, and the interlinkages between vulnerability, hazards and investment performance, and
3. Work towards reaching a view among the banks on key areas of vulnerability and related hazards for specific sectors.

To meet these objectives, this module reviewed the Acclimatise physical risk heatmapping framework,[j] and the banks examined its vulnerability and hazard components. The Acclimatise framework is provided as an example of how heatmapping can be undertaken, and the key components that can be included.

3.2. Heatmapping concept and methodology

3.2.1. Physical risk heatmapping framework

Acclimatise's heatmapping framework adopts the core concepts for defining physical climate risk in the IPCC Working Group II Fifth Assessment Report (AR5)[39] and its conceptual framework (see Figure 3.1). Within the framework, the level of risk in any geographic location is determined as a function of three dimensions, as discussed in Box 3.1:

Risk = *f* (Vulnerability [V], Hazard [H], Exposure [E])

The vulnerability component varies by sector and sub-sector; the hazard component is location-specific; and exposure varies by sector/sub-sector and location, as discussed further below.

j Acclimatise's heatmapping framework is provided as an example. Other groups have also developed heatmaps which cover physical risk. See for instance: https://www.mckinsey.com/business-functions/sustainability/our-insights/climate-risk-and-response-physical-hazards-and-socioeconomic-impacts [last accessed 6 July 2020] and https://www.moodys.com/sites/products/ProductAttachments/Infographics/Environmental-Risks-Global-Heatmap-Overview.pdf [last accessed 6 July 2020].

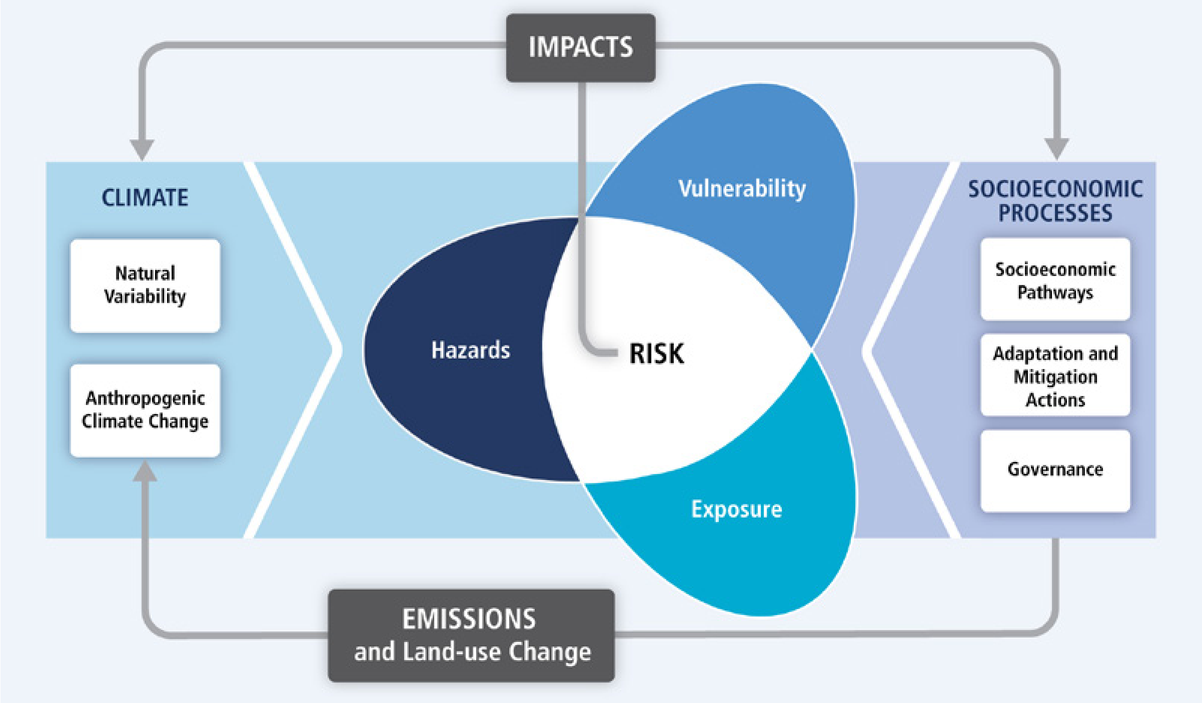

Figure 3.1: Core concepts/framework for defining physical climate risk in Acclimatise's heatmapping framework. Source: IPCC AR5.

Box 3.1: Definitions of vulnerability, hazard, and exposure from the IPCC Fifth Assessment Report

Vulnerability is '*the propensity or predisposition to be adversely affected*' and encompasses '*a variety of concepts and elements including **sensitivity or susceptibility** to harm…*' This includes the concept of sensitivity defined as follows:

- **Sensitivity** is defined by the IPCC as '*the **degree** to which a system or species is affected, either adversely or beneficially, by climate variability or change*'. *It is 'typically shaped by natural and/or physical **attributes** of the system' but also 'refers to **human activities** which affect the physical constitution of a system, such as tillage systems, water management, resource depletion and population pressure*'. As most systems have been designed to, and therefore adapted to historic climate (e.g. construction of bridges, road drainage systems), '*sensitivity already includes historic and recent adaptation*'.[k]

Hazard is defined as '*climate-related physical **events** or **trends**, or their physical impacts' that may cause 'loss of life, injury, or other health impacts, as well as **damage** and **loss** to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources*'.

Exposure is defined as '*the **presence** of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in **places and settings** that could be **adversely affected***'.

k **Vulnerability** in the heatmapping of FI portfolios is therefore defined as the propensity of an investment in a particular sector/sub-sector to be adversely affected by climate variability and change.

3.2.2. Key components of physical risk heatmapping

The following sections describe the Vulnerability, Hazard and Exposure components of Acclimatise's heatmapping framework, including how they link to each other and how they are applied to bank portfolio data.

3.2.2.1. Vulnerability

Adopting a Vulnerability Indicator approach can help capture both direct and indirect physical impacts on bank's investments from a changing climate, accounting for chronic (incremental) changes as well as extreme events. The indicators chosen should capture a wide range of impact channels through which climate hazards can affect investment performance at the sub-sector level (see Table 3.1). They are designed to provide a comprehensive coverage of potential risk areas and to capture the extent of the physical climate-related factors that might affect the value chains of investments. Analysis of the Vulnerability of sectors / sub-sectors to a changing climate considers eight indicators:

- reliance on **natural resources**,
- reliance on **secure energy supplies**,
- reliance on **climate sensitive supplies**,
- reliance on **secure transport routes**,
- reliance on **efficient operation of assets and processes**,
- climate sensitivity of **market demand**,
- potential for **environmental and social impact**,
- reliance on **labor health and productivity**.

Table 3.1: Eight vulnerability indicators and example channels through which vulnerability and hazards may affect sub-sector investment performance. Source: Acclimatise.

Vulnerability indicator	Example channels through which vulnerability and hazards may affect sub-sectors
Natural resources	▪ **Tourism** businesses may be affected by loss of beaches or other recreational land due to coastal erosion and sea level rise. ▪ The **hospitality** sector may be affected by disruptions in potable water supply caused by drought and/or severe flooding-related water contamination.
Energy supply	▪ Functioning of **Information and Communications Technology (ICT)** equipment and facilities can be affected by disruption to power supply resulting from storms or severe flooding. ▪ Productivity of **manufacturing** businesses may be vulnerable to downtime caused by disruptions to energy supply from extreme weather events such as heatwaves, flooding and storms.
Climate sensitive supplies	▪ Primary production in **agriculture** and **forestry** may be affected by multiple climate variables including, but not limited to, temperature, precipitation, droughts, windstorms. ▪ Sub-sectors dependent on supplies of agriculture and forestry inputs (e.g. **agribusiness, retail, construction**) may potentially experience changes in input availability, price and quality.
Transport routes	▪ **Agribusiness** may be highly dependent on reliable transport routes as a vital part of its value chain. It may be severely affected by disruptions to transport links caused by severe weather conditions potentially damaging transport infrastructure. ▪ **Services** sub-sectors such as **retail** and **hospitality** may be adversely affected through the unavailability of staff who are unable to travel to work due to climate/weather-related conditions disrupting transport links.
Assets & processes	▪ Productivity of solar **power** plants may be affected by a reduction in power generation efficiency as a direct result of rising temperatures. ▪ **Utilities** businesses with large physical infrastructure stocks may be adversely affected by increasing maintenance and repair costs as a result of more frequent and intense weather events such as strong winds, heatwaves, storms and flooding.

Market demand	▪ **Clothing manufacturers** may be vulnerable to changes in market demand due to rising temperatures. ▪ **Technology companies** specialised in water conservation products and services may see their market expand as water shortages becomes more prevalent.
Environmental & social impact	**Industrial sub-sectors** which have the potential for causing environmental and social (E&S) impacts may see their E&S performance deteriorate due to climate change. For example: ▪ More intense rainfall events, storms and storm surge may increase risks of pollution incidents from industrial facilities, with potential consequential impacts on surrounding communities and potential non-compliance with regulations. ▪ Industries operating in areas of growing water stress may experience increased competition for water with other water users, potential affecting their social license to operate.
Labor health & productivity	Climate change may increase risks to workers' health and safety and working conditions, particularly for **sub-sectors reliant on a large workforce or outdoor workers** (e.g. construction). For instance: ▪ Extreme heat typically leads to reduced productivity and increased risk of heatstroke. ▪ Heavy precipitation, floods and storms typically increase risks of accidents and injury. ▪ Changing climatic conditions may result in changing disease patterns (e.g. geographical locations prone to vector-borne diseases) affecting workforces.

In Acclimatise's heatmapping framework, sub-sectors are assigned Vulnerability Indicator scores of Low (1), Medium (2), or High (3) for all eight indicators, reflecting their relative importance to the sub-sector. Figure 3.2 presents a sample of Vulnerability Indicator scores for sub-sectors in the power sector. The score represents the extent to which a Vulnerability Indicator may affect the value of an investment in that sub-sector when subject to a combination of relevant hazards in a geographic location. Scoring the indicators allows heatmapping risks score calculations to be weighted by the relative significance of an indicator to a sub-sector. For example, two different sub-sectors in the same location may have relatively different reliance on natural resources such as water or land. In this case, the risk score would be weighted higher for the sub-sector that is more reliant on these resources. Vulnerability indicators scores are agnostic of location, though it should be noted that investments may be more vulnerable in countries where the sub-sectors' physical assets and supply chains are older and in poorer condition.

		Sub-sectors				
		Thermal power stations: natural gas	Biomass power stations	Solar CSP	Hydropower	Power transmission & distribution
Vulnerability indicators	Natural resources	High	High	Low	High	Low
	Energy supply	Med	Med	Low	Low	High
	Climate sensitive supplies	Low	High	Low	Low	Low
	Transport routes	Med	Med	Med	Med	Med
	Assets & processes	Med	Med	Low	Med	Med
	Market demand	High	High	High	High	Med
	Environment & social impact	Med	Med	Low	Med	Low
	Labour health & productivity	Low	Low	Med	Med	Med

Figure 3.2: Example Vulnerability Indicator scores for power-related sub-sectors. Source: Acclimatise

3.2.2.2. Hazard

Linked to each Vulnerability Indicator are sets of climate variables and climate-related hazards–covering incremental changes and extreme events–that may drive negative or positive performance of the indicator. Performance is dependent on the direction and magnitude of change in climate and climate-related hazards under various future climate change scenarios. Spatial data on future changes in climate are obtained from multiple climate models, and are applied together with spatial data on climate-related hazards (e.g. water stress, sea level rise etc.). These data, drawn from modeling studies and observations, are provided for future time horizons and Representative Concentration Pathways (RCPs)[I] of interest. Figure 3.3 presents an example of how two Vulnerability Indicators can be linked to climate-related hazards.

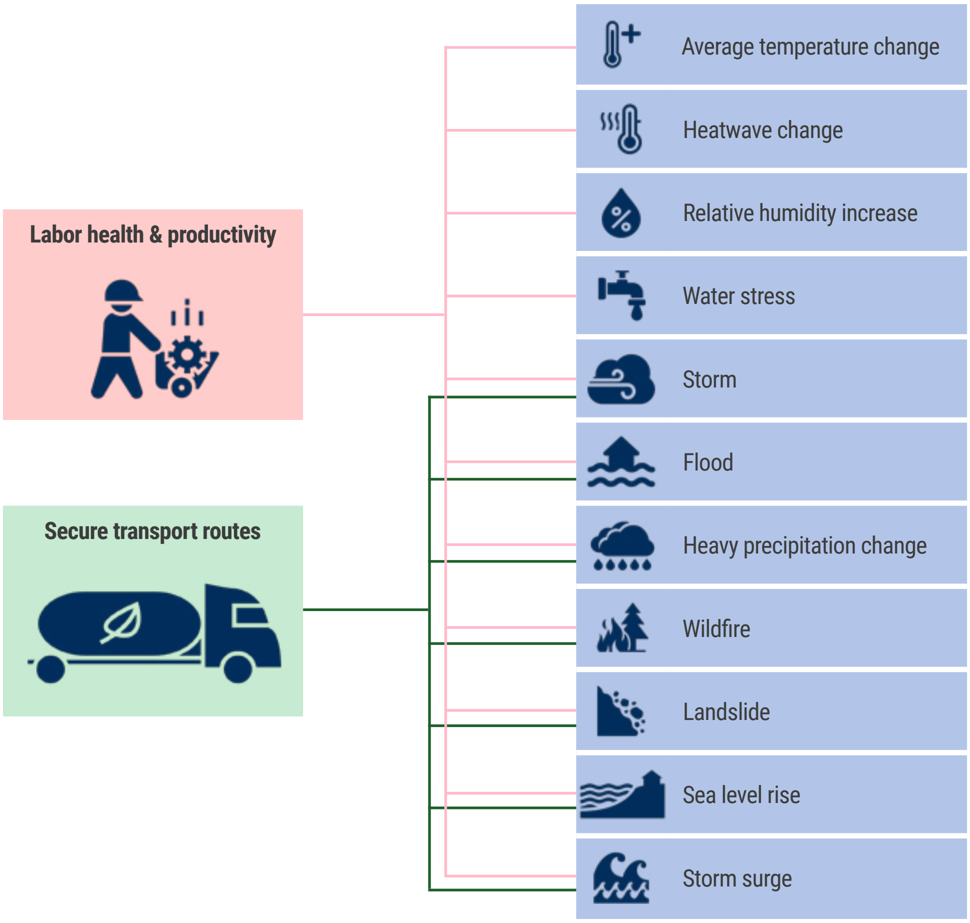

Figure 3.3: Relating Vulnerability Indicators 'labor health and productivity' and 'secure transport routes' to relevant climate-related hazards. Source: Acclimatise

Hazard datasets are processed to provide spatial hazards data normalized to a common scale. Hazard datasets can have various statistics and units of measurement. A simple overlay of these datasets does not allow for results to be numerically compared to one another within the same time horizon, as well as for different time horizons, RCPs and geographies. An index-based approach is therefore applied, where data are normalized to a common scale. This allows for multiple hazard datasets of differing units to be layered and aggregated up to produce location-specific risk scores. All relevant location-specific hazard indices are aggregated up for each Vulnerability Indicator. Each Vulnerability Indicator score itself is also normalized by the number of contributing hazards.

I Representative Concentration Pathways represent possible future greenhouse gas emissions and atmospheric concentration scenarios. Four RCPs were used in the IPCC's Fifth Assessment Report.

3.2.2.3. Exposure

Exposure data–the presence of segments of the portfolio in geographies exposed to hazards–completes the risk calculation. The core exposure data required on the portfolio is a matrix of investment sectors/sub-sectors and associated geographies (Figure 3.4). Line-by-line portfolio data, categorized by sector/sub-sector and geography can also be assessed. Portfolio geographic data granularity can range from point location data for individual investments, to country-level data. Although the heatmapping can work at any spatial scale, coarser-scale exposure data 'smooths' within-country climatic variations which may be particularly important in larger or geographically-diverse countries. For example, the U.S. includes colder northern states such as Alaska, and hotter, drier states to the south. Climate-related hazards and risks will differ substantially across these geographies, and a country-average will mask these variations.

Sector	Subsector	Canada	Colombia	Guatemala	Hong Kong	Indonesia	Netherlands
Section A: Agriculture, forestry and fishing	Animal raising, production, support activities						
Section A: Agriculture, forestry and fishing	Crop growing, production, support activities						
Section A: Agriculture, forestry and fishing	Land development, improvement						
Section A: Agriculture, forestry and fishing	Land drainage						
Section D: Electricity, gas, steam and air conditioining supply	Biofuel						
Section D: Electricity, gas, steam and air conditioining supply	Biomass						
Section D: Electricity, gas, steam and air conditioining supply	Geothermal						
Section D: Electricity, gas, steam and air conditioining supply	Solar CSP						
Section D: Electricity, gas, steam and air conditioining supply	Solar PV						
Section H: Transportation and storage	Airports & airport installations						
Section H: Transportation and storage	Freight air transport - airport						
Section H: Transportation and storage	Passenger air transport - airport						
Section H: Transportation and storage	Business activities - cargo handling - buildings						
Section H: Transportation and storage	Business activities - land transport & transport via pipelines						
Section H: Transportation and storage	Business activities - Other passenger land transport						
Section H: Transportation and storage	Business activities - Other transportation support activities						

Figure 3.4: Example of exposure data (sector/sub-sector and geography matrix). Source: Acclimatise.

3.2.2.4. Heatmapping outputs

The portfolio heatmapping output provides insight into total portfolio exposure, and helps to identify segments facing higher physical risk, for different time horizons from the present day into the future, and for different RCPs. To derive the output, for each investment sub-sector/location combination in the exposure dataset, the Vulnerability Indicator scores are weighted by their sub-sector sensitivities and computed into spatial risk scores. In turn, the Vulnerability Indicators scores are summed for each location, and all results are normalized back to a common scale. The results are analyzed to determine appropriate risk ratings and associated color bandings, e.g. low (green) to high (red). The results can also be presented as charts and maps (see for example, Figure 3.5). The outputs can thus help to readily identify potential 'hotspots' of risk for further, more detailed analysis.

Sector	Subsector	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6	Country 7	Country 8
A	A1								
A	A2								
A	A3								
A	A4								
B	B1								
B	B2								
B	B3								
B	B4								
B	B5								
B	B6								
C	C1								
C	C2								
C	C3								
D	D1								
D	D2								
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D	D9								
D	D10								

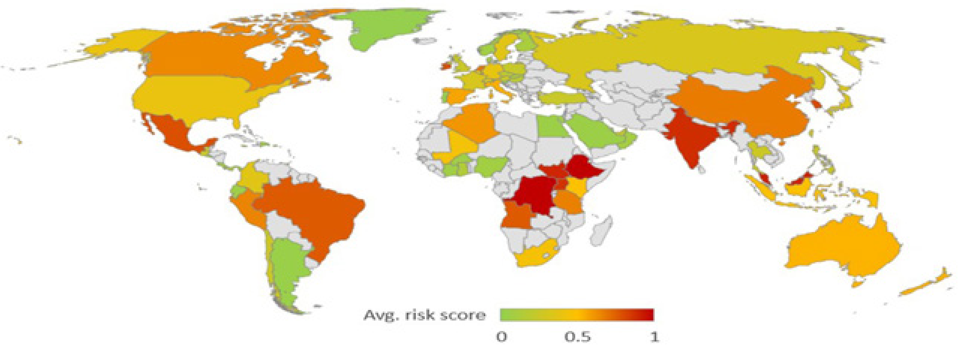


Figure 3.5: Example heatmap outputs: portfolio segment risk ratings (top); and average portfolio risk scores per country (bottom). Source: Acclimatise

3.3. Heatmapping exercise by Phase II banks

3.3.1. Introduction

Using the Acclimatise heatmapping framework, the Phase II banks worked towards reaching a view on key areas of vulnerability and relevant hazards for six sectors of interest – agriculture, metals and mining, power and energy, oil and gas, real estate and manufacturing. Sector-based working groups and a heatmapping pilot group discussed a short-list of four of the eight Vulnerability Indicators described in Section 3.2 together with a selection of 14 key hazards. They provided their views on:

1. The significance of the Vulnerability Indicators to the six sectors and their associated sub-sectors, assigning Low (1), Medium (2) or High (3) ratings, and
2. Hazards they considered to be relevant to each Vulnerability Indicator.

3.3.2. Results from bank heatmapping exercise

Discussions among the sector working groups and the heatmapping pilot group of banks aimed to reach a shared view of sub-sector vulnerability scores and relevant hazards, demonstrating that banks' views differed. Sector experts from the banks debated the relative significance of four of the Vulnerability Indicators to sector/sub-sector performance, namely: reliance on natural resources; reliance on efficient operation of assets and processes; climate sensitivity of market demand; and reliance on labor health and productivity. Opinions differed on the extent to which climate change could challenge the design thresholds for industrial facilities. Bank experts also noted that Vulnerability Indicator scores for the same sub-sector could vary from country to country, depending on asset age and condition. With these caveats in mind, the outputs of the heatmapping exercise are discussed below.

Higher overall Vulnerability Indicator scores were given to the agriculture, forestry and fisheries sector and the metals and mining sector, alongside sub-sectors including thermal power generation, petroleum and natural gas extraction, manufacturing of basic metals and fabricated products, and commercial property. The outcomes of the Vulnerability Indicator exercise undertaken by the banks are shown in Table 3.2.

The main findings for each Vulnerability Indicator can be summarized as follows:

- **Reliance on natural resources** tended to score higher than other Vulnerability Indicators, reflecting the fact that the sectors/sub-sectors involve physical assets that require large amounts of land and secure water supplies for successful operation.
- **Reliance on efficient operation of assets and processes** was commonly scored as medium vulnerability across many sub-sectors.
- **Climate sensitivity of market demand** showed more variation between sub-sectors, with real estate scoring highly.
- **Reliance on labor health and productivity** scored lower overall relative to other indicators, with the exception of higher scores in sub-sectors dependent on large workforces or outdoor workers (e.g. in agriculture), or where health and safety may be more stringently controlled, such as the metals and mining sector, and in extraction of crude petroleum and natural gas.

The main findings by sector discussed among the banks include:

- **Agriculture, forestry and fisheries:** This sector was noted as being highly vulnerable to reliance on natural resources, reflecting its dependency on the availability and quality of water and land. It was also scored high for labor health & productivity, as outdoor labor exposes its workforce to extreme events.
- **Metals and mining:** Similar to the agriculture sector, the primary vulnerabilities noted by banks were reliance on natural resources and labor health & productivity. Water availability is a key issue for mining operations, particularly when considering competition with other water users in surrounding communities. The banks also noted that increasing temperatures and more frequent heatwaves could greatly impact operating hours and labor productivity at mine sites. Although they noted that sub-surface mining activities may be an exception to this since temperature would be more regulated, they recognized that higher above-ground temperatures can impact the efficiency of mining ventilation systems. For open cut mines, a series of excessively hot days was noted as potentially impacting on productivity through changes in work-rest ratios.
- **Power and energy:** Vulnerabilities in this sector were noted to vary greatly between the sub-sectors. In both the hydropower and thermal power generation sub-sectors, a key vulnerability noted by banks was the dependence on water. Thermal power plants typically require cooling water, and abstraction and discharge licensing conditions can constrain operation when river levels are too low for abstraction or water temperatures are already too elevated to receive discharged cooling water. Banks agreed that the solar and wind sub-sectors were potentially less relatively vulnerable compared to other forms of generation.

- **Oil and gas:** Within the oil and gas sector, extraction of crude petroleum and natural gas was noted to have high vulnerabilities to dependence on natural resources, changes in market demand and dependence on outdoor labor (who are also often working in extreme environments). This sub-sector is vulnerable to changing seasonality of market demand for its fuels for heating (e.g. gas used in space heating) and cooling (where its fuels are used in thermal power generation). Liquefaction and gasification were also noted as being highly vulnerable to reliance on natural resources due to the sub-sectors' dependency on adequate supplies of water for operations.
- **Manufacturing:** Chemical manufacturing and manufacture of fabricated products were noted to be more vulnerable to natural resources reflecting the need for large volumes of water and large land areas required for the sector's fixed assets.
- **Real estate:** Banks noted changes in market demand as a key vulnerability for the real estate sector. Demand for real estate can change as a consequence of front-of-mind extreme events such as floods, storms and wildfires, particularly when coupled with related insurance concerns (cost of insurance, insurance terms and insurability). Changes in climate, rising sea levels and more frequent extreme events could, over time, make certain real estate locations less desirable, while opening up real estate investment opportunities in others.

The banks did not score the sectors/sub-sectors against four of the eight Vulnerability Indicators. The four indicators which were not scored were: need for a secure energy supply; reliance on climate sensitive supplies; reliance on secure transport routes; and potential for environmental and social impact. If these additional indicators had also been scored, the overall Vulnerability Indicator scores for each sector/sub-sector would have been different. The output shown in Table 3.2 should therefore not be taken to indicate the full range of vulnerabilities any sector or sub-sector may face in a changing climate.

The banks identified that a wide range of incremental climate changes as well as extreme events were relevant to each Vulnerability Indicator, as shown in Table 3.3. Through this exercise, the banks identified many cause-effect chains through which changes in climate and related hazards can affect indicators of investment performance. This demonstrates the richness and complexity of physical climate risk, and emphasizes the benefits of a comprehensive approach to portfolio-wide heatmapping. The process of discussion between climate and sector experts in the banks on these topics is also helpful in building a shared understanding.

The maps in Table 3.2 and Table 3.3 represent the consolidated scores from the bank heatmapping exercise. Though the scores are reflective of discussions amongst the group of piloting banks, they may not reflect the judgement of individual banks. The differences may be due to regional exposure of institutions and individual preferences. Under different circumstances and with a different group of banks, a different set of ratings may be determined. Professional judgment should be applied in using these maps.

Table 3.2: Phase II banks' combined views of the relative importance of four Vulnerability Indicators to a selection of sectors and sub-sectors. These are combined scores and may not represent the views of individual banks.

		Vulnerability Indicator scores			
Sector	**Sub-sector**	**Natural resources**	**Assets & processes**	**Market demand**	**Labor health & productivity**
Agriculture, forestry & fisheries	Animal raising, production, support activities	3	2	2	2
	Crop growing, production, support activities	3	2	2	3
Metals and mining	Ore mining	3	2	1	3
Power and energy	Hydropower	3	2	2	1
	Solar	1	2	2	1
	Thermal power station	3	2	2	2
	Wind	2	2	2	1
Oil and gas	Extraction of crude petroleum and natural gas	3	2	3	3
	Liquefaction and regasification	3	1	1	1
	Manufacture of refined petroleum products	2	1	1	1
	Oil & natural gas transmission & distribution	1	2	1	1
	Support activities for petroleum and natural gas extraction	1	2	2	2
Manufacturing	Chemical manufacturing	3	2	1	1
	Basic metals and fabricated products	3	2	2	2
Real estate	Commercial property	2	2	3	2
	Residential property	2	1	3	1

Table 3.3: Phase II bank's combined views of the relevance of climate and climate-related hazards to vulnerability indicators. These are combined views and may not represent the views of individual banks.

	Vulnerability Indicator															
Climate-related hazard	**Natural resources**				**Assets & processes**				**Market demand**				**Labor health & productivity**			
	Agr	Ener	M & M	RE	Agr	Ener	M & M	RE	Agr	Ener	M & M	RE	Agr	Ener	M & M	RE
Annual average temperature	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓			
Seasonal average temperature	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Solar radiation	✓	✓	✓	✓	✓				✓		✓		✓		✓	✓
Heatwave	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Wildfire	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓
Annual average precipitation	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓			✓
Seasonal average precipitation	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Heavy precipitation events	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
Relative humidity	✓	✓	✓	✓	✓	✓		✓	✓		✓		✓	✓	✓	✓
Water stress	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Riverine and surface water flooding	✓	✓	✓	✓	✓		✓	✓	✓			✓	✓		✓	✓
Landslide	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓
Sea level rise and coastal flooding	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓		✓	
Storms	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓

Notes:

Sector Working Groups: Agr = Agriculture; Ener = Energy; M & M = Metals and Mining; RE = Real Estate

4. Tools for physical climate risk assessment of financial risk

4.1. Overview

An initial methodology for analyzing financial impacts of physical climate risks was developed during Phase I of the UNEP FI TCFD banking pilot. The Phase I physical risk methodology is implemented in Excel, and it provides a simplified, initial assessment of the physical risk present in loan portfolios. The method is labor-intensive to implement and provides only high-level (country-scale) estimates of future changes in physical risk.

Building a tool for robust quantification of physical risk in financial terms is a significant endeavor, involving data science and analytics[m] in a geographic information system (GIS) environment. Some commercial providers have developed proprietary tools or analytics. Phase II aimed to help banks understand a selection of commercial physical climate risk assessment tools and analytics which are now available to banks. These are tools and analytics which generate financial metrics of physical climate risk, or assess aspects of physical risk to counterparty performance which have financial consequences.

This module aimed to improve banks' understanding of tools and analytics for physical risk assessment of loan portfolios that are available on the market, as well as training the banks to utilize the Phase I Excel-based methodologies. Along with presentations to the Phase II banking group by commercial providers, several of the Phase II banks engaged in direct discussions with providers to evaluate their tools and analytics. In addition, some of the Phase II banks elected to apply the Excel-based Phase I methodologies to develop initial physical risk assessments for specific sectors. The datasets underpinning the Phase I methodologies were therefore expanded to cover new countries of interest to the Phase II banks, and new datasets for changes in flood risk were provided for the countries covered in Phases I and II.[40, 41, 42]

This chapter provides an overview of these proprietary tools and analytics, summarizing their key features using a systematic review framework. Only tools and analytics that generate financial metrics or assess aspects of counterparty performance which have financial consequences were included in the review. The tools and analytics use climate hazard data as an input and calculate risks to client value chains posed by the hazards, and consequent risks to banks, typically in financial metrics.

The tools and analytics are designed for different, but not mutually exclusive, purposes. These include portfolio assessment, security selection (or investment appraisal), for strategic and tactical asset allocation, risk management, and regulatory reporting. Some tools are generic and can be applied to all asset classes (public and private equities,[n] debt, real assets, sovereigns) by a wide range of users (banks, insurers, asset owners, asset managers and corporates). Others focus on specific asset classes or have versions (or modules) for specific types of users, as discussed further below.

m Data science involves designing and constructing new processes for data modeling and production, e.g. using algorithms and predictive models. Data analytics includes examining large data sets to identify trends, develop charts, and create visual presentations, to help make decisions.

n Assessment of private equities / unlisted companies is generally less well covered by analytics providers than public equities / listed companies.

The tools and analytics can be differentiated according to the following aspects of risk analysis:

- **Level of analysis**: Depending on the target users, tools and analytics differ in their level of analysis, ranging from portfolio-wide assessments through to analysis of individual assets.
- **Impact channels covered**: Risk analyses can differ in their scope, ranging from covering the counterparty's macroeconomic environment and its full value chain (including supply chain, operations and physical assets, and markets) to covering only some of these channels through which projected climate change could affect counterparty performance.
- **Methods and approaches for impact assessment**: Tools and analytics also differ in the methods and approaches that they employ to assess (and quantify) impacts of climate change on counterparties. These range from simply reporting on the physical exposure; using a range of vulnerability indicators to (implicitly) link physical climate hazards to financial performance; applying physical impact models to (explicitly) estimate impacts of changes in specific climate hazards on economic or financial indicators; to modeling the financial outcome for counterparties.

The key features of the physical climate risk assessment tools and analytics are mapped in Table 4.1 using the following framework:[o]

- climate scenario coverage,
- time horizon coverage,
- hazard coverage,
- risk analysis approach,
- user inputs, and
- outputs.

4.2. Review of physical climate risk assessment tools and analytics

This section discusses eight featured tools and analytics based on information from the providers. Table 4.1 summarizes the tools and analytics, and each element in the review framework is further discussed below.

o The framework for review used here draws on the framework set out in Changing Course: A comprehensive investor guide to scenario-based methods for climate risk assessment, in response to the TCFD. Available from: https://www.unepfi.org/publications/investment-publications/changing-course-a-comprehensive-investor-guide-to-scenario-based-methods-for-climate-risk-assessment-in-response-to-the-tcfd/

Table 4.1: Overview of physical climate risk assessment tools and analytics

			Provider[p]								
			427 (1)	427 (2)	ACC	ACC-VE	C4 (1)	C4 (2)	CD	CLIMAFIN	RhG
Scenarios		<2.0°C (RCP 2.6)			✓	✓				✓	✓
		2.0°C (RCP 4.5)			✓	✓	✓	✓		✓	✓
		3.0°C (RCP 6.0)			✓	✓	✓			✓	✓
		>4.0°C (RCP 8.5)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Time horizons		Baseline/historical	✓	✓	✓	✓	✓	✓	✓		✓
		Near-term (2030–2040)	✓	✓	✓	✓				✓	✓
		Medium-term (2050)			✓	✓	✓	✓		✓	✓
		Long-term (2100)					✓	✓	✓	✓	✓
Climate hazards		Chronic changes	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Acute events	✓	✓	✓	✓	✓		✓	✓	✓
Risk analysis	Level of analysis	Asset[q]	✓	✓[r]	✓	✓	✓	✓	✓	✓	✓
		Firm	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Sector	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Country	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Portfolio	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Impact channel	Macroenvironment		✓	✓	✓	✓			✓	✓
		Supply chain		✓	✓	✓	✓			✓	
		Operations and assets	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Markets and customers		✓	✓	✓	✓	✓		✓	✓
	Method	Physical exposure	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Vulnerability indicators		✓	✓		✓	✓			
		Physical impact modeling	✓	✓		✓			✓		✓
		Financial modeling		✓		✓			✓		✓
User Inputs		Counterparty name (ISIN code)		✓[s]	✓	✓	✓	✓	✓	✓	✓
		Location	✓		✓	✓		✓	✓	✓	✓
		Value of asset			✓	✓		✓	✓	✓	✓
		Characteristics of asset	✓		✓	✓		✓	✓	✓	✓
Outputs		Semi-quantitative	✓	✓	✓		✓	✓			
		Quantitative		✓		✓		✓	✓	✓	✓
		Non-financial metrics	✓		✓		✓	✓			
		Financial metrics	✓	✓[t]		✓			✓	✓	✓

p The respective physical climate risk assessment tools and analytics reviewed are:
427 (1) – On-demand physical climate risk scoring application
427 (2) – Physical climate risk scores for publicly listed companies
ACC (Acclimatise) – Physical climate risk heatmapping tool
ACC-VE (Acclimatise-Vivid Economics) – Sector deep-dive assessments tool
C4 (1) (Carbone 4) – Climate risk impact screening (CRIS)
C4 (2) (Carbone 4) – Infrastructure and real estate portfolio assessment tools
CD (Carbon Delta) – Climate Value-at-Risk (VaR)
CLIMAFIN – Physical risk toolbox
RhG (Rhodium Group) – Valued asset-level physical risk data

q Inclusive of physical and financial assets

r Four Twenty Seven also provides portfolio-specific analyses

s The user provides the name(s) of the listed entity(ies) if they choose to assess a subset of the data in the tool.

t Leveraging Moody's Analytics' Public Expected Default Frequency structural credit risk model, 427's physical climate risk scores for listed companies can be translated into credit metrics such as probability of default term structures, expected loss estimates, credit spread effects, price effects, and value-at-risk. This is currently offered as consultancy services and will be offered in future as an on-demand analytics product.

4.2.1. Scenarios

		Provider								
		427 (1)	427 (2)	ACC	ACC-VE	C4 (1)	C4 (2)	CD	CLIMAFIN	RhG
Scenarios	<2.0°C (RCP 2.6)			✓	✓				✓	✓
	2.0°C (RCP 4.5)			✓	✓	✓	✓		✓	✓
	3.0°C (RCP 6.0)			✓	✓	✓			✓	✓
	>4.0°C (RCP 8.5)	✓	✓	✓	✓	✓	✓	✓	✓	✓

Greenhouse gas concentration scenarios
Using two or more scenarios allows users to explore a range of potential future physical risks and aligns with the TCFD recommendations. All of the analytics / tools include the IPCC Representative Concentration Pathway (RCP) 8.5. This high emissions scenario implies an average global temperature increase of about 4.3˚C by the end of the 21st century, relative to pre-industrial levels. The majority of the tools also incorporate a contrasting lower emissions scenario, such as RCP 2.6 which aligns with the aims of the Paris Agreement to keep global temperature rise this century well below 2˚C.

Some tools use one concentration pathway, like Four Twenty Seven and Carbon Delta which use RCP 8.5. For Four Twenty Seven, the rationale for focusing on RCP 8.5 is due to the time horizons covered in their analytics. Their standard screening is for the 2030–2040 period. Under all RCP scenarios, the world is projected to warm by about 1.2–1.5°C above pre-industrial levels by 2040, and climate models do not show meaningful differences between the scenarios until after 2040, as we are already 'locked into' a certain amount of unavoidable climate change for the next 20–30 years due to greenhouse gases already emitted. Four Twenty Seven are working to include scenario analysis going out to 2100 to capture the differences in RCP projections post–2050.

Climate models
Using a wide range of climate models provides a better understanding of the range of possible climate futures, and most of the tools use General Circulation Models (GCMs) from the World Climate Research Programme's fifth phase of the Climate Model Inter-comparison Project (CMIP5), in line with the IPCC's Fifth Assessment Report (AR5). The number of GCMs used in the providers' tools varies: some offer outputs based on a subset of models, while others cover the full suite of 50 models included in CMIP5. Carbon Delta is the only provider not to use CMIP5 model outputs, although they plan to integrate them in the future. Their methodology is based on a reanalysis of historic data and extrapolating the trends out to 2100. For extreme events they use more detailed, probabilistic risk assessment models.

The CLIMAFIN toolbox uses the full suite of CMIP5 models, the outputs of which are processed through different impact models. Their climate impact assessment is built on a chain of models connecting GCMs, Regional Climate Models (RCMs), and high-resolution hydrological, land-use and meteorological models. Carbone 4's tools for infrastructure and real estate use a selection of five GCMs/RCMs couples.

Rhodium Group uses output from CMIP5 models as well as synthetic models in order to capture a full distribution of potential outcomes. Along with their partners in the Climate Impact Lab, Rhodium developed a methodology for combining downscaled output from the 21 leading GCMs and 12 synthetic models created by pattern scaling GCM output into an integrated probability distribution of temperature, precipitation and other climate variables.[43] The same probabilistic approach is applied to Rhodium Group's sea level rise projections.[44]

Time horizons

Time horizons	Provider								
	427 (1)	427 (2)	ACC	ACC-VE	C4 (1)	C4 (2)	CD	CLIMAFIN	RhG
Baseline/historical	✓	✓	✓	✓	✓	✓	✓		✓
Near-term (2030–2040)	✓	✓	✓	✓				✓	✓
Medium-term (2050)			✓	✓	✓	✓		✓	✓
Long-term (2100)					✓	✓	✓	✓	✓

All of the providers offer a forward-looking assessment of physical risk, often for multiple future time periods, ranging from near-term (circa 2030s) to long-term. Several tools also include either a baseline period or historical conditions. Rhodium Group, CLIMAFIN and Acclimatise offer the broadest range of future time periods, whereas Four Twenty Seven and Carbon Delta provide one future time period.

4.2.2. Climate and climate-related hazards

Climate hazards	Provider								
	427 (1)	427 (2)	ACC	ACC-VE	C4 (1)	C4 (2)	CD	CLIMAFIN	RhG
Chronic changes	✓	✓	✓	✓	✓	✓	✓	✓	✓
Acute events	✓	✓	✓	✓	✓		✓	✓	✓

Hazard type

Most of the tools offer analysis of a wide range of climate and climate-related hazards, including a combination of chronic and acute hazards. The term 'climate hazards' refers to extreme (acute) climate and weather events, as well as incremental (chronic) changes in climate variables. The main acute events analyzed by the tools are: extreme precipitation, heatwaves, drought and storms. Chronic changes analyzed include changes in temperature and precipitation. Many tools include analysis of 'climate-related hazards' – a term which covers environmental variables influenced by climatic (and non-climatic) factors, such as flood, water stress, wildfire and landslides. Carbone 4's CRIS tool offers a number of climate-related hazards not included in other methodologies, such as coastal erosion, urban heat island, air quality and biodiversity migration and loss.

Spatial resolution and coverage

The spatial resolution of the hazards data included in the tools/analytics varies depending on the assessment methodology, the stage of the analysis (i.e. portfolio-wide screening vs. deep dives), the datasets used for each hazard type, the data used for observed (baseline) conditions compared to future climate scenarios, and even the specific country. Some analytics are undertaken at point location level; others at the country or sector level. Four Twenty Seven uses a 25 km resolution for heat stress and extreme precipitation; their water stress data varies between a few km to 50 km based on the size of the watershed; and floods and sea level rise are reported at 90 m resolution. For the Acclimatise tools, the resolution varies between the different stages of the analysis. The portfolio-wide screening ('heatmapping') uses 50 km spatial resolution data, and the second ('deep dive') stage from Acclimatise-Vivid Economics uses the highest available resolution, which varies from 10 m to 50 km. Carbone 4's real estate and infrastructure tools use a spatial resolution of 12 km over Europe for climate hazards, whereas specific predisposing contexts are assessed at 100 m to 1 km scale. Rhodium Group provides analytics at resolutions specific to the asset being analyzed.

In terms of the spatial coverage that each of the tools provide, currently all but Rhodium Group offer global coverage for their assessments. The Rhodium Group Climate Risk Service currently covers US-based assets, but global coverage is expected to be available in 2020. Some tools with global coverage had regions with lower data coverage, e.g. African banks found that African data were limited for several tools.

4.2.3. Risk analysis

			Provider								
			427 (1)	427 (2)	ACC	ACC-VE	C4 (1)	C4 (2)	CD	CLIMAFIN	RhG
Risk analysis	Level of analysis	Asset[u]	✓	✓[v]	✓	✓	✓	✓	✓	✓	✓
		Firm	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Sector	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Country	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Portfolio	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Impact channel	Macroenvironment		✓	✓	✓	✓			✓	✓
		Supply chain		✓	✓	✓	✓			✓	
		Operations and assets	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Markets and customers		✓	✓	✓	✓	✓		✓	✓
	Method	Physical exposure	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Vulnerability indicators		✓	✓		✓	✓			
		Physical impact modeling	✓	✓		✓			✓		✓
		Financial modeling		✓		✓			✓		✓

Level of analysis

The tools and analytics differ in their level of analysis, ranging from portfolio-wide, country, sector, firm or individual asset level (including physical and financial assets). Most tools also provide the option of aggregating asset-level risk analyses for assessments at portfolio, country, sector and firm levels.

Some tools are designed for specific asset classes or have tailored versions or modules for specific user groups. For example, Four Twenty Seven's physical climate risk scores for publicly listed companies is relevant for all asset classes of listed entities while its on-demand risk scoring application can be used to assess climate risk in loan portfolios at the individual facility level. Carbone 4's CRIS tool has two, more detailed, "derivative" versions designed for banks: a screening tool for infrastructure and a real estate portfolio assessment tool. CLIMAFIN's physical risk toolbox has specific modules for banks to assess risks to loan portfolios. The Acclimatise-Vivid Economics deep-dive assessments tool can assess most types of loans and also covers equities, real estate and infrastructure investments. Rhodium Group's analytics cover a range of asset classes, at both the individual asset and portfolio level, including commercial mortgage-backed securities (CMBS), residential mortgage-backed securities (RMBS), credit risk transfer securities (CRTs), commercial mortgage loans (CMLs), municipal and sovereign bonds, real estate investment trusts (REITS), corporate equity and fixed income and private assets (e.g. real estate, infrastructure, and corporate equity).

All the featured tools and analytics can work at physical asset level, either using proprietary datasets or relying on users (or other providers) to provide portfolio composition data. Four Twenty Seven's physical climate risk scores for publicly listed companies and Carbon Delta's Climate Value at Risk (CVaR) tools incorporate proprietary data on the locations of physical assets for listed companies. The other tools require third-party datasets (for which the providers may already have existing contracts or agreements) or rely on users providing physical asset-level data. The latter may have limitations due to client confidentiality requirements and unavailability of granular data for clients.

u Inclusive of physical and financial assets.

v Four Twenty Seven also provides portfolio-specific analyses.

The quality of physical risk analysis is often hampered by a lack of data on physical asset locations and characteristics, and this is a particular challenge for unlisted companies and some regions. Proprietary data included within analytics generally only cover listed counterparties, and there can be major gaps in geographic coverage (for instance, in Africa). Asset-level data from users (e.g. banks) can be incorporated in the analysis, but users also often lack these data, particularly for asset classes other than real assets and infrastructure. Initiatives such as the Spatial Finance Initiative and its GeoAsset project[w] are examples of ongoing efforts to address this gap.

Notable gaps in data on physical climate risks facing unlisted companies and SME counterparties remain a key challenge for financial institutions' risk assessments. SMEs are not yet engaged in any form of public climate risk disclosure reporting and have often not undertaken assessments. Where assessments do take place, there is no standardized reporting across sectors or companies, (both for public and private entities) which also limits the potential use of artificial intelligence (AI) in collating relevant information on physical climate risks faced by unlisted companies and SMEs.

Client data confidentiality can prevent banks from uploading data to external analytics platforms. For real estate mortgages, banks hold asset-level data, but data confidentiality issues need to be overcome for these data to be uploaded into external analytical tools. Supplying precise location data to external tools and analytics providers could constitute a breach of client data privacy.

Impact channels

All the featured tools and analytics consider the impacts of climate change on counterparties' operations and physical assets, with varying degree of coverage for other impact channels. Given the direct impacts of climate change, counterparty operations (the productivity and efficiency of which are often sensitive to ambient climate conditions) and physical assets (often subject to loss and damage from extreme weather events) have been the focus of physical climate risk assessment tools. Most of the tools and analytics also take into account impacts on the macroeconomic environment, upstream (supply chain) and downstream (market) aspects of the counterparty value chain, to different degrees and taking different approaches (see below), with the exception of Four Twenty Seven's on-demand physical climate risk scoring application which is primarily used for real estate.

Impacts on the macroeconomic environment are reflected in most tools and analytics, particularly in assessing sovereign counterparties. In addition, most tools also consider physical climate impacts on the macroeconomic environment in company- and sector-level analysis. Four Twenty Seven's physical climate risk scores for publicly listed companies, Acclimatise-Vivid's sector deep-dive assessments tool, and Carbone 4's CRIS tool consider macroeconomic changes in assessing supply chain and market risk, and in their company-level and sector-level analyses.

Most tools and analytics consider impacts on counterparties' supply chains and markets, albeit only at country-sector level of granularity and indirectly through the use of indicators. Impact assessments in most tools and analytics tend to use sector- or country-level trade data and/or input-output tables, considering the country of origin (for raw materials production) and sales (for products and services). Some tools use proxies (e.g. vulnerability indicators) for supply chain and market impacts, rather than empirical data and process models. These approaches reflect a lack of data on individual suppliers and customers of bank's counterparties, which prevents taking a granular approach to analyzing physical impacts on individual suppliers and customers.

Most tools and analytics focus on assessing changes in exposure of counterparties' physical assets to climate and climate-related hazards, and the physical, economic and financial sensitivity of counterparties to such hazards, but do not account for counterparties' adaptation actions. The ability of counterparties to adapt to and cope with potential impacts is seldom taken into account in existing tools, due to the considerable challenge related to the availability of and access to counterparty climate adaptation plans. The physical risk assessments produced by the tools therefore represent a view of the 'gross' risk, and not the 'net' risk after set-off strategies. Inclusion of information on adaptation would provide a clearer picture of residual risks. Increased disclosures by companies of physical climate risk and adaptation strategies and plans, as encouraged by the TCFD recommendations, would contribute towards improved data availability, enabling more systematic consideration of corporate counterparties' adaptive capacity. The exception is sovereign investments, where indicators associated with national economic development status, governance and regulatory environment are used in some tools to characterize a country's adaptive capacity.

w See: https://spatialfinanceinitiative.com/geoasset-project/ for more information.

Given the nascent nature of physical climate risk analysis, more attention could be given to strengthen dialogue and engagement on the topic between banks and counterparties. Building on the findings of physical climate risk analyses, banks can engage with their clients on the nature and drivers of physical risks, and clients' strategies to manage them. This kind of engagement would help to raise awareness of physical risks by both groups and facilitate more effective climate-resilient investment strategies. To this end, analytical tools such as Acclimatise's corporate benchmarking tool can help to assess the relative strengths and weaknesses of corporate counterparties across the four core TCFD elements.[x]

While analyses of climate risks to "tangible" assets is important, the risks to intangible assets of counterparties have so far received little attention. With the shift over time in how market value is assessed, intangible assets (e.g. brand value, governance, social license to operate and environmental performance) have grown in importance in their contribution to the value of corporates, particularly listed companies. Climate change impacts and companies' risk management thereof are already and will increasingly affect intangible value. This will need to be accounted for as the process of physical risk assessment and disclosure evolves.

4.2.3.5. Methods and approaches for impact assessment

Most tools and analytics estimate impacts on counterparties through indicators that link climate hazards with counterparty value chains or financial performance. Leveraging literature and extensive engagement with clients in different sectors, Acclimatise's heatmapping tool relies on a set of eight vulnerability indicators (e.g. reliance on climate-sensitive supplies; reliance on efficient operation of assets; potential for environmental and social impact – see Chapter 3 for more information on these vulnerability indicators), aiming to capture the full spectrum of possible channels through which climate hazards could affect sub-sectors to analyze the risks from climate change. Similarly, Carbone 4's CRIS tool applies 15 climate-sensitive vulnerability factors, proxies of the state of counterparty value chains, as well as the macroeconomic environment. The key strength of these vulnerability-based approaches is that they enable a broad range of physical impacts to be evaluated across any industry sector; however, they do not generate financial output metrics. Four Twenty Seven's physical climate risk scores for publicly listed companies apply a set of risk indicators associated with counterparty value chains as well as country climate risks.

Some tools and analytics assess impacts using physical climate impact modeling, and to a lesser extent, economic and financial modeling. Physical impact models estimate the impacts of changes in climate hazards to aspects of counterparty performance such as changes in productivity or output, which in turn can be used to estimate impacts on counterparty financial performance. Economics-based approaches are exemplified by the Rhodium Group's Climate Risk Service, which leverages evidence-based economic models linking key impact categories (e.g. mortality rate, labor productivity, energy cost) with climate variables (e.g. daily maximum temperature), to assess the combined financial loss to a counterparty from a range of impacts. CLIMAFIN's physical risk toolbox uses historic data-based damage curves to estimate economic and financial impacts. Acclimatise-Vivid Economics' sector deep-dive assessments tool uses econometric and economy-wide models to assess geographic and sectoral impacts, and counterparty-level modeling to assess financial impacts on physical assets and operations.

x Acclimatise has developed a corporate benchmarking tool to facilitate engagement between financial institutions and companies on gaps and areas of improvement in managing physical climate risks and opportunities. Using criteria structured around the four pillars of the TCFD disclosure, the tool draws on and analyses information on corporates which is in the public domain (e.g. annual reports, sustainability reports, CDP responses, industry publications).

4.2.4. User inputs

		Provider								
		427 (1)	427 (2)	ACC	ACC-VE	C4 (1)	C4 (2)	CD	CLIMAFIN	RhG
User Inputs	Counterparty name (ISIN code)		✓	✓	✓	✓	✓	✓	✓	✓
	Location	✓		✓	✓		✓	✓	✓	✓
	Value of asset			✓	✓		✓	✓	✓	✓
	Characteristics of asset	✓		✓	✓		✓	✓	✓	✓

Nearly all tools and analytics require users to provide portfolio composition as input data. For each counterparty or security, the following information is typically required:

- name (or ISIN code for listed companies),
- sector, or type / nature of activities,
- value (absolute or a percentage of a portfolio), and
- other relevant characteristics (e.g. construction details for real estate assets, date of maturity for mortgages etc.).

Banks have noted that it would be helpful for tools to use more than one unique identifier for listed companies, e.g. Legal Entity Identifier or BvD,[y] in addition to ISIN codes.

Data on the counterparty or security may already be incorporated in the tool, obtained from third-party providers or provided by the user. As already noted in Section 4.2.3, some tools include proprietary datasets for listed companies. However, no tools already incorporate data on unlisted companies, SMEs or real assets (real estate and infrastructure). In some cases, these can be obtained from third party datasets (either by the analytics provider or by the bank), but in others they will need to be collated by the bank. For instance, data on SMEs may require research to identify where their physical assets are located and data on retail mortgage portfolios are only held by the bank. Collating these data for analysis within a tool can be an onerous process for a bank to undertake, and can also present data confidentiality issues. Banks intending to undertake such analysis will require sufficient resources to ensure this can be done.

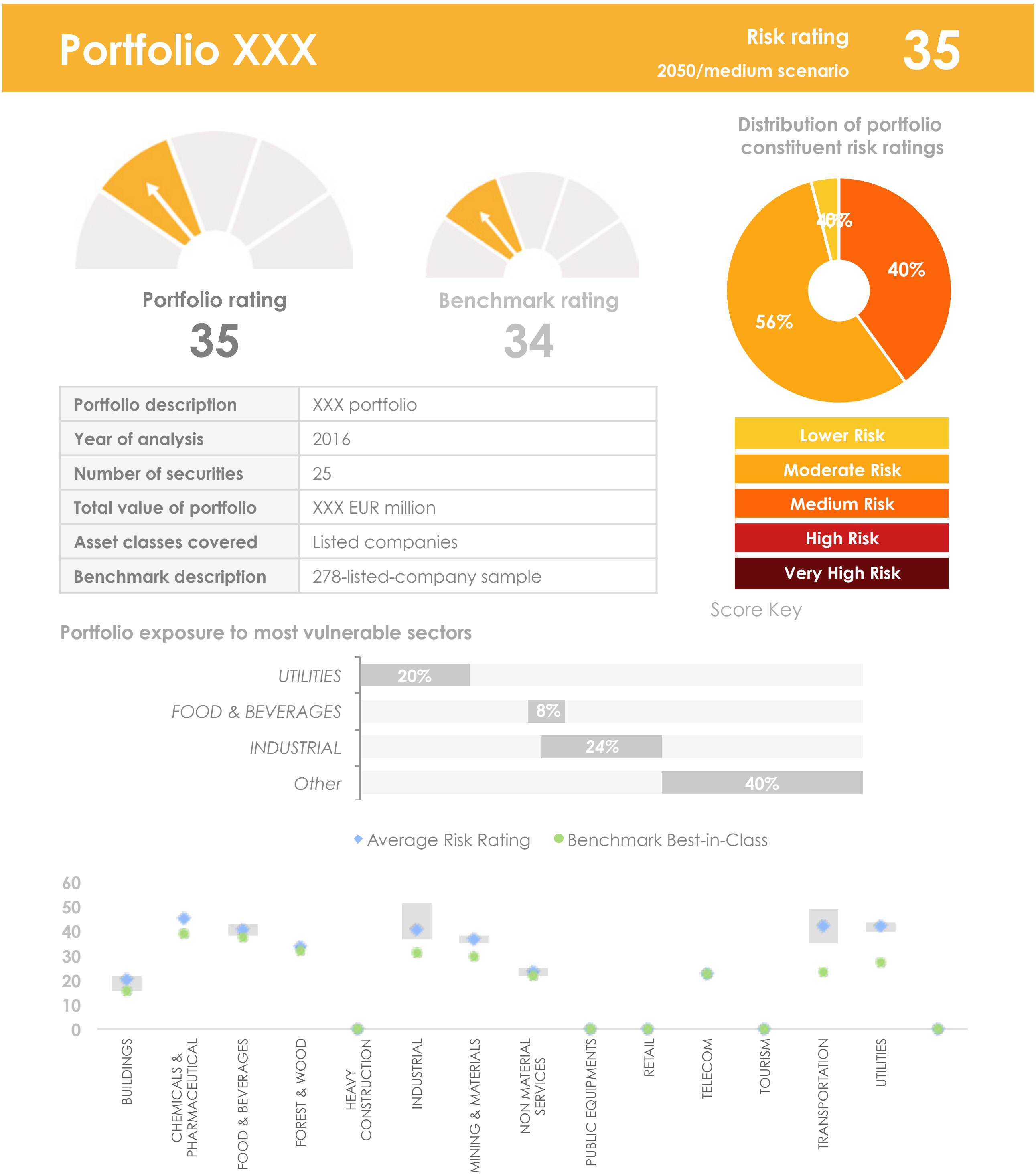
Location data facilitates the assessment of physical asset exposure to hazards, while information on the sector or nature of activities is central to determine the sensitivity to hazards. Data on asset value can be used to aggregate asset-level risk scores to obtain portfolio-level risk scores, as well as to estimate the financial impact of physical climate risks. For some tools (e.g. Carbon Delta's CVaR), user input data are required in an Excel file with a prescribed data structure while the others are typically flexible with input data format. For listed companies, users only need to provide names or ISIN codes of entities of interest. Users of Four Twenty Seven's physical climate risk scores for publicly listed companies can either have all listed companies covered by the tool without having to provide any inputs, or they can select a subset of the data by providing information on the composition of their portfolio. Rhodium Group can receive input for its models via various flat file formats and is also developing the capability to receive via API.

4.2.5. Outputs

		Provider								
		427 (1)	427 (2)	ACC	ACC-VE	C4 (1)	C4 (2)	CD	CLIMAFIN	RhG
Outputs	Semi-quantitative	✓	✓	✓		✓	✓			
	Quantitative		✓		✓		✓	✓	✓	✓
	Non-financial metrics	✓		✓		✓	✓			
	Financial metrics	✓	✓		✓			✓	✓	✓

y BvD refers to data from Bureau van Dijk who provide company information via their Orbis platform. See https://biblioteka.vdu.lt/files/Orbis.pdf

Some tools and analytics provide semi-quantitative physical climate risk scores. Four Twenty Seven's two analytical tools, Acclimatise's heatmapping tool and Carbone 4's CRIS tool all provide physical risk ratings expressed in unitless scores ranging between 0 or 1 (least at risk) to 99 or 100 (most at risk), presented visually on heatmaps or similar. These unitless risk scores can be aggregated to provide an overall portfolio-level risk score (for example, see outputs from Carbone 4's CRIS tool in Figure 4.1), as well as sector and geography-level[z] physical climate risk scores. In addition, with information on asset value, portfolios can be assessed to show asset values at different levels of risk.

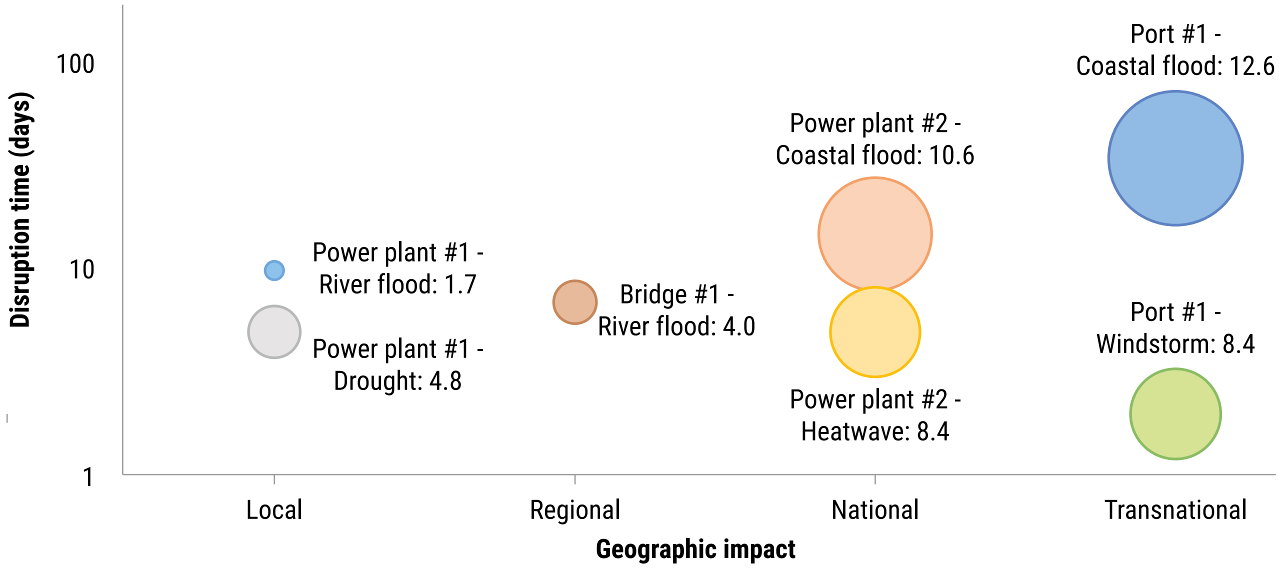


Portfolio description	XXX portfolio
Year of analysis	2016
Number of securities	25
Total value of portfolio	XXX EUR million
Asset classes covered	Listed companies
Benchmark description	278-listed-company sample

Figure 4.1: Example risk rating outputs for a portfolio and its constituents from Carbone 4's CRIS tool. Source: Carbone 4

z Usually at country level.

More tools and analytics provide quantitative and financial risk assessment outputs. Carbone 4's real estate portfolio assessment tool provides a quantitative assessment expressed in non-financial metrics. It analyzes the vulnerability of real estate assets to climate hazards using vulnerability profiles for each building type, and quantifies the evolution of climate hazards, and asset exposure to the hazards. Acclimatise-Vivid's sector deep-dive assessments tool provides outputs in financial metrics such as annual average expected loss (see Figure 4.2), cash flow changes, (real and financial) asset value corrections and probability of default. Carbon Delta's Climate Value at Risk (CVaR) provides estimates for individual listed companies, disaggregated for debt, equity and real estate assets. CLIMAFIN's physical risk toolbox can provide climate-adjusted probability of default, climate-adjusted asset valuation, climate induced change in rating, climate value at risk, climate conditional value at risk and tailored risk metrics. The Rhodium Group's Climate Risk Service provides combined financial impacts of a range of physical climate impact categories for various asset classes. Four Twenty Seven and partner Moody's Analytics translate companies' climate exposure into credit metrics, including probability of default, expected loss estimates, credit spread effects, price effects, and value at risk.



Size of circle represents annual average expected loss (US$ million) in 2050

Figure 4.2: Example outputs of Acclimatise's financial risk assessments for a portfolio of infrastructure assets: Annual average expected loss (US$ million) due to reduced productivity and business interruption under climate hazard scenarios. Source: Acclimatise

In addition to semi-quantitative climate risk scores and quantitative or financial metrics, some tools and analytics also provide qualitative narratives on drivers of physical climate risks, and options for responding to identified risks and opportunities. Sector- or country-level semi-quantitative risk scores provided by tools of Four Twenty Seven, Acclimatise and Carbone 4 facilitate the identification of key hazards which contribute most to the physical risk facing a particular sector or within a specific country, helping to target further in-depth risk analyses and management. Further, Carbone 4's CRIS tool provide recommendations on strategies for asset managers and investors to engage counterparties with most at-risk assets and portfolios on how to effectively manage identified risks.

4.3. Summary of gaps and areas for improvement

Table 4.2 summarizes the data gaps and areas of improvement identified by the Phase II banks for physical risk tools and analytics.

Table 4.2: Summary of data gaps and areas of improvement for physical risk tools and analytics

Data gap or area of improvement	Summary
Physical asset locations and other characteristics	While some tools incorporate datasets on the locations of physical assets for listed companies, such datasets are distinctly lacking for unlisted companies / SMEs. Even where the location of physical assets is included in datasets, they typically do not take account of the asset design characteristics, age and condition – all of which are relevant to understanding how climate hazards will affect asset performance.
Supply chains and market demand	Risks to counterparties' supply chains and market demand are typically assessed using sector- or country-level trade data and sector input-output tables. Data on the specific suppliers and customers of individual counterparties are lacking.
Unlisted companies and SME counterparties	Climate risks facing unlisted companies / SME counterparties are often unknown.
Counterparties' adaptation and resilience measures	The ability of counterparties to adapt to and cope with physical risk is not often captured in tools and analytics (with the exception of sovereigns).
Intangible assets	Climate impacts on intangible assets (e.g. brand value, governance, social license to operate and environmental performance) are largely unresearched and difficult to value.
Engagement	Banks would benefit from strengthening engagement with counterparties on the nature and drivers of physical climate risks and opportunities.

4.4. Bank case studies

Some Phase II banks piloted the Excel-based Phase I tools to develop initial physical risk assessments for specific sectors, whereas others engaged in direct discussions with market providers to evaluate their tools and analytics (Table 4.3). The banks cited some benefits from trialing the physical risk tools, including bringing together teams of experts from across the bank to look at climate change risk, and developing their understanding of potential risks to segments of their portfolios. The banks have also faced challenges during the piloting process, including collation and processing of bank-held data and insufficient granularity or lack of data. The bank case studies, which provide more detail on these insights, are provided in the following sections.

Table 4.3: Overview of bank case studies on physical climate risk assessment of financial risk

Bank	Scope of case study
Bradesco	Applied Excel-based Phase I tool for real estate to segment of retail mortgage portfolio
Intesa San Paolo	Applied Excel-based Phase I tool for energy and oil & gas to portion of top exposures in those sectors
Lloyd's Banking Group	Applied Excel-based Phase I tools for real estate (extreme events) and agriculture (incremental climate change)
NatWest Group	Applied Excel-based Phase I tool to assess flood risk to a sample of UK residential mortgages
Santander	Provided feedback on aspects of physical risk analytics considered more important for credit risk assessment, challenges in progressing assessments, and how commercially-available physical risk assessment tools can help address these
Standard Bank	Trialed a number of physical climate risk assessment tools, to determine their potential suitability for meeting the bank's needs Applied Excel-based Phase I tool for agriculture to a sample of exposures

Bradesco case study: Climate change physical risk impacts on the real estate sector

Banks can be affected by climate change impacts in different business lines, overlapping opportunities and risks. Among the areas of importance for assessing this type of impact is the real estate sector, which is highly influenced by climatic factors.

The Bradesco Organization comprises the second largest Brazilian private bank, the third largest asset manager in the country and the largest insurance company in Latin America. In these three lines of business, we see Bradesco's significant involvement in the real estate sector, mainly in financing construction, property acquisition for individuals and companies, and in offering insurance solutions for properties.

Flood risk as a critical factor for the real estate sector

Climate change affects weather patterns, including rainfall, and can make rains more intense and longer and high-impact storms more frequent. In urban spaces, the combination of such climatic changes with large areas covered by asphalt pavement and the continuous removal of vegetation can trigger extreme floods.

January 2020 was the hottest month since global temperature records began, reaching 1.19ºC above pre-industrial levels. In that same period, heavy rains and accompanying landslides and floods affected areas in Southeastern Brazil, such as the Santos region and Greater São Paulo - one of the largest megalopolises in the world, with about 20 million inhabitants.

In cities like São Paulo, and many other Brazilian ones, there are buildings in the flood fringe areas, a portion of the floodplain that is expected to be covered with water during rainy seasons. With the intensification of climate change, floods will tend to be more frequent in such areas and to surpass currently mapped limits.

In coastal areas—where one quarter of the Brazilian population lives—rising sea levels combined with more intense storms could lead millions of people in the world to leave coastal cities, resulting in impacts for cities in the order of US$ 1 trillion annually by 2050.[45]

Pilot study in Bradesco's portfolio

Considering the relevance of flood risk in Brazil, we developed a study focused on property financing for individuals, i.e. retail mortgage portfolio, which is a relevant segment within Bradesco's total credit portfolio.

The analysed portfolio only included properties for which construction was also financed by Bradesco. This type of financing is particularly interesting for analysis due to the extension of the bank's exposure period, which can reach 33 years considering the construction financing period (from 2 to 3 years), and the purchase financing period, which can last up to 30 years.

Tools employed in the study

We used two tools for this analysis. The current frequency of climatic events was obtained from Swiss Re's CatNet portal, a tool developed to analyze portfolios' exposure to physical risks based on location data and occurrence history. Therefore, it was necessary to use the postal code or geographic coordinates of the financed properties as part of CatNet inputs.

For the calculation of future impacts related to climate scenarios, we used the Excel tool developed for the real estate sector in the first phase of the UNEP FI pilot project. In this second phase of the pilot, the tool was complemented with future frequency rates of climatic events in some countries, including Brazil, where it is projected that by the 2040s, flood frequency could rise by 140% compared to the baseline if greenhouse gas emissions follow an evolution curve that would lead to a 4°C global warming context[aa] (Table 4.4).

Table 4.4: Change in flood frequency in the 2040s compared to baseline (4ºC scenario)[46]

Country	Change
Brazil	**+140%**
Netherlands	+125%
Canada	+80%
China	+40%
United States	+35%
United Kingdom	+30%
Australia	0%

aa Scenario of change in global average temperature by 2100 compared to pre-industrial

Results of the risk analysis
A minor share of the properties in the analyzed portfolio are located in areas with a current exposure to the occurrence of flooding at an annual probability rate ranging from 0.2% (1 in 500 years) to 2.0% (1 in 50 years).

Considering the impacts of the 4°C warming scenario on current weather patterns (Table 4.4), the future probabilities of flooding were calculated for the 2040s, from which depreciation rates on property values were derived (Table 4.5). These rates were calculated using an estimated 10% reduction in property value due to extreme events and an average remaining mortgage term of 12 years. Both these values were provided in the Phase I Excel tool.

Table 4.5: Probability of flooding and resulting property value depreciation compared to present day

Annual probability of flood occurrence		Depreciation
2020	**2040s (4°C)**	**2040s (4°C)**
2.0% (1 in 50 years)	4.8% (1 in 20 years)	4.5%
1.0%	2.4%	2.5%
0.5%	1.2%	1.3%
0.2% (1 in 500 years)	0.5%	0.6%

As a result, in the worst case, for example, flood events which have a 2% (1 in 50 year) annual probability of occurrence in 2020 become more frequent, reaching 4.8% per year (1 in 20 years) in the 2040s. This results in an estimated depreciation of 4.5% in the value of property in the affected areas due to flooding risk compared to the present day.

One of the limitations of the study was its focus on areas that are currently exposed to flooding. In other words, the study does not consider new locations that may become exposed to flood hazard due to climate change.

In addition, the study did not consider mitigation elements recently implemented by government and by construction companies to manage or mitigate the impacts of flooding on assets. Flood barriers, flood protection walls and buildings above the flood level are some examples of measures that reduce possible impacts.

Conclusion

The present study demonstrates the relevance of actions to measure and manage climate risks, especially in the real state sector. In this sense, two perspectives are relevant: the evaluation and management of the total exposure of banks' portfolios to climate risk; as well as the detailed assessment of risk factors and mitigating elements in each property under analysis.

In addition, understanding climate risk factors, and the consequent extent of their impacts, can also be an important tool for banks to expand their ability to support customers in measuring risks and becoming increasingly resilient to climate change impacts.

In summary, the growing physical climatic risks and their connection with the real estate sector, demonstrated in the study, reinforce that the application of methodologies, models and tools for measuring and controlling risk in the analysis of operations, customers and portfolios will become increasingly critical in the banking sector given future scenarios of changes in climatic conditions.

Intesa Sanpaolo case study: Physical climate risk measurement: the UNEP FI Phase I Excel tool applied to Energy and Oil & Gas companies

Introduction

As a participant in the UNEP FI Phase II working groups, **Intesa Sanpaolo evaluated the impact of physical climate change risk on a portion of its top exposures portfolio in the energy and oil & gas sectors**. The aim was to estimate the financial impact of physical climate risk on this portfolio, which required translating climate risk data into a change in the probability of default (PD).

Our enterprise and credit risk teams with the support of the CSR structure were involved in the exercise. Our participation in this working group has been a great opportunity to have a first glance at various data providers, climate and environmental methodologies, as well as a way to understand the challenges related to physical risk measurement.

Clearly, a full application of the framework would require a more detailed information set that includes details such as the geographical location and the physical characteristics (type of buildings, physical risk management measures already in place, etc.) of each borrower's site.

Therefore, during the implementation of the exercise one of the major critical issues was the availability of this data both at the borrower level and at geospatial level. Despite cross-checking information against several data providers, we encountered several difficulties in ensuring an accurate representation of the portfolio.

The analysis was then labor-intensive, it required data check and qualitative adjustments. The adoption of simplifications helped us finalizing the exercise, but the high level of assumptions entailed some approximation in the outcome. These actions can hardly be extended to the whole portfolio or to SMEs or unlisted companies where the data availability is smaller. A higher level of engagement with customers would help in terms of data reliability, but it would be heavily time consuming.

From the point of view of the simulation, we measured the PD changes for the companies considered. The calculation is conducted in two hypotheses of global warming of + 2°C and + 4°C (increases in global average temperatures compared to pre-industrial), so as to capture most of the scenario variations and their impacts in 2040. Given that the UNEP FI Phase I Excel methodology is limited in providing the impact on revenues and costs (COGS) changes, we approximated the internal rating system to analyze the change in PDs. Despite these limitations the observed results appear reasonable and, also depending on the severity of the scenario considered, in the order of 1 notch downgrade for the energy sector and 1–2 notches downgrades for the oil & gas sector.

Main challenges and next steps

As mentioned before, the simulation focused on a sample of exposures belonging to the energy and oil & gas sectors. Regarding the energy sector, the borrowers have been chosen considering main lending exposures of the Group; while for the oil & gas sector further considerations were made with the aim of diversifying as far as possible the counterparties in terms of sub-sector, geographic location and size of the counterparty. The selected counterparties represent around 25% of the total exposure of our group in the energy sector and 65% for the oil & gas sector. In terms of geographical presence, the selected counterparties are active worldwide.

Unfortunately, the lack of data related to country-level return period changes factors for each extreme event for all countries led to strong approximations. For this reason, the reliability of the results with respect to this part of the exercise is significantly affected.

For each borrower, the following fields have been populated with the aim of better identifying the borrower size, its credit quality and the relationship with the bank:

- basic financial data such as revenues and COGS (total operating costs in absence of the latter): specifically, last year and last 3 years average sourced from external provider (e.g. Bloomberg or Capital IQ);
- inclusion of individual assets (power plants) owned and utilized by borrowers, including the assets of their subsidiaries;
- credit exposure with the bank, information on risk-weighted assets (RWAs), exposures at default (EADs), internal and external rating-equivalent, probabilities of default (PDs) and losses given default (LGDs), sourced from our internal databases;
- plant geographical location – which required several estimates as detailed information was not provided by the companies. Where available the plant's location had been intended as location of production facilities and where not available revenues generation by geographical area, sourced from the companies' websites or public info provider (e.g.

Bloomberg or Capital IQ), had been used. In case of absence of public disclosure, the segment information (i.e. mostly revenues details) had been sourced from bank internal credit applications;
- where available, we used Bloomberg MAPS geospatial analytical technology to identify the location of each plant and to understand the climate-related risk factors for each asset. To add further granularity to the geographic location of companies' plants, although not always up to date, we cross-checked that information against borrowers' websites.

The asset production was fundamentally driven by the availability of the input data referring to the types of sub-sector provided by the tool. Therefore, the outcomes do not faithfully reflect the business activity of the counterparties. These considerations are valid both for the energy sector (for example, alongside thermal power generation, the only renewable source of energy considered by the tool was "hydropower") and for the oil & gas sector (where it was not possible to consider the "downstream" sub-sector, a significant portion of revenues for some counterparties). This obviously had substantial impacts on the final outcome of this exercise.

Furthermore, several sub-sectors (e.g. conventional / unconventional oil & gas) have not been used since it was not possible to find a clear definition and a specific reference in the public documents.

Another point of reflection concerns the granularity of the analysis. Due to the large amount of borrower sites and the lack of granularity of related site data, the exercise was carried out through aggregation of sites by geographical area, therefore the results of extreme events data portals are somewhat approximate.

Nevertheless, the results are extremely interesting and in line with the expected physical risk impacts. The methodology found a variation in the production capacity of the borrowers between 5% and 15% given the incremental climate change in the 2040s +2°C and +4°C scenarios, as compared with a present-day baseline. These changes had been then translated into PD changes by utilizing internal methodologies and obtaining substantial impacts on the creditworthiness of the borrowers. The final impacts could be summarized as follows:

- energy sector: invariant or 1 notch downgrade, depending on geospatial location of the plants, initial rating of the borrowers and the severity of the scenarios;
- oil & gas sector: 1 or 2 notches downgrades, considering the general critical issues of this specific business as well as the above factors.

As a final remark, Intesa Sanpaolo Group believes that further developments and a wide and accurate application of these methodologies cannot be reached without a more comprehensive set of metrics and instruments for granular analyses, in line with regulatory recommendations. This coincides with the recent European Central Bank (ECB) expectations[47] for a holistic approach in the climate and environmental fields to promote a general adoption by banks of these arguments. It follows that methodologies, platforms and datasets will need to evolve and to be aligned with upcoming regulation and disclosure requirements.

Lloyds Banking Group case study: Applying the Phase I Excel tools on real estate and agriculture

Lessons learned from applying the Phase I Excel tools

We applied the Phase I methodologies on Real Estate (extreme event) and Agriculture (incremental change only). We also took the initiative to source scenario data which are more relevant to the UK where a significant proportion of our exposures are held, as the country-scale and regional-scale scenarios provided by the Excel tools were considered too broad to provide tangible outputs for our UK portfolio. In the process, these are the learning points:

- Improvements in the quality of internal and external datasets are required to support the ongoing climate risk activities that will underpin the TCFD activity and the broader climate risk challenge.
- As we are a UK-focused bank, we need to be able to build consistent climate change scenarios that are relevant to the UK.

Teams involved from the bank

The following teams and staff were involved:

- Risk who own the asset/collateral data for the Real Estate portfolio and the client risk data,
- Data analysts to process both the asset data and the scenario data,
- Quantitative analysts to build the model based on the Phase I methodologies,
- Weather modeling subject matter experts (SMEs) for extreme event analysis,
- Group Sustainability to coordinate the work.

Challenges identified and how they were overcome

Some of the challenges include:

- Availability of granular data e.g. flood probabilities at given properties,
- Limited in-house geographical information system (GIS) capability.
- Difficulty in identifying UK scenario data at a granular level,
- Scenarios for extreme events differ from scenarios for incremental change and so there is a disconnect,
- Complexities in mapping the internal data to the external data.

We cleansed the internal data and used postcode-level data to match to the external data. For this exercise we accepted the disconnect in the scenarios we used. We used databases and coded the methodology to allow for a more efficient calculation.

We also face challenges in translating the impact of extreme events and incremental change on our portfolio in our PD models. This is an active area of work in Risk.

Next steps

The initial findings have allowed us to understand which of our assets are at risk. We are working to translate these findings into inputs of our Probability of Default models for stress testing. We are also working to formulate a consistent set of climate change scenarios relevant to our portfolio in the UK.

NatWest Group case study: Assessment of flood risk to a sample of UK residential mortgages

Background

On February 14th, 2020 NatWest Group announced it was becoming a purpose-led bank. Three key areas were identified where we believe our business and role in society means we can make a meaningful contribution (Figure 4.3). One of these areas is to be a leading bank in the UK & Republic of Ireland (RoI) helping to address the climate challenge – in line with UN Sustainable Development Goals 13 and 7. Listening, engaging and partnering with stakeholders including UNEP FI helps us to address our business impacts and improve outcomes for communities, customers and the environment (SDG 17).

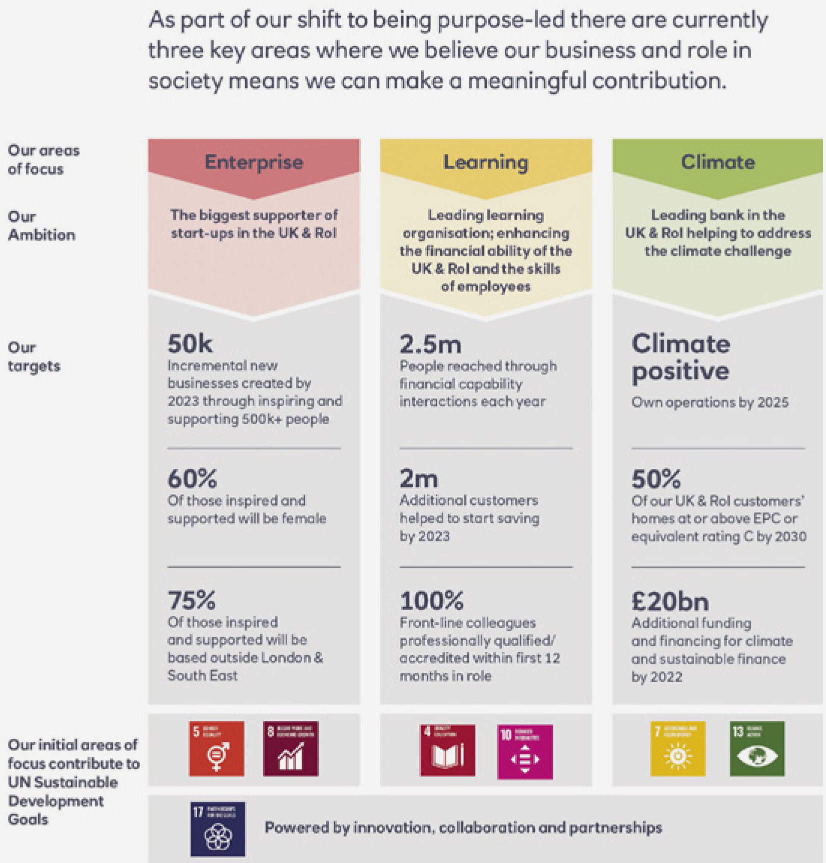


Figure 4.3: As part of our shift to being purpose-led there are three key areas where we believe our business and role in society means we can make a meaningful contribution. Source: RBS Group, 2019.[48]

Introduction

One of the projects NatWest Group (NWG) participated in as part of the UNEP FI pilot was focused on physical risk. This was to undertake an exploratory climate scenario analysis on part of the residential mortgage portfolio, using the methodology developed by UNEP FI and Acclimatise during the Phase I pilot. Conducting this analysis on a large sample of residential mortgages contributed to the aims of the pilot.

This case study complemented work NWG had already undertaken with a consortium of partners led by D-Risk Group Ltd and Airbus Defence and Space supported by CLS Data. NWG piloted Airbus' Geospatial Financial Hub (GFH). The GFH maps flood risk against residential properties in the UK using JBA Risk Management Flood Map. This was used to help determine the current level of flood risk to a property.

Figure 4.4 provides an illustrative example of the data available for flood risk assessment for properties in an area. We are committed to the ongoing use of the best performing and most reliable data and innovative climate risk tools as skills and knowledge in the climate space evolve. Collaborative work including the UNEP FI pilot has and continues to help drive this evolution in skills and knowledge.

Figure 4.4: Flood Risk Map. This image shows the varying degrees of river flood risk with the darker blue colours showing greater depth of flooding for an event with a 1.3% annual probability of occurring (1 in 75 years). © Ordnance Survey & © JBA Risk Management Ltd.

Scope of analysis

Flooding types analysed included surface water, river, and coastal flooding across the range of scenarios provided by UNEP FI and Acclimatise. Over 900,000 property loans from the UK mainland were assessed as part of the case study. The majority of properties in the initial sample of 900,000 will not be impacted in the scenarios, because they are not at risk or have adequate existing flood defences to mitigate the increased risk of flooding when using this model. Properties most exposed to flooding risk were identified and represented under 3% of the loans initially assessed. Climate scenario analysis was undertaken on this small subset of properties most exposed to flooding risk.

Data and tools

Present-day flood risk

Part of the pilot project is to investigate the use of climate tools and data sources. To help establish the current flood risk to properties in the UK we were able to use the JBA flooding scores. The JBA flood score is at property level and considers a number of factors including the elevation of the property. JBA data also combine the risks from several types of flooding, for instance a 1 in 75-year chance (return period) of a coastal flood and a 1 in 38-year chance of a river flood both contribute to the overall JBA flood score. For this project the property flood score had to be translated into a return period. Currently only the scores attributed to individual flood risk types can be translated into return periods. Therefore, flooding risks from river, coastal and surface water were assessed as standalone events. Only the highest risk event per property was taken forward for the climate scenario analysis with the others disregarded.

Climate scenarios

The analysis was conducted on a small subset of properties, under 3% of the initial sample, most exposed to flooding risk. The analysis assessed the flood risks to properties now and in the future when global temperatures and the risk of flooding are projected to increase due to climate change.

Two climate scenarios (2°C and 4°C global average temperature increases by 2100 relative to pre-industrial) and two time periods (2020's and 2040's) were considered. For each climate scenario and time period, changes in flood frequency were provided in the UNEP FI Phase I tool, based on UK-average changes in future flood frequency, and more 'precautionary' data for the within-country 90^{th} percentile of changes (i.e. changes in future flood frequency for specific locations within the UK projected to experience the 90^{th} percentile changes):

1. Standard scenarios (UK-average changes in flood frequency):
   - 2020's, 2°C & 4°C
   - 2040's, 4°C
2. Precautionary scenarios (90^{th} percentile changes):
   - 2020's, 2°C & 4°C
   - 2040's, 4°C.

In the 2020's, increased flood risk to properties due to climate change is estimated to be the same for a global mean temperature rise scenario of 2°C and 4°C by 2100. This is because of inertia in the climate system, whereby changes in the 2020's are already built in. When the analysis looks forward to the 2040's the differences between the 2°C and 4°C scenarios are visible, though our assessment only considered the 4°C scenario as a worse-case.

The UNEP FI / Acclimatise Phase I Excel model draws on data from a recent global assessment of future changes in flood risk.[49] However, these data do not account for construction of future flood defences and finer-scale models of future flood risk would provide more precise data for locations within the UK.

The modeling tool estimated increases in the property Loan to Value (LTV) ratio due to a reduction in property value for those properties experiencing an increase in flood risk under climate change scenarios.

Results – for a small subset of properties most exposed to flooding risk

Figure 4.5 shows the distribution of properties in the analysed subset by LTV. Over time, and in more severe scenarios, the proportion of properties with LTV above 80% increases. In the precautionary 4°C scenario in the 2040's, the proportion of such properties more than doubles to 18%, from the current level of 8%.

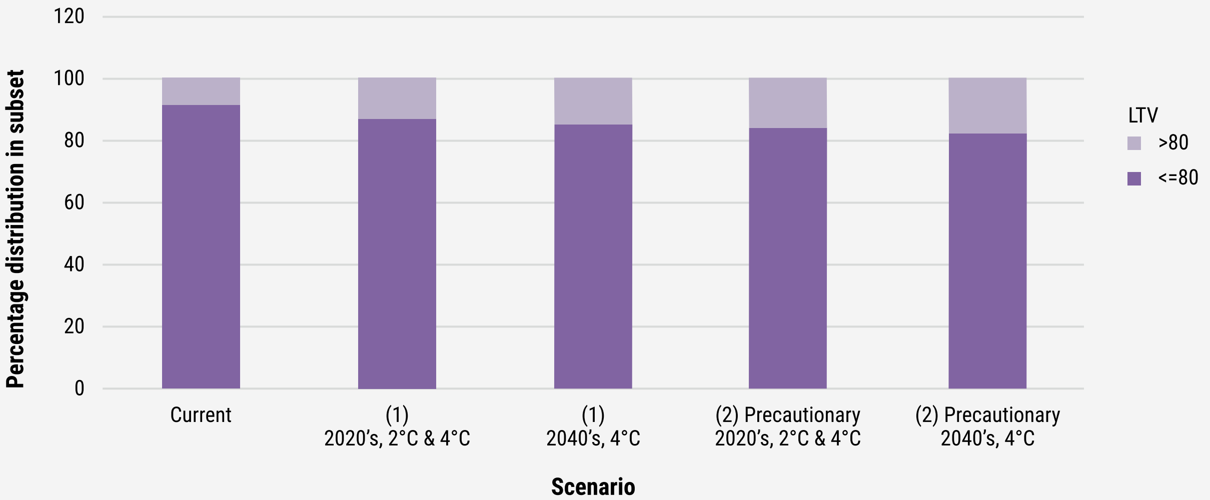


Figure 4.5: Proportion of properties in the analyzed subset with LTV ratios above and below 80% under different climate scenarios and time periods

The variation in LTV impact across different scenarios and time periods demonstrates that there is scope for impacts caused by climate change to be reduced if measures are taken rapidly to reduce global greenhouse gas emissions and limit warming to well below 2°C.

The pilot project required collaborative working and teams from across the bank were involved including data, credit risk, sustainable banking, strategy and financial risk analysts. We are sharing the detailed results of the project internally. The UNEP FI pilot will be used to help inform benchmarking of our internal models in preparation for the Bank of England Biennial Exploratory Scenario (BES) on climate risk. The BES seeks to explore the financial risks posed by climate change. It will test the resilience of the current business models of the largest banks, insurers and the financial system to climate related risks and therefore the scale of adjustment that will need to be undertaken in coming decades for the system to remain resilient.

These results will also help to inform our wider ongoing work on climate risk, as well as future climate scenario analysis. NatWest Group would like to extend our thanks to all Peer Banks involved in the pilot, UNEP FI and Acclimatise, as we continue partnerships to take action on climate.

Santander Group case study:
Tools for assessment of financial risk

Aspects of physical risk analytics which we consider are more important for credit risk assessments

The definition of a clear and comprehensive framework for the calculation of potential financial impacts arising from climate change is the basis for a good risk assessment. The details of scenarios (coverage, time horizons and hazards), risk analysis methods, as well as inputs and outputs obtained from the external tools available help us compare the functionalities of different providers related to the key general aspects of risk assessment. The "Overview of physical climate risk assessment tools and analytics" (Table 4.1) is a good example of the work done by Acclimatise, as it allows us to quickly understand the differences between providers.

In order to obtain the maximum benefit of the analysis, as a first step in the assessment of any external tool we must consider the content of scenarios, the hazards covered and the granularity by geography and sectors that determine the capacity of the tool to assess the physical risk in our portfolios. One of the characteristics of Santander Group is the diversity in geographies and businesses that translates into a very stable financial performance in stress test exercises. This strategic characteristic must be reflected in our data and models, so the tool has to be sufficiently granular to capture with the highest precision the differences of the hazards in each geography. Other aspects such as time horizons are also relevant as we would like to use the same tool for business management, to run scenario analysis and for regulatory purposes in stress test exercises, where the time horizons are different.

The second step in the review of the external tools involves evaluating the methods and approaches they use for impact assessment. Versatility is very important to adapt the specificities of portfolios by sensitivity or vulnerability factors. Impact channels need to be wide to reflect also possible impacts on productivity and inefficiencies that may occur due to incremental changes in climate and acute physical events that bring financial impacts of loss and damage, and which, in turn, may translate into losses in the assets' values. The final purpose should be that these external tools be used to support internal calculations of quantitative impacts on loan to values, probabilities of default and loss given defaults.

A semi-quantitative assessment, such as the use of heat maps, sensitivity factors and other indicators are essential as intermediate steps in the process to assess and manage physical risks, and the right approach to understand a clients' strategy to adapt their businesses to the transition, although they are not enough to obtain advanced data on financial impacts. In our opinion, climate risks have to be measurable and need to be embedded in our procedures to obtain credit risk metrics which incorporate climate-related events.

Challenges identified internally on progressing physical risk assessments, and how commercially-available physical risk assessment tools can help to address these

The main challenge to address is the information on scenarios and companies. A global framework that establishes the basis and the references to contrast events, effects and impacts would be desirable. The industry is advancing little by little and setting out its requirements, and UNEP FI is helping the Banks to set general definitions. However regulators are demanding more effort to analyse impacts and results to include as prudential requirements. There is a misalignment between the requirements and the advances in physical risk analytics.

Physical risk analytics are not homogenous between vendors even for listed companies, while there are particular challenges in assessing physical risks for SMEs due to a lack of data on those companies. Scenarios are not granular enough and not all the hazards are integrated. Overall, there is still a lot of room for improvement in the information area. Key areas of improvement we would wish to see from physical risk analytical tools include greater flexibility, accuracy and easy management of massive volumes of information (e.g. retail mortgages).

Standard Bank

The Standard Bank Group case study: Tools for Physical Climate Risk Assessment

A. Standard Bank's reflections on physical risk assessment tools

Bank's risk management and reporting requirements

As part of the Phase II pilot program, the Standard Bank Group ('SBG' or 'the bank') trialled a number of different physical climate risk assessment tools, to determine their potential suitability for meeting the bank's TCFD disclosure requirements as well as for ongoing portfolio analysis and stress testing. All tools reviewed were subjected to an internal qualitative rating for their potential fit with the bank's requirements, with the result that a ranking schedule of all tools assessed was produced for internal use.

In evaluating the range of tools, SBG applied a number of key considerations in arriving at an objective rating of each tool's functionality and appropriateness, including data rules, African coverage, and whether each tool was portfolio or transactional risk focused. Being a multi-national African-based group with a lending footprint spread across multiple geographies, industries, sectors, listed and unlisted counterparties, and a range of lending and investing products, the right tool needs to cater for as much of this diversity as is possible.

Portfolio and transactional tools

The bank's trials highlighted the important distinction that tools make between whether they are designed for portfolio and/or transactional risk assessments. The former are better suited to drive concentration risk analyses, vulnerable sector stress tests and disclosable metrics quantifications, while the latter were felt to be more suited to deal-screening at pre-credit or origination stage. For purposes of achieving a level of alignment with the Recommendations of the TCFD, the bank applied higher internal assessment ratings to tools that delivered a portfolio measurement result, such as a drought risk indicator for a portfolio of exposures for example. The potential for transaction-specific tools that make use of the updated climate scenarios that are in general use, being applied within a wider ESG-ratings framework for evaluating new and existing lending transactions, was however also recognised but not accorded the same value-ratings.

Sector classifications and instrument types

The importance of having a clearly delineated classification of exposures into recognisable and standardised sectors and sub-sectors, was highlighted in the testing the bank performed. The use of global sector codes such as International Standard Industrial Classification (ISICs) to identify sector sources of risk, is widely used in the financial services industry. In arriving at physical risk metrics such as for example drought or flood sensitivity ratings, SBG's trials revealed that some tools rely directly on the industry classifications applied by the bank - for example the tool ingests client data that is already classified by sector – while others require exposures to be inputted with a code such as an International Securities Identification Number (ISIN) or a ticker which the tool matches to other ratings databases in order to assign a physical risk factor. Furthermore, in some cases the latter type of model was found to be limited in terms of the type of security (loan, bond, etc) issued, resulting in instruments such as advances to unlisted entities for example not being able to be rated. Accordingly, SBG internally assigned higher value-ratings to those tools which allowed a measure of flexibility in terms of the input data required of them, with a greater preference for those that allowed for own sector classification to be applied, rather than reliance on securities codes such as tickers.

Data requirements and confidentiality compliance standards

In addition to the exposure identification data requirements highlighted above, many of the physical risk tools reviewed relied on detailed locational (spatial) data such as latitude and longitude co-ordinates identifying the exact site of the asset (for example property funded at the coast in an area expected to be exposed to greater risk of rising sea levels). It stands to reason that the more specific the locational data inputted to the model, the more refined the result. However, on internal review of the bank's customer data, challenges were found not only in sourcing this level (e.g. geolocation fields) of data, but also in some cases the question of confidentiality in terms of client approval to use the data in an externally housed application. The trials therefore revealed the practical challenge of ensuring internal compliance clearance on the use of customer data by third-parties. Those tools that offered the capability for uploading bank-owned client-data (including loan balances, exposures, asset locations, etc.) onto the platform for analysis and dashboard reporting, were rated as being of more value than those tools that required the bank to submit data for external analysis. Balancing an appropriate mix between the need to have rich

data for accurate model results with requirements to maintain high standards of customer compliance is a challenge faced by this bank and likely by others.

Africa coverage

Being a large multi-national financial services group with an extensive African footprint, the ability to measure physical risks from climate change across a spread of different geographies is an important criterion. Stemming, it would seem, from a shortage of current and credible scientific data on variables such as forecasts of extreme weather scenarios for parts of the African continent, the trials conducted revealed that some physical risk models did not provide adequate African coverage to yield meaningful group portfolio scores. The potential to extrapolate existing data or supplement these gaps with scientific data sourced locally was considered, and could be a temporary solution for tools that allow for such manipulations, until tool providers are able to offer wider coverage for African assets and exposures.

B. Standard Bank's reflections on using the UNEP FI Phase I Excel tools

Case study - Agriculture

Understanding group sector exposure

In testing the physical risk methodology shared on the pilot program, a clear understanding of what component sub-sectors and industries made up the agricultural sector was required. The widespread use of industry sector codes (such as ISICs and regional equivalents thereof) was used to isolate primary agriculture producers (i.e. farmers and other prime source producers), as distinct from agriculture commodity traders, secondary marketers, post-production agri-traders and other intermediary parties for which physical risk measurement would not have yielded meaningful results.

A recent deep drill of agriculture exposures across regions, products, sub-sectors and customers proved useful in identifying areas of primary agriculture exposure, as well as those in areas more obviously prone to physical risks such as drought. The deep drill revealed that the Agriculture and Forestry sector makes up 4% of the group's credit exposures, with the sugar sub-sector contributing the highest concentration of that (around 18%).

Physical risk heatmapping

The physical risk qualitative heat map exercise, performed for the primary producer (farmer) exposures in the business and commercial banking segment only, provided a sense of where the portfolio vulnerabilities to key indicators such as natural resources and market demand might lie. Other than as background context to potential portfolio vulnerabilities, the heatmap was not relied on for the purposes of this exercise. Going forward however, once the portfolio has been heat-mapped at an appropriate sector level, the intention will be to utilise these maps for more targeted scenario testing, including for incremental and extreme events physical risk testing.

Sample selection

Based then partly on the portfolio deep drill and mainly on professional judgment, a small (time and resource limitations notwithstanding) sample of exposures was selected for testing. The sample concentrated on the sugar sub-sector (including cane growing, sugar milling and refining and animal feeds, as well as some starch sub-sector and agri production property exposure). The sector was selected due to its material contribution to the group agriculture portfolio as measured by total aggregate exposures, as well because the largest single name agriculture obligors are entities in this sub-sector. Geographically the test included agricultural revenues earned in six different Southern African countries, which satisfied the tool's requirements for understanding the spatial scale for the analysis (country and region). Going forward, samples tested will be from a wider range of sub-sectors and will include livestock farming, which was not tested in this round.

Scenario testing

The scenario testing focused primarily on assessing sensitivities for incremental changes in climate risk, rather than for extreme event vulnerabilities. Latest financial results were sourced from the bank's credit division records and segmental financial information such as revenue and cost of goods sold reported by geography and product type, were extracted. The incremental module of the physical risk tool tests for changes in production output and price under two different warming scenarios (2°C and 4°C) and over two different time horizons (2020s and 2040s). Minimum and maximum production ranges under each scenario were produced for all of the geographic regions covered in the sample tested. Across all warming scenarios and time horizons as well as all regions, the results yielded an interesting range of potential changes in production output and price variations. It was noted however that in terms of additional testing, a noteworthy challenge will be the sourcing of reliable price and yield data for specific crops in a particular region, particularly for the sub-Saharan African region. The tool relies on finely calibrated inputs, such as region-specific crop yield data, as discussed further below.

Challenges encountered and steps taken to address

On quantification of the results of the test and conversion of the yield and price impacts into local currency, discussions in the team centred around whether or not the results reflected a material or significant enough deviation from current financial performance, to sufficiently highlight the potentially severe nature of the climate risk effects that were being modelled. Detailed calculations on translating sample results into portfolio impacts, including possible ratings changes, were not performed at this stage but will be done as the testing becomes embedded in ongoing risk management operations. Further work needs to be done on ensuring that the models are adequately calibrated for regional Africa-specific expectations for yield and price changes under various scenarios. Such recalibrations may indeed result in more significant financial deviations for the sample tested, and which on translation to an aggregate portfolio level may present a more material result that will make a meaningful impression on the strategic decision makers in the business.

Other challenges experienced included obtaining reliable Sub-Saharan African forecasts for changes in yield and price for the warming scenarios and time horizons required for the model. In terms of this exercise, yield and price detail for the sugar and the tobacco industries were the focus of the enquiry, however we believe that sourcing price and yield data for a wide range of crop types may be a notable challenge. The assistance of the bank's climate analyst was requested and further research and contact with UNEP FI's team yielded workable vari-

ables for both price and output. A potential weakness identified with the variables used is that spatially they were not granular enough to account for the quite different climatic conditions in, for example, the warmer and wetter eastern part of the continents, compared to the drier western sections. Likewise, in terms of identifying the precise location of assets (a key requirement for the model), we relied on additional tools (CMAP on Bloomberg) which revealed some useful information on exact location of assets such as plants. The tool was somewhat limited in that it didn't provide further detail on the extent of crop plantations for example, which may be needed for more precise measurement. Going forward, more accurate spatial forecasts that focus on regions and not just the continent as a whole, will be required to provide the level of precision that strategic decision-making will demand. This approach will also, by the way, be required in the preparation of portfolio heat maps that have qualitative ratings which allow for the distinct regional differences in climatic conditions across the continent.

Personnel involved

The prior-performed deep drill was produced by members of the bank's portfolio risk management and reporting team as well as group credit risk personnel, with further input provided by sector specialists (relationship managers and analysts) in corporate and business banking. The heatmapping was performed by an agribusiness specialist whose responsibilities include strategy and risk appetite setting for the agri sector. The Phase I physical risk testing on the sample of agri exposures was performed by an executive from the bank's portfolio risk management and reporting team, with additional research and input provided by the bank's own climate analyst whose speciality is 'weather, water and climate change' analytics.

Key takeaways and next steps

The exercise has provided valuable insight into the methodology adopted to identify areas of heightened sensitivity to physical risk. As a platform to upskilling team members who for the most part do not have a background in climate risk science, the application of the Phase I tool has facilitated meaningful thinking about such risks in a structured and logical manner. Notwithstanding the need to source reliable forward-looking yield and price data at a region- and crop- specific level, as well as credible spatial (location) data on production facilities, the intention will be to extend the testing performed in the Pilot phase to a wider sample across more sub-sectors and more geographies, and then importantly to start estimating portfolio impacts based on sample results obtained. Important too will be engagement with business and other stakeholders to start driving discussions on potential strategic decision-making informed by credible scenario testing, in addition to obtaining granular client information.

5. Physical risk correlation analysis of FI portfolios

A growing body of research shows that climate-related hazards such as floods, droughts, windstorms, and wildfires can impact bank portfolios via property values, farm revenues, loan delinquency rates, mortgage approval rates, and other indicators. Correlation analysis is an entry-level technique for finding potentially useful associations between climate hazard indices and financial information. As well as highlighting potential risks, correlation analysis may also reveal where resilience to climate hazards has been capitalized.

The UNEP FI TCFD banking pilot Phase I recognized the value of having a deeper understanding of observed relationships between loan performance metrics and climate-related events. Some Phase I banks reported that borrowers were already being affected by climate and weather events (e.g. impacts of floods on property values; impacts of droughts on agricultural borrowers). These effects provide early signals of a changing climate, and empirical evidence which may help to calibrate forward-looking physical climate risk assessments. They can also shed light on emerging opportunities for banks to support clients' adaptation needs.

This chapter describes the use of correlation analysis within a physical risk assessment of a bank's portfolio – a technique which can be applied to analyze these relationships. Correlation analysis uncovers patterns of behavior in pairs of data—such as between the value of a property and height above sea level. In this case, correlation analysis is used to explore associations in space. The technique can also reveal associations in time—such as between farm revenues and drought severity.

Care must be taken when interpreting the outcome of correlation analysis because results may be affected by various confounding factors that are unrelated to climate. Hence, correlation analysis should not be used uncritically.

5.1. Objectives

The objectives of the module on physical risk correlation analysis in Phase II were to:

1. Develop a workflow for correlation analysis and demonstration of climate impact detection using credible financial metrics for loan portfolios in the real estate and agriculture sectors.
2. Support banks in the application of the correlation analysis workflow to their own data and in the creation of pilot studies.
3. Discuss the underlying science, analytical approach, and practical application of the techniques with Phase II banks.

This chapter meets the above objective by providing an introduction to correlation analysis (Section 5.2) and summarizing key climate patterns that can have financial consequences for real estate and agriculture (Section 5.3). It then describes step-by-step activities (Section 5.4) with accompanying resources to guide banks through worked examples of correlation analysis. A recap of key ideas is given (Section 5.5) before a pilot study of property values before/after wildfire (Section 5.6) and an advanced statistical analysis of flood zoning on property prices (Section 5.7). Readers are advised that the narrative is necessarily quite technical in places, but key terms and concepts are defined in Box 5.1 from outset.

5.2. Correlation analysis

5.2.1. Purpose and terminology

The purpose of correlation analysis is to measure the strength of association between two continuous variables (e.g. farm loan delinquency rate versus drought severity). This helps to establish any connections between pairs of variables. The value of the correlation coefficient varies between +1 and –1. When the value is positive, both variables tend to rise or fall at the same time; when negative, one variable may be rising while the other is falling; when close to zero, there is no association. See Box 5.1 for a review of key terms and concepts used in correlation analysis.

Box 5.1: Key terms and concepts used in correlation analysis

Autocorrelation is the correlation between pairs of successive values in time (e.g. the temperature today depends a lot on the temperature yesterday) or in space (e.g. house prices are similar for neighboring properties).

Continuous variables can take any value between their lowest and highest amounts (e.g. property values in a neighborhood might range from $289,361 to $753,250, with values in between).

Correlation matrices are tables showing correlations among multiple pairs of matched variables.

Dependent variables are affected by the value of an ***independent variable*** (e.g. sheep farm revenues depend on rainfall).

Homogeneous data are typically gathered from the same sources and same sites, using the same techniques, so their properties remain constant in space and/or time.

Independent variables influence the value of a ***dependent variable*** and are assumed to be unaffected by other variables (e.g. rainfall affects sheep farm revenues).

Normally distributed data have most values clustered around the mean with a symmetrical tapering off on either side – the overall distribution of the data is 'bell-shaped' (e.g. air temperatures).

Ordinal variables describe a rank order or ordered category (e.g. "low", "medium" and "high" flood risk).

Outliers are data values which fall outside the expected range of behavior or are somewhat different to the rest of the data set (e.g. Figure 5.1b).

Pearson correlation coefficient (r value for short) is the most widely used correlation index and is derived from ***continuous variables***.

Scatterplots show pairs of data where the horizontal (x) axis is the ***independent variable*** and the vertical (y) axis is the ***dependent variable*** (e.g. Figure 5.1).

Significance level establishes whether the result of a correlation analysis is likely due to chance or to some variable of interest.

Spearman Rank correlation coefficient (rho value for short) uses ranked rather than ***continuous variables*** and should be used when data are not ***normally distributed*** or contain ***outliers***.

5.2.2. Key assumptions and concepts of correlation analysis

The following sections describe the key assumptions of correlation analysis and how these relate to the identification of potentially useful associations between climate risk indicators and financial information. This material is provided as an instructional guide to help avoid some of the most common pitfalls of correlation analysis.

5.2.2.1. Correlation does not imply causation

Correlation measures the strength of association between pairs of observations. Just because two variables behave in concert does not necessarily mean that there is a causal relationship between them. The correlation between ice cream sales and sunburn is a classic example of false causation that is due to the common dependency of both these variables on the amount of sunshine.

One way of avoiding the trap of false causation is to have a strong rationale (or hypothesis) for why two variables might be expected to correlate. For instance, before examining correlations between property values and site elevation, one might hypothesize that the altitude of a neighborhood is a useful proxy for flood risk – properties at greater elevations are less likely to be flooded and this is reflected by their values. In other words, properties at higher elevations are expected to have higher values.

5.2.2.2. Linearity of associations

The correlation coefficient is a measure of the linear association between two variables. If the data follow a curved pattern, the correlation coefficient will tend to underestimate the true strength of association between the variables (Figure 5.1a). Conversely, if the data contain an outlier, the correlation coefficient may overestimate the strength of the association which is otherwise weak (Figure 5.1b). The Pearson correlation is known to be neither robust to non-linearity nor resistant to outliers.[50] Visual inspection of scatterplots is an effective way of detecting both issues.

Transforming data by, for example, converting to logarithms or ranking values can improve linearity. Outliers can sometimes be problematic to detect and resolve. There is no rigid definition for 'outlier', but some define these as any value that is more than ±4 standard deviations from the mean. The presence of such values may suggest a need to consider other variables, or to check for data entry or measurement errors.[51] If the latter, it may be justifiable to correct or even omit the identified outlier(s) from the analysis.

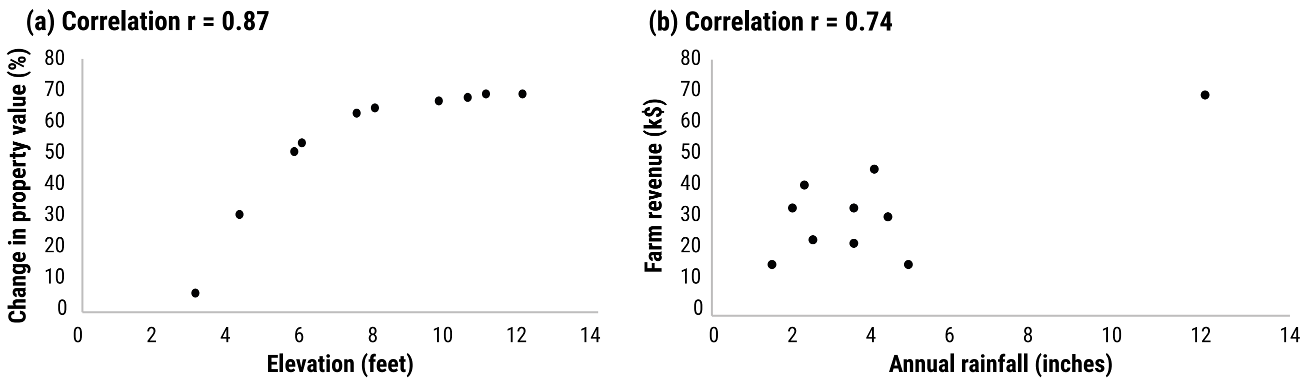


Figure 5.1: Scatterplots of artificial data where there is (a) underestimation of the association between variables due to non-linearity and (b) overestimation due to presence of a single, influential outlier. The Pearson correlation coefficient (r) is given for both.

Normally distributed data

The value of the correlation coefficient can be sensitive to non-normally distributed samples, thereby giving a false sense of the strength of the association between two variables. Logarithmic transformation is widely used to convert skewed data and/or samples containing outliers (Figure 5.2a) into a distribution that more closely approximates the 'bell shape' symmetry of the normal distribution (Figure 5.2b).[ab,52]

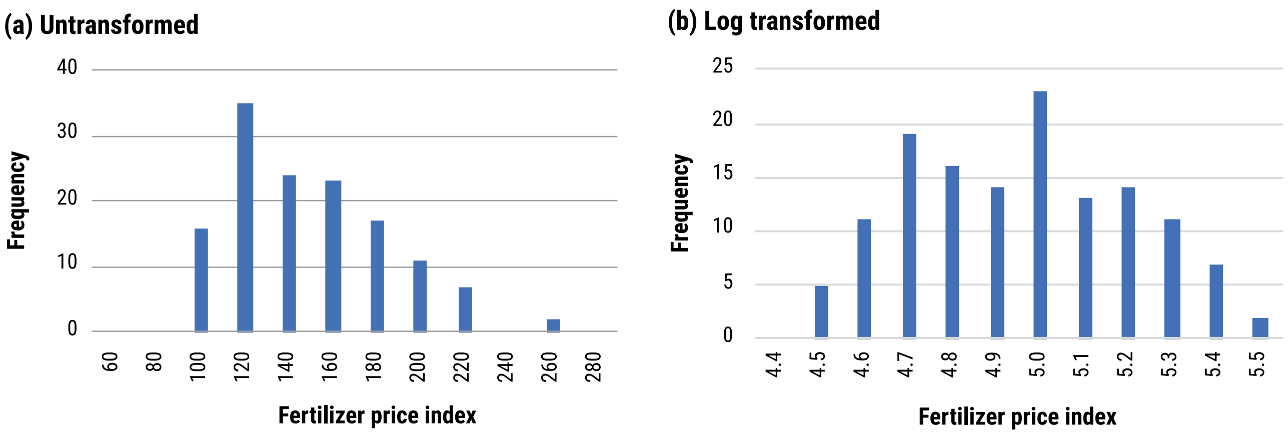


Figure 5.2: Frequency histograms for non-normal data (a) before and (b) after transformation.

5.2.2.3. Stationary data

Trends within data can increase the value of the correlation coefficient and potentially suggest false association between two variables. For example, a monthly agricultural commodity index might decline through time while a monthly climate index of regional floods and droughts (Niño4) rises over the same period, giving the false impression of a strong negative correlation (Figure 5.3a). However, after removing the long-term trend in both data sets, there is no correlation between the variables at the global scale (Figure 5.3b). This does exclude the possibility of correlations between these variables at regional scales (see below).

Data are stationary when there is no trend with time. The simplest way of detrending data is to take the difference between successive values and to use these in the correlation analysis. As in Figure 5.3b, it may sometimes be necessary to detrend both variables.

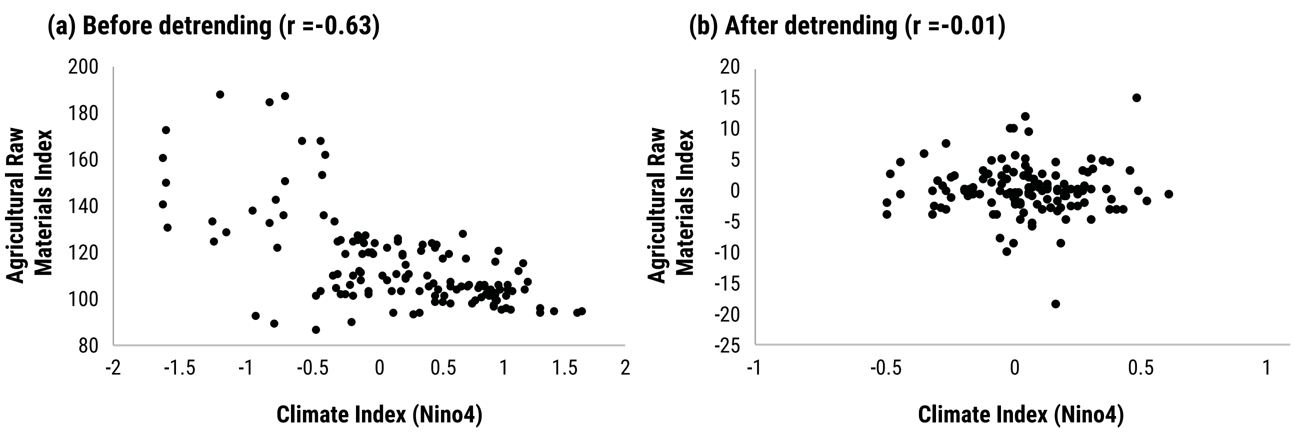


Figure 5.3: Scatterplots of data (a) before and (b) after detrending.

5.2.2.4. Significance of the correlation

The correlation coefficient (r) measures the strength and direction of the association between paired data (x and y variables). Sometimes the correlation can appear strong just by chance leading to false association. Significance testing is used to judge the likelihood of this type of error or to set a critical correlation value (r_{crit}).

ab The Box-Cox transformation can be used to convert most data to an approximately normal distribution.

Statistical significance depends on the value of the correlation and the sample size (Figure 5.4). Even weak correlations can be significant for large samples. For example, the critical value r_{crit} = 0.40 for a sample size of 20, but r_{crit} = 0.19 for a sample size of 100. When large numbers of repeat correlation tests (trials) are made there is a danger that an apparently significant correlation is found by chance (statisticians call this a Type I error). For example, if the significance level (Box 5.1) is set at 5% and 100 trials are performed on a data set, 5 of the correlation results would be expected to exceed r_{crit} just due to randomness. A Bonferroni correction[ac] is applied to protect against such Type I errors.

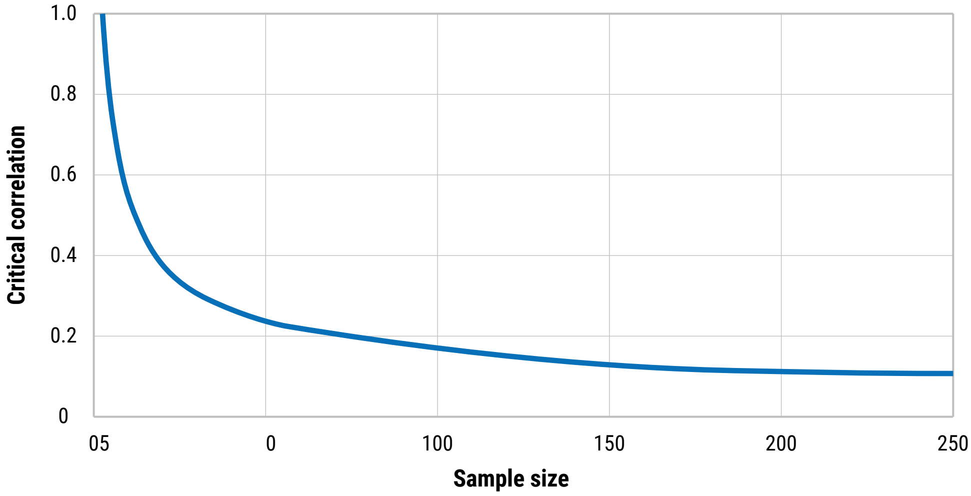


Figure 5.4: Critical correlation values r_{crit} for statistical significance at the 5% level. At this level, there is a 5 in 100 chance that the result occurred by chance.

5.3. Modes of climate variability with impacts on real estate and agriculture

This section explains how global weather patterns can be correlated with regional and local impacts on real estate and agriculture. Here, the assumption is that recurrent patterns of atmospheric pressure and/or ocean temperatures are linked to recurrent patterns of weather extremes (e.g. floods and droughts) and associated socio-economic impacts. Examples are given of most commonly associated global weather patterns (called 'climate modes') and financial indicators.

5.3.1. Impacts on real estate and agriculture

Large-scale patterns of climate variability interact with local physical and socio-economic factors and can have financial consequences for real estate and agriculture. Table 5.1 provides a summary of typical predictor variables and financial indicators based on a review of more than 50 studies within the real estate and agricultural sectors. Further details of these studies are provided in Appendix A (real estate) and Appendix B (agriculture). Whereas correlation analysis might relate a single climate index (e.g. ENSO, see Table 5.2) to a single impact metric (e.g. detrended crop yields), multivariate techniques are capable of also representing a host of non-climatic factors (e.g. farm and farmer characteristics). This enables evaluation of the relative weight of climatic and non-climatic factors, for example, in determining loan delinquency rates or changes in property values (see section 5.7).

ac In this case, the Bonferroni correction would change the 5% significance level to 0.05% for each trial, making it much harder to find a false correlation for individual tests, but 5% chance overall from 100 trials.

Table 5.1: Examples of predictor variables and financial indicators used to evaluate physical climate risks in the real estate and agricultural sectors.

Sector	Predictor variables	Financial indicators
Real estate	▪ Buyer and seller characteristics ▪ Local amenities and economy ▪ Property characteristics (e.g. age, tenure, type) ▪ Property location and elevation (relative to hazards) ▪ Weather (indices, mean climate, and extremes)	▪ Delinquency rate ▪ Loan denial rate ▪ Mortgage approval rate ▪ Property and/or rent values ▪ Value exposed and/or cost of hazards
Agriculture	▪ Farm characteristics (e.g. size, soils, water use) ▪ Farmer characteristics (e.g. age, education, gender) ▪ Loans (e.g. amount, interest rate, term, type) ▪ Risk management measures (e.g. irrigation system) ▪ Weather (indices, mean climate, and extremes)	▪ Crop area, yield, and value ▪ Delinquency rate ▪ Economic risk profile ▪ Likelihood of managing financial risk ▪ Net revenue

When undertaking a multivariate analysis of climate and non-climate risks it is important to be transparent about the choice of statistical method, independent and dependent variables. Transparency about methods, assumptions and data builds confidence in the weight attached to identified physical risks, as well as in the effectiveness of any risk management measures.

5.3.2. Climate modes

Large-scale modes of climate variability, or 'climate modes', are recurrent patterns of sea surface temperatures (SSTs) and linked weather patterns with profound regional, even global impacts. The El Niño-Southern Oscillation (ENSO) is perhaps the best-known index. When the central Pacific Ocean is warmer than average in winter (called an El Niño event), there are typically droughts in NE Brazil, SE Asia and Australia; when the same region of the Pacific is cooler than average (a La Niña event), there can be heavy rainfall and flooding in the same regions (Figure 5.5).

Table 5.2: Most influential global and regional climate patterns. Source: Wilby et al., 2017.[53]

Climate mode	Definition	Periodicity (years)
Arctic Oscillation (AO)	Oscillation in surface atmospheric pressure gradients and associated speed of the upper westerly vortex around the North Pole.	0.5–3
Atlantic Multi-decadal Oscillation (AMO)	A coherent pattern of variability in sea surface temperatures (SSTs) across the North Atlantic basin.	60–80
El Niño-Southern Oscillation (ENSO)	Variations in the state of the ocean-atmosphere system in the Pacific equatorial region, manifested by warm (El Niño) and cold (La Niña) surface water temperature phases.	2–7
Indian Ocean Dipole (IOD)	Variation in SSTs across the Indian Ocean. During positive phases SSTs in the western Indian Ocean are above average but the eastern Indian ocean is cooler than average. During negative phases, the opposite conditions apply.	1.5–10
North Atlantic Oscillation (NAO)	Variation in the state of the ocean-atmosphere system in the North Atlantic. During positive phases there are large pressure differences between the Azores High and the Atlantic Low near Iceland with strong westerly winds and flow of the Gulf Stream. During negative phases, the opposite conditions apply.	5–8
Pacific Decadal Oscillation (PDO)	Variation in SSTs in the North Pacific manifest positive phases when waters are anomalously warm along the Pacific coast yet cold in the North Pacific. During negative phases, the opposite conditions apply.	20–30

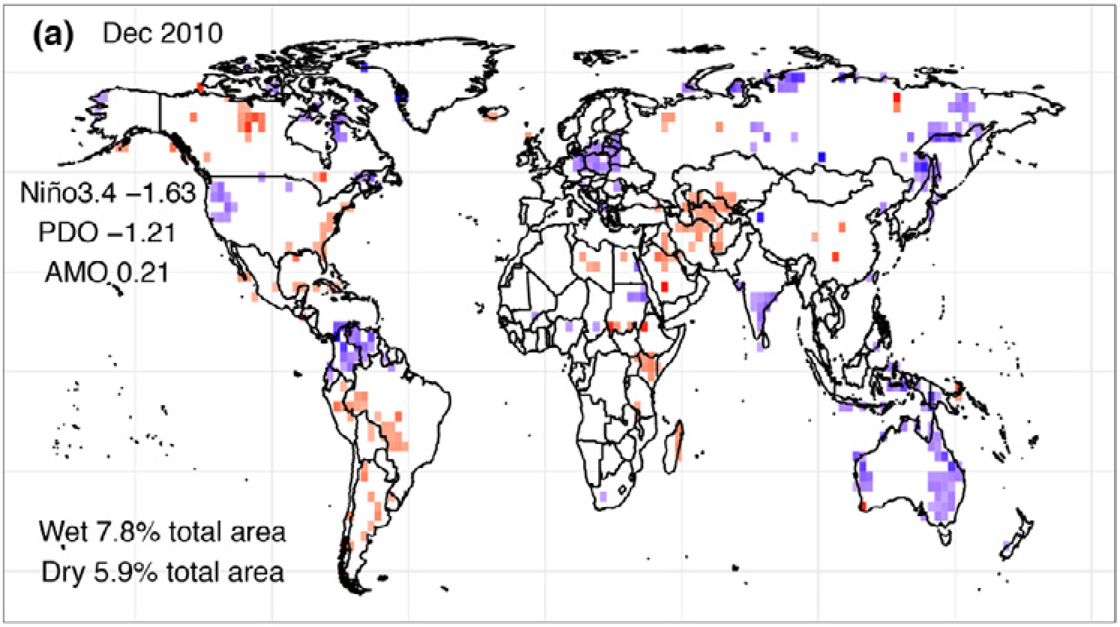


Figure 5.5: Regions with above and below average rainfall during a strong La Niña event. Source: De Luca et al., 2020.[54]

Other climate modes with global consequences for weather extremes include the Pacific Decadal Oscillation (PDO) and the Atlantic Meridional Oscillation (AMO) (Figure 5.6). For instance, when the PDO is positive, large parts of sub-Saharan Africa, Central and East Asia tend to be drier than average. Positive AMO brings wetter than average weather over much of the northern hemisphere and the tropics. Climate modes such as the North Atlantic Oscillation (NAO) are linked to warmer-wetter/cooler-drier winters across Europe,[55] North Africa and Central Asia. The Indian Ocean Dipole (IOD) affects the strength of monsoon over the Indian subcontinent[56] and when positive is associated with droughts in Indonesia and Australia, but higher than average rainfall across East Africa.

Some modes are known to act in combination (such as ENSO with PDO, or ENSO with IOD), further amplifying regional weather extremes and impacts.[57,58]

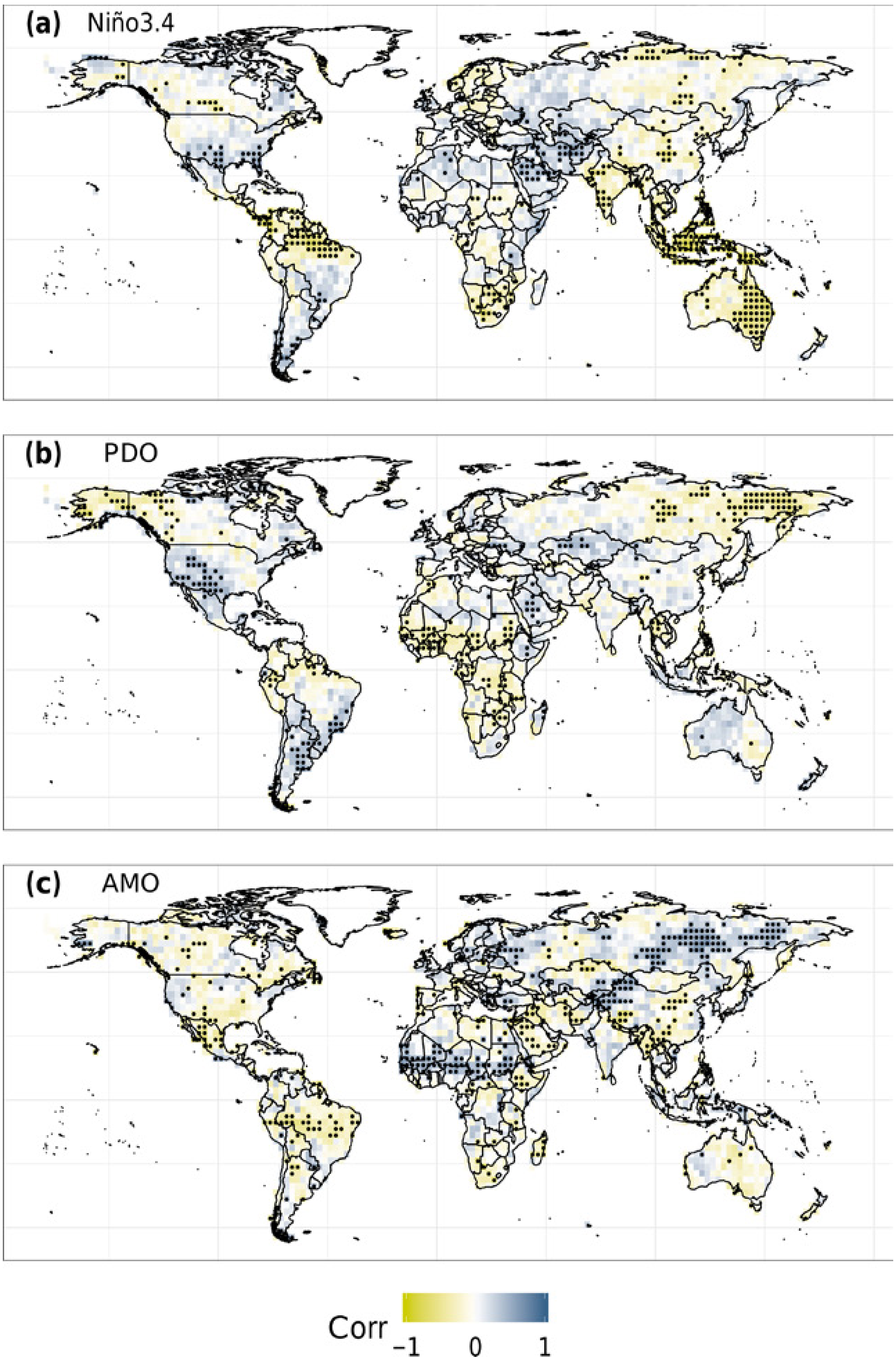


Figure 5.6: Correlations between monthly wet and dry hydrological extremes and (a) ENSO (Niño3.4), (b) PDO, and (c) AMO. Correlations significant at the 5% level are stippled. Source: De Luca et al., 2020.[5]

5.4. Worked example of correlation analysis

A step-by-step process was developed to guide the Phase II Banks through a correlation analysis. This is provided to help institutions undertake their own correlation analysis with in-house data. The worked example uses actual property values for an anonymized coastal city and its neighborhoods in the US.

The aim of this illustrative exercise is to uncover changes in house value with elevation (a proxy for flood risk) using correlation analysis. The results reveal neighborhoods and types of house experiencing 'climate gentrification'. This term is used to describe the increase in real estate values in neighborhoods that are more resilient to climate-related threats such as stronger/more frequent hurricanes, rising sea levels, and expanding flood/wildfire zones.[59]

5.4.1. Step 1: Source data

Obtain climate hazard and other physical variables to bring alongside financial information. Here, the anonymized house value data cover the 10-year period April 2010 to March 2020, for the city, broken down by neighborhood and by house type. During this period there were two major hurricanes (September 2017 and October 2018). Home value, neighborhood elevation and hurricane data were obtained from three public sources:

- The Zillow Home Value Index (HVI),[60]
- A global elevation finder by address,[61]
- The NOAA Historical Hurricane Tracks - GIS Map Viewer (Figure 5.7).[62]

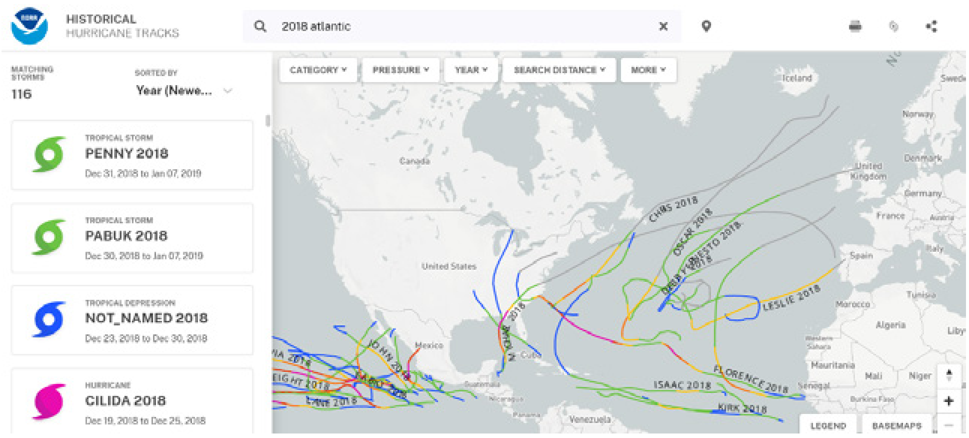


Figure 5.7: NOAA Historical Hurricane Tracks for the 2018 Atlantic season. Source: NOAA.[62]

5.4.2. Step 2: Prepare data

Gain a sense of the range of values and their variability to establish whether any data transformation or detrending is required. This can be achieved through visual inspection of the data, paying attention to any outliers, trends, or unusual patterns of behavior.

5.4.2.1. Visual inspection

Plot time series to reveal any significant variations in the data across space and/or through time. The demonstration data (Figure 5.8a) show neighborhoods with rising home values during the decade as well as some with declines in recent years (e.g. neighborhoods C, D, G, H and T). Correlation analysis will help to establish the extent to which these variations are associated with differences in elevation.

5.4.2.2. Detrend

Detrend data before undertaking correlation analysis, especially when there appears to be limited variation between successive months (i.e. data are autocorrelated). The simplest way of detrending is via the 'first difference' method. In the example, detrended values for each month are given by the HVI for the present month minus the HVI of the previous month (Figure 5.8b). Marked variations in detrended home values then emerge between the neighborhoods (Figure 5.8b). For instance, neighborhoods C (yellow line) and H (gray line) show greatest variability at the monthly scale. This suggests that home values in these neighborhoods are changing in a different way to the rest of the city (thick black line) and merit further investigation.

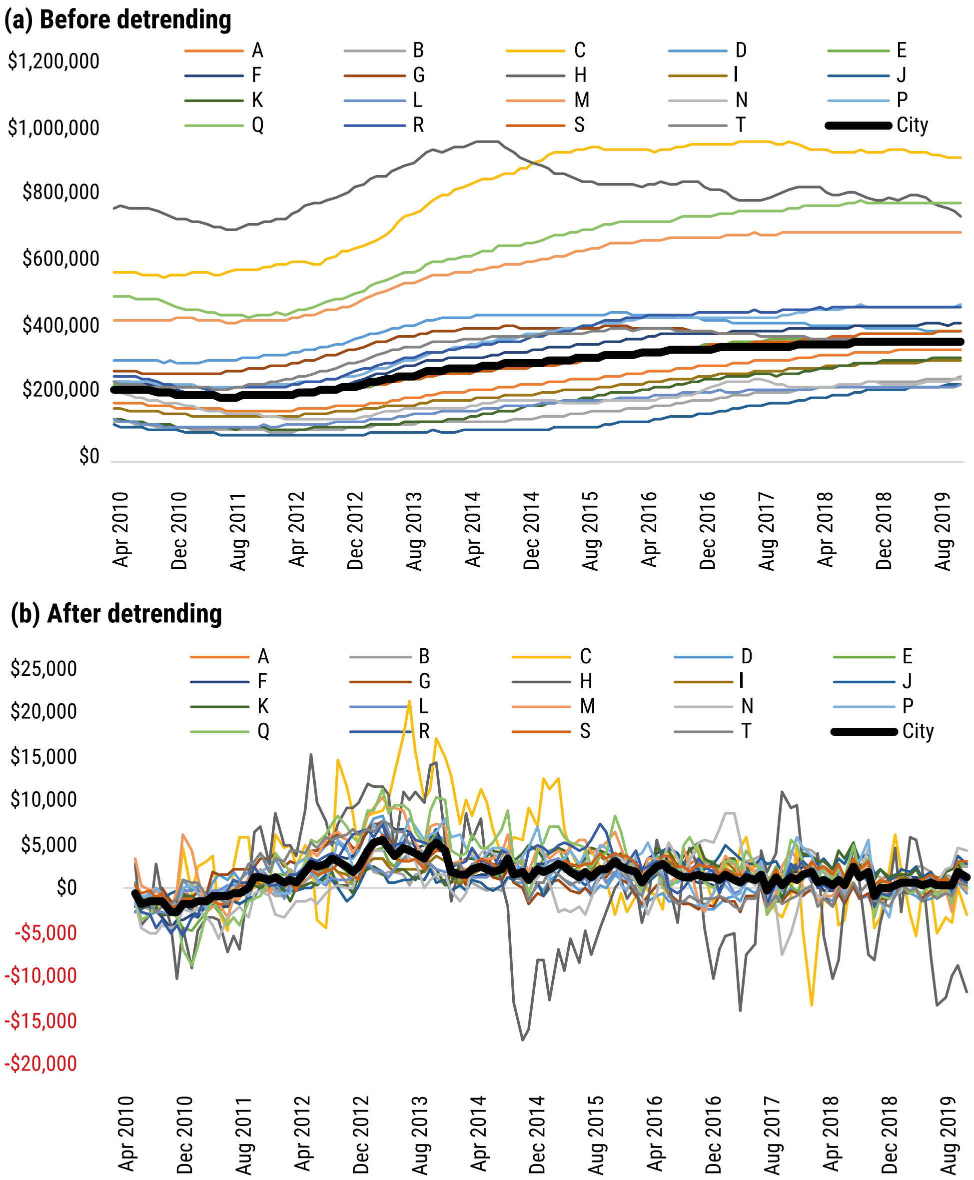


Figure 5.8: Variations in home value index by neighborhood (A to T) and through time (years 2010–2020) (a) before and (b) after detrending by the 'first difference' method.

5.4.3. Step 3: Correlate data in space

Produce a correlation matrix to show associations between more than one pair of matched variables. The matrix reveals those pairs of variables that are behaving similarly (positive correlation), independently of each other (zero correlation), or in opposite ways (negative correlation). Here, the correlation matrix is used to identify those neighborhoods where monthly home values are behaving differently to other areas of the city (Figure 5.9).

Neighborhood	City	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
City	1																				
A	0.83	1																			
B	0.51	0.69	1																		
C	0.56	0.35	0.00	1																	
D	0.69	0.27	-0.10	0.59	1																
E	0.88	0.84	0.61	0.42	0.37	1															
F	0.95	0.77	0.51	0.54	0.65	0.83	1														
G	0.66	0.20	-0.08	0.52	0.96	0.35	0.62	1													
H	0.50	0.23	-0.01	0.30	0.62	0.27	0.48	0.61	1												
I	0.84	0.90	0.72	0.28	0.27	0.85	0.77	0.26	0.24	1											
J	0.36	0.59	0.75	-0.22	-0.24	0.54	0.33	-0.23	-0.06	0.67	1										
K	0.54	0.73	0.74	0.14	-0.09	0.64	0.49	-0.10	-0.09	0.76	0.65	1									
L	0.77	0.77	0.61	0.49	0.37	0.69	0.73	0.38	0.24	0.73	0.37	0.64	1								
M	0.77	0.52	0.24	0.61	0.71	0.53	0.76	0.63	0.43	0.52	0.02	0.27	0.49	1							
N	0.54	0.56	0.53	0.22	0.10	0.59	0.48	0.11	-0.02	0.62	0.55	0.60	0.47	0.30	1						
O	0.68	0.58	0.26	0.54	0.52	0.60	0.59	0.53	0.28	0.53	0.10	0.35	0.62	0.59	0.20	1					
P	0.75	0.64	0.32	0.58	0.56	0.56	0.73	0.51	0.35	0.58	0.12	0.40	0.64	0.71	0.24	0.65	1				
Q	0.90	0.74	0.42	0.59	0.63	0.80	0.85	0.60	0.47	0.75	0.28	0.48	0.62	0.77	0.42	0.76	0.70	1			
R	0.87	0.70	0.49	0.55	0.58	0.74	0.86	0.57	0.36	0.75	0.21	0.55	0.72	0.69	0.39	0.64	0.74	0.82	1		
S	0.89	0.83	0.60	0.37	0.41	0.90	0.81	0.38	0.28	0.87	0.56	0.68	0.67	0.61	0.65	0.58	0.62	0.78	0.75	1	
T	0.74	0.32	0.06	0.57	0.90	0.45	0.71	0.93	0.59	0.35	-0.18	0.05	0.48	0.76	0.20	0.58	0.58	0.67	0.68	0.50	1

Figure 5.9: Correlation matrix for pairs of neighborhoods using detrended home values. Pink cells show the lowest 25% (weakest) correlations in the data, i.e. home values are behaving in a different way. The sample size is 119 for each correlation pair which means that *r* > 0.18 or *r* < -0.18 are significant (see Figure 5.4). Cells with bold borders are shown in the scatterplots of Figure 5.10.

Note from negative correlations those pairs of variables that change in opposite ways. Here, it is where home values are rising in one neighborhood while falling in another – possible evidence of gentrification. This is occurring in neighborhoods D (falling) and J (rising) where *r* = -0.24 (Figure 5.10a). Meanwhile, there is no association between the changes in home values for neighborhoods B and H (Figure 5.10b) where *r* = -0.01.

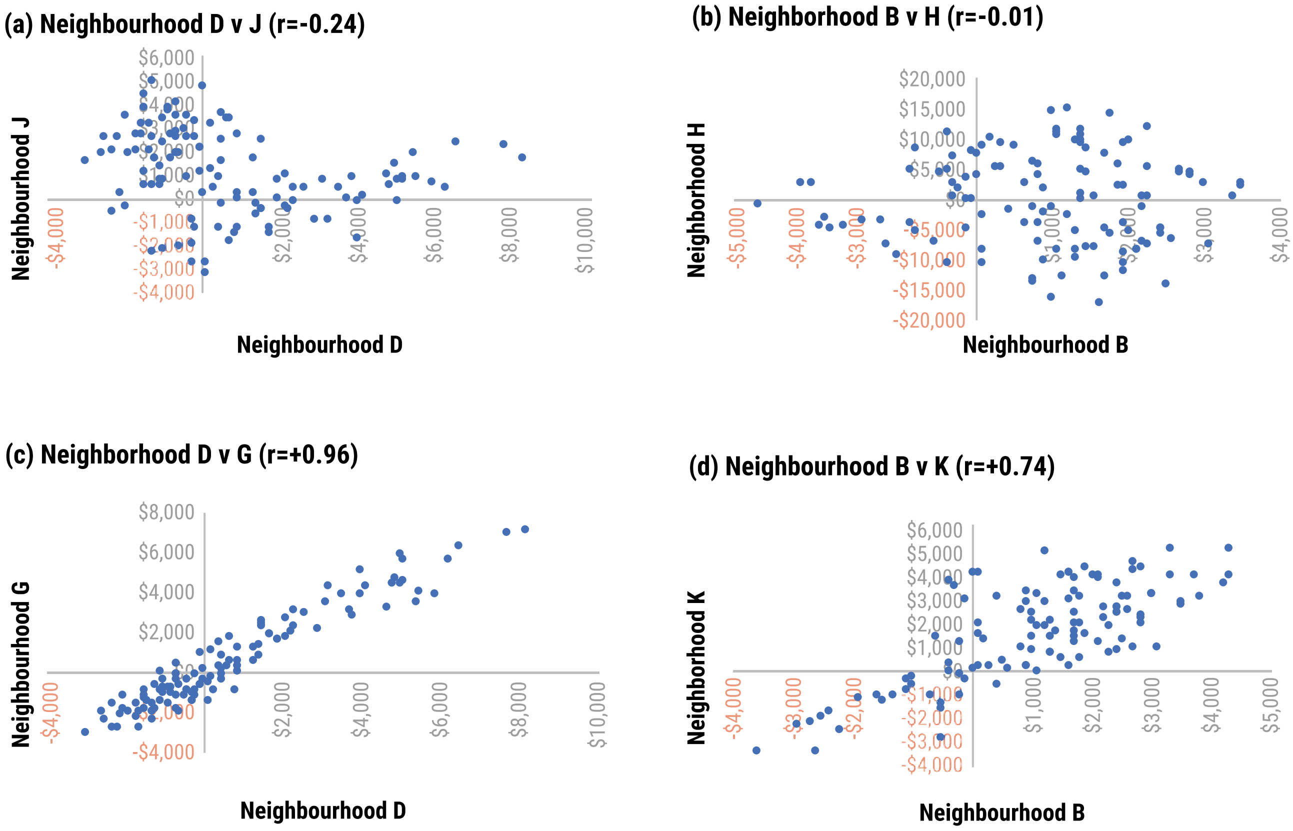


Figure 5.10: Scatterplots and correlations (*r* value in brackets) for detrended home values in selected pairs of neighborhoods.

Note from positive correlations those pairs of variables that change in similar ways. This is the case for home values in neighborhoods D and G (Figure 5.10c), as well as in B and K (Figure 5.10d). However, further inspection of the detrended time series (Figure 5.8b) is needed to establish whether values are rising together or falling together. This reveals that home values are falling simultaneously in D and G, but rising together in B and K.

5.4.4. Step 4: Benchmark data

Use before and after analysis to uncover impacts of extreme weather events on financial data at specific locations. In the worked example, the city was struck by two powerful hurricanes during the period 2017 to 2020. By comparing home values before and after these events it is possible to evaluate whether the property market was impacted differentially, by neighborhood. However, due to inertia in home sales (or commercial leases), a lagged response is expected, i.e. any change in property value will not be observed until a property is sold.[63] Eventually, there may be a recovery of any lost value as the memory of an extreme event fades in the market.

Benchmark changes in financial data with respect to a reference period or value. Here, changes in average home values in each neighborhood were compared with their value in January 2017. This date was chosen because it was several months before the first hurricane (September 2017). Five neighborhoods saw home values fall between the benchmark and March 2020: C (−4%), D (−9%), G (−10%), H (−12%) and T (−9%). Meanwhile, average values across the city rose by 8% over the same period, with largest increases in neighborhoods B (+39%), J (+67%) and K (+31%).

5.4.5. Step 5: Correlate data in time

Identify variations in financial data that correlate with changes in climate indicators through time. In the worked example, it was hypothesized that changes in house values reflect differences in resilience to climate threats such as flooding. Hence, high-ground neighborhoods are expected to have greater rises in home values over time, because they are less exposed to sea level rise, storm surges and coastal flooding. Homes with a sea view or that are well-defended against flooding may attract a premium too.[64]

Use property elevation or zoning as a proxy for flood risk.[10] Here, there are weak, non-linear correlations between benchmarked value changes and elevation, that depend subtly on property type (Figure 5.11). Home values in lower elevation neighborhoods are generally falling (i.e. ratio changes less than one) but rising in all higher elevation neighborhoods (i.e. ratio changes greater than one). This seems to confirm the climate gentrification theory.

Disaggregate data to reveal other factors that may be influencing the strength of correlations. For example, home value data may be further interrogated by property type using best fit lines (Figure 5.11). In the worked example, the size of the power-term for each line shows the strength of the association. This suggests that values of bottom tier (lower cost) homes are most sensitive to elevation ($x^{0.2218}$), whereas condos are least sensitive ($x^{0.175}$). However, the best-fit lines are strongly influenced by outliers and clustering of the data so should, therefore, be treated with caution.

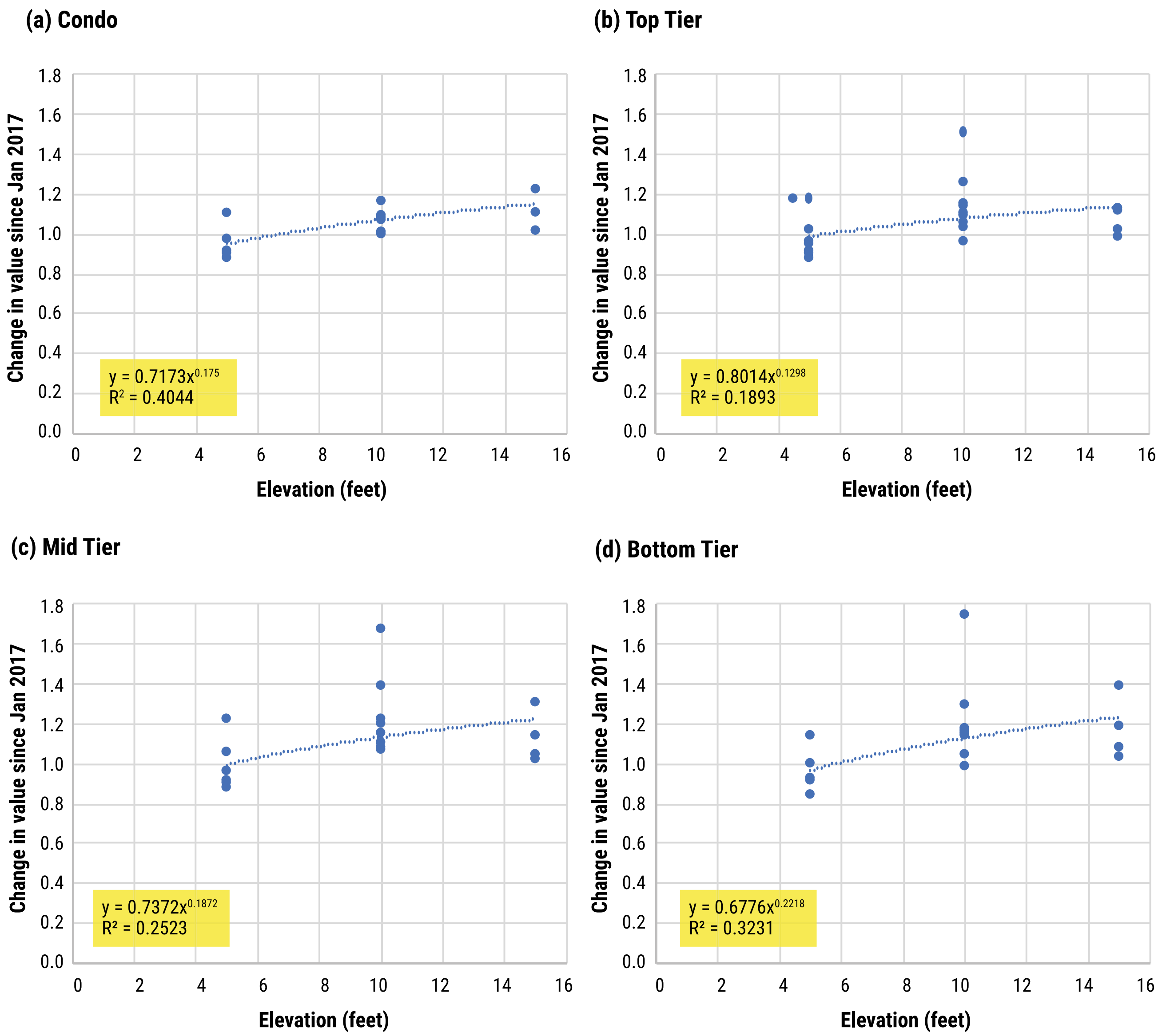


Figure 5.11: Relationship between changes (ratio) in home values between January 2017 and March 2020 with elevation for (a) condos, (b) top, (c) mid and (d) bottom tier properties. The equation of the best-fit power curve (dotted line) is shown in the yellow box. The amount of explained variance (R^2) is also given. This is equivalent to the square of the correlation coefficient (*r*). All relationships shown are statistically significant.

Recognize that correlation analysis can be affected by confounding issues, especially when there are multiple factors at play. Home values in the worked example may reflect a host of factors such as age of the property, access to amenities or quality of coastal defenses. More sophisticated, multivariate techniques such as hedonic pricing models (Section 5.7) and Ricardian analysis can account for this (see Appendix A and B).

5.4.6. Step 6: Evaluate correlations

Review the results of the correlation analysis carefully, taking note of key assumptions and confounding factors. The key findings and points to note from the worked example might be that:

- Neighborhoods B, J and K have rising home values, and these are all at mid- to higher elevations.
- Neighborhoods C, D, G, H and T have falling home values and are all at lower elevations.
- Relationships between changes in home values and elevation are non-linear.
- Values of lower cost homes are more sensitive to the elevation effect than mid-value and high-value homes and condos.
- The elevation data used in the exercise was only to the nearest 5 feet (1.5 meters), which might conceal variations in plot elevation *within* neighborhoods.
- The form of the value-elevation relationship appears to be non-linear but best-fit lines are influenced by outliers and the coarse resolution of the elevation data.
- Price shocks and loan delinquency rates due to successive hurricanes could be explored with more granular time-series data.

5.5. Summary

Correlation analysis is a useful technique for exploring linear associations within data and is a stepping-stone towards more sophisticated interrogation of relationships between financial data and climate-related data. Despite the relative simplicity of correlation analysis, care should still be taken to comply with key assumptions – especially the expectation of stationary data. Visual inspection and scatterplots can quickly give insights about the data; the first difference method can be used to remove long-term trends.

Previous correlation studies show that storm surges, wildfires, sea level rise, inland flooding, drought, and other hazards are already impacting financial portfolios. This is because globally significant climate modes such as El Niño and the Pacific Decadal Oscillation drive extreme weather, physical risks, and related socio-economic impacts. By discovering opposing associations (such as floods in one region coinciding with droughts in another) it may eventually be possible for portfolio managers to hedge against such physical risks.

Correlation analysis is part of a much larger universe of statistical and modeling approaches for uncovering climate signals in financial data. Such techniques help to analyze climate alongside client and property characteristics as well as property-level adaptation measures taken by the homeowner to reduce vulnerability to physical risks. Advanced diagnostic techniques are available for the real estate (Appendix A) and agriculture (Appendix B) sectors. These include discriminant analysis, generalized linear modeling, hedonic pricing, longitudinal (repeat sales) analysis, Monte Carlo simulation, multiple regression, Ricardian models, and vulnerability analysis. Those seeking to progress beyond correlation analysis are encouraged to refer to these resources.

The next section is a pilot study based on the practical experiences and insights gained by applying the correlation analysis workflow to a study of wildfire and property values. This highlight that sourcing (Step 1) and preparing (Step 2) financial data are non-trivial stages in the correlation analysis. Some issues around the granularity of financial data and institutional capabilities for geospatial data handling were also revealed. Above all, it is critical to have a clearly defined set of study aims before starting the correlation analysis because these will narrow the search for data and specify most suitable statistical techniques.

The final section demonstrates an advanced statistical technique for uncovering associations between property prices and exposure to river flooding at the city scale. This is based on hedonic analysis of property values for homes located within or outside a flood zone. The results reveal that property values in the flood zone are sensitive to the number of years since flooding and property type. Overall, property prices in the flood zone are on average 2.5% lower than those outside the floodplain.

5.6. Pilot study

The Standard Bank Group: Correlation analysis of wildfires and property values (South Africa)

Context and objectives

This case study used best available sourced internal and external data to evaluate associations between the incidence and intensity of wildfires in a region of southern Africa with subsequent movements in property values. A lack of usable time series for property values in different areas meant that a spatial correlation analysis was not feasible. Thus, the study focused on trialling a temporal analysis by evaluating average property prices before and after an identified major wildfire event, to determine any changes in price trends.

South Africa is a semi-arid country. Research shows that changes in climate are creating warmer, drier conditions, with increased drought, and a longer fire season contributing to higher risk of wildfire.[ad] Hence, wildfires were selected as the climate hazard to trial the correlation methodology. It was not the intention of the analysis to draw any conclusions about the extent to which drier climate conditions and wildfires may or may not have been driven by human-induced climate change.[ae] As the methodology evolves, this type of testing may be included.

Pilot study location and extreme event identification

The region selected (termed the 'fire area' in this report) was chosen because it:

a. Is known for its susceptibility to droughts and recent history of extreme wildfires;
b. Has a robust market for primary residential as well as second home holiday property, which by and large has seen demand at levels at or above the national average; and
c. Has a reasonable level of property lending exposures for the bank, from which to draw some insights.

Although hazard data for a significant period was obtained (see below) what is considered to be one of the most noteworthy fires in literature (termed the 'fire event' in this report) was selected as a key measurement point around which to analyse property price movements. The fire was recognised as amongst the largest fire disasters that South Africa has experienced.

External data sources

Various external sources were considered for the historical wildfire data, including from the South African Council for Scientific & Industrial Research. Although this source was noted for future work, the present study was based on the open source NASA Fire Information for Resource Management System (FIRMS). This archive contains records of near real-time fires based on satellite observations by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) and NASA's Visible Infrared Imaging Radiometer Suite (VIIRS). Records of wildfires in South Africa were retrieved for the last 20 years with relative ease and at no cost. The data are presented in .csv file format and include locational co-ordinate fields (latitude and longitude), as well as 'brightness' data which provide some indication of the intensity of the fire as observed and captured by the satellite imagery.

Internal data sources and limitations in final data set used

For internal data purposes, reliance was placed on a dataset of mortgage lending exposures from the bank's retail portfolio. This comprises of loans for primary and holiday home purposes, taken out by borrowers who are individuals or corporate entities such as close corporations or limited liability companies. Data from the corporate and investment banking business unit lacked usable locational data such as post codes,[af] partly because much of this real estate related exposure is concentrated in listed investment trusts and mutual fund type entities, which do not contain this type of georeferenced data. Area post codes and importantly latitude and longitude data for each property from the retail mortgage dataset were used to match exposures to the wildfire area. Property valuation data sourced from an external provider of property market intelligence was overlaid on the internal portfolio exposure data. When using such data, care needs to be taken to ensure that all internal compliance requirements regarding client confidentiality are adhered to (e.g. anonymity of personal details, re-basing of values and no references to specific locations).

ad https://www.csir.co.za/sites/default/files/Documents/CSIR%20Global%20Change%20eBOOK.pdf "The occurrence of fires is closely linked with climate and increases in temperature combined with an increase in dry spells in some areas may result in wildfires affecting larger areas and fires of increased intensity and severity (IPCC 2012)"

ae Wildfire frequency and severity also depends on the fire management regime and other factors such as peri-urban growth into potentially high fire risk areas

af For correlation analysis, geo-referenced financial information is a necessary pre-cursor, even at postcode level but ideally much finer resolutions for overlaying with hazard data.

The unitless chart (Figure 5.12) shows how the internal property value data for the wildfire area compares with that for other areas (when grouped by post code and labelled 'N1' to 'N8'). This enables an assessment of the relative performance of the property market in the selected area over the period March 2015 to March 2020. Property value data for the whole country were sourced for the same five-year period. The value measurement points were at quarterly intervals, with 20.15% of all records available for the province with the fire, whereas the fire area itself covered 0.13% of all country records. The high value performance of the fire area can clearly be seen, both before and after the fire event.

Average Property Values by Region

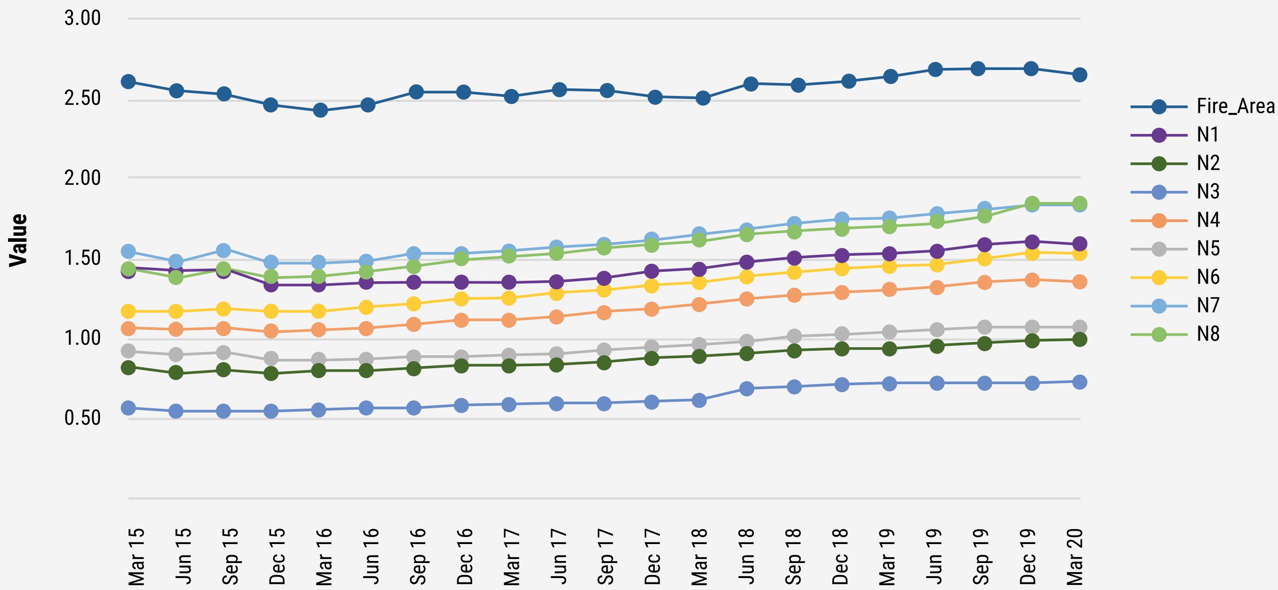


Figure 5.12: Average property values for the wildfire area and by postcode region

Figure 5.13 provides further insight into the performance of the property market in the fire area, relative to that of neighbouring areas. Each bar reflects value performance of the property market over a 3-, 6-, 12- or 24-month period before the fire compared with the same averaging period after the fire. For example, in the fire area region, the property market reflected a 0.28% increase in average values (for properties in the bank records) for the 6-months after the fire event, relative to the 6-months before the fire event. The equivalent statistic for the rise in average values for 3-months before and after the fire was 1.20%. For comparison, values for the neighbouring region N3 are also included.

Figure 5.13 suggests that, for the properties to which the bank has exposure—despite the fire zone being a high value area relative to other areas in the province (as per Figure 5.12)—average property value after the fire as measured over a range of different time periods did not increase at the same rates as other areas in the wider province. This observation is explored in more detail in the correlation analysis below.

Changes in average property values per regional area at different time periods before and after fire event

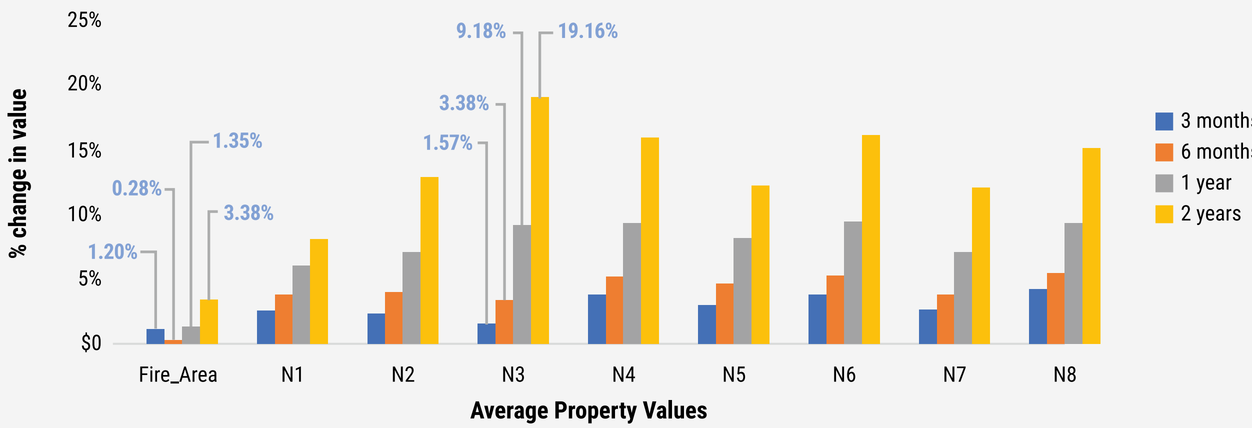


Figure 5.13: Change in average property values at different time periods for various areas pre and post the fire

Correlation analysis

The raw fire event data from FIRMS, as well as the property valuation data, were analysed using the open-source geographic information system Quantum GIS ('QGIS'). Running a distance matrix in QGIS yielded a calculation of the separation between fires and properties, at metre-level accuracy. QGIS-generated images for fires in the area are illustrated by Figure 5.14. FIRMS uses a confidence variable to assign purple blemishes to the image for areas where fires have occurred, with those parts of the blemishes that appear more solid reflecting a higher confidence of fire occurrence. The inclusion of the major fire event is factored into the image on the right and both images are overlaid with bank-financed properties (represented by scatter dots) classified according to their values, with the higher values coloured in a darker shade of red.

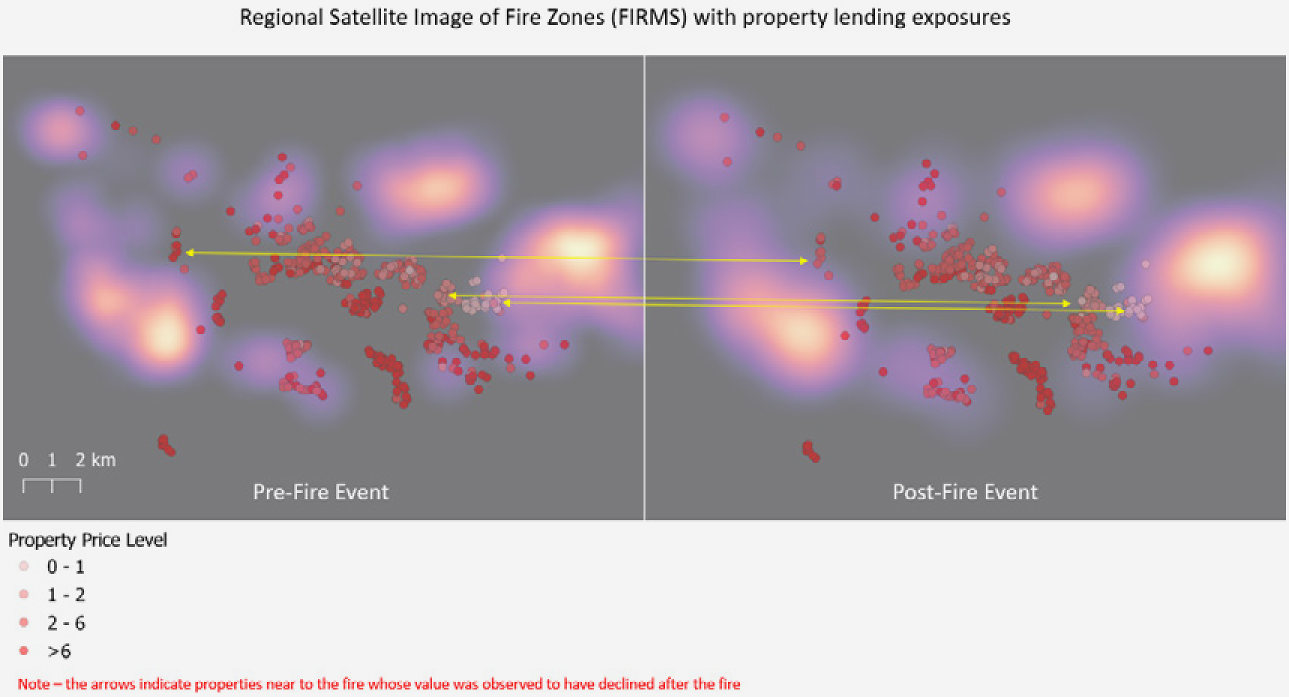


Figure 5.14: Satellite Image of Fire Zones (FIRMS) with lending exposures to individual properties

The arrows in the charts above denote individual properties and clusters of properties whose values declined after the fire. Although this sample is not a significant proportion of the population of the bank's total lending exposures, their proximity to the epicentres of the major fires is noteworthy, as is the fact that they are of lesser value than those located at greater distance from the fires. In addition, properties further from the areas impacted by fire appear to be more valuable and to have retained their value after the fire.

Extending the analysis, Table 5.3 below shows average property prices (for 419 records used in the sample) 12-months before the fire, during the fire episode, and then 12-months after the fire event, grouped by distance from the nearest fire zone according to the FIRMS data. Note that all values are reflected in 'common state' form with the average for properties situated less than 906 metres from the nearest fire in the 'before the fire' time period assigned the value '100'. All other values reference to this value so, for example, the 'at the fire' average for properties greater than 906 metres has a value of 130.325 or 30.325% more than the average value of properties less than 906 metres before the fire. The selection of 906 metres as the boundary between 'near' and 'far' properties relative to the nearest fire, was informed by (1) the accuracy of the satellite data used (i.e. there is a property that is exactly 906 metres from the fire), and (2) an assumed ~1000 metre 'higher hazard' zone. The placement of the boundary zone was sensitivity-tested below.

The results show a deceleration in property price increases after the fire event for those properties located within the higher hazard zone of <906 metres relative to both their values before the fire as well as to the values of properties further from the fire (i.e. beyond 906 metres). To illustrate this, we can see that the value of the 'near' properties increased by on average 5.79% up to the date of the fire, relative to their values 12-months before, and this was comparatively higher than the 4.84% growth rate achieved for properties that are further away. However, after the fire, the same properties increased by a lower amount of 2.84% (i.e. [108.792 - 105.793] / 105.793). This increase was also lower than the average growth rate of 3.02% recorded in the 12-months after the fire by properties located further from the fire.

Table 5.3: Average property values 12-months before and after the fire as well as during the year of the fire

Average property values at points in time (PIT) Before / At / After the fire event by distance away from nearest fire

BEFORE THE FIRE

Zone	Distance from Fire (m)	n	"PIT Before"	Average
NEARER THE FIRE ZONE	<106	1	81.179	
	106-306	11	67.501	
	306-506	6	155.838	100.000
	506-706	14	99.485	
	706-906	33	95.997	
FURTHER FROM THE FIRE ZONE	906-1106	42	94.817	
	1106-1306	40	100.866	
	1306-1506	29	78.655	
	1506-1706	37	88.741	
	1706-1906	52	132.786	124.31
	1906-2106	66	118.179	
	2106-2306	52	175.082	
	2306-2506	23	149.389	
	2506-2706	13	180.251	
	Total	419	115.626	

AT THE FIRE

Zone	Distance from Fire (m)	n	"PIT Before"	Δ Before-At	Average
NEARER THE FIRE ZONE	<106	1	80.450	-0.90%	
	106-306	11	68.810	1.94%	5.79%
	306-506	6	156.947	0.71%	105.793
	506-706	14	125.641	26.29%	
	706-906	33	97.116	1.17%	
FURTHER FROM THE FIRE ZONE	906-1106	42	99.328	4.76%	
	1106-1306	40	107.319	6.40%	
	1306-1506	29	80.826	2.76%	
	1506-1706	37	89.100	0.40%	4.84%
	1706-1906	52	138.425	4.25%	130.325
	1906-2106	66	122.149	3.36%	
	2106-2306	52	187.904	7.32%	
	2306-2506	23	157.977	5.75%	
	2506-2706	13	189.895	5.35%	
	Total	419	121.563		

AFTER THE FIRE

Zone	Distance from Fire (m)	n	"PIT Before"	Δ Before-At	Average
NEARER THE FIRE ZONE	<106	1	80.424	-0.03%	
	106-306	11	70.449	2.38%	2.84%
	306-506	6	162.429	3.49%	108.792
	506-706	14	124.788	-0.68%	
	706-906	33	105.871	9.02%	
FURTHER FROM THE FIRE ZONE	906-1106	42	104.279	4.98%	
	1106-1306	40	114.281	6.49%	
	1306-1506	29	80.916	0.11%	
	1506-1706	37	94.253	5.78%	3.02%
	1706-1906	52	129.011	-6.80%	134.261
	1906-2106	66	128.499	5.20%	
	2106-2306	52	195.184	3.87%	
	2306-2506	23	170.807	8.12%	
	2506-2706	13	191.122	0.65%	
	Grand Total	419	125.17		

Table 5.4 shows the results of sensitivity tests on the assumption that properties situated less than 906 metres from the nearest fire are considered 'near' for averaging purposes. Boundaries of 821 metres, 1021 metres and 1421 metres were applied. Overall the results show that for the available sample of 419 records, the growth rate slowed from 4.79% to 2.23% for the 12-month periods before and after the fire respectively.

Likewise, for all boundary locations tested, the growth rate for both 'near' and 'far' properties slowed before and after the fire. For example, when the boundary between 'near' and 'far' fire is set at 821m, 'near' property value growth rate slowed from 5.79% to 2.84%; when the divide was set at 1421m, growth in 'far' property values slowed from 4.86% to 2.65%. Furthermore, and more poignantly for purposes of ascertaining an association between distance from a fire and property value, is that the growth rates for the near properties at all boundary levels have declined by **relatively more** than for those further away. For example, at the 1021m limit, the drop from 5.63% to 3.18% for the near properties is greater (2.45%) than the reduction from 4.85% to 2.84% (−2.01%) for the properties further away. Further analysis showed that only from a distance of 1506m from the nearest fire, was this relationship not observed, suggesting that perhaps this is the 'indifference point' or the distance at which nearness to a fire zone does not inform value. This observation should be caveated by saying that it is not possible to draw that definitive conclusion based on this assessment, simply because of the many other factors which are acknowledged as being drivers of value.

Table 5.4: Sensitivity test to compare different boundary limits for near and far fire zones for averaging values

	Near	Far	Near	Far	Near	Far	Market
Distance (metres)	0-821	821-2621	0-1021	1021-2621	0-1421	1421-2621	
Average Before Fire	100.000	124.307	99.136	127.994	96.792	140.738	115.626
Average At time of Fire	105.793	130.325	104.715	134.199	102.055	147.575	121.563
Average After Fire	108.792	134.261	108.040	138.009	105.430	151.479	125.165
Growth Before to At	5.79%	4.84%	5.63%	4.85%	5.44%	4.86%	4.79%
Growth At to After	2.84%	3.02%	3.18%	2.84%	3.31%	2.65%	2.23%
Difference in growth rates	-2.96%	-1.82%	-2.45%	-2.01%	-2.13%	-2.21%	-2.57%

Conclusion

This activity has been invaluable as an introductory exercise in trialling a methodology designed to determine (1) whether any association exists between climate hazards and asset values, and (2) if there is some correlation, then the extent to which such values (in this case for properties) may be influenced by said natural events. Potential data limitations notwithstanding, deeper analysis (for example testing the approach at another major fire area, and examining variations within the 'near' and 'far' zones due to property type, age, size, and other variables) is required to draw meaningful conclusions that could be extrapolated to the portfolio as a whole.

5.7. Advanced analysis

Correlation analysis is useful when searching for associations between pairs of data, but more advanced techniques are needed for multivariate data. For instance, the correlation between rainfall and farm revenues may depend, in part, on farm size, crop and irrigation type, soil properties, farmer experience, and so forth. Ideally, a statistical model would capture the influence of these multiple factors whether in isolation or in combination.

Hedonic pricing models estimate the demand or value of a good depending on multiple internal factors and external 'treatments'. Dummy variables are used in the model to switch mixtures of factors and treatments 'on' or 'off'. Hedonic modeling has been widely used for analyzing variables affecting real estate and agriculture (see Appendices A and B). For example, changes in prices between repeat sales of the same property could depend on house type, size, and age (internal factors) as well as on the frequency, severity and/or time since flooding (treatments). One study of repeat sales for England showed that the price of property in an entirely flooded postcode is on average 24.9% lower than non-flooded property.[65] A similar hedonic analysis is demonstrated in Box 5.2.

Box 5.2: Impact of flood zoning on property prices at the city scale

Authored by Rob Wilby and Josh Thompson

A hedonic model was developed for the Phase II pilot for a flood prone city in the UK to explore the effect of flood zoning and flood history on changes in property prices at postcode level. The model was calibrated using three sources of data covering years 1995 to 2020: (1) property details and prices from the UK Government land registry; (2) flood zone maps and (3) historical flood outlines, both from the Environment Agency (England).

Property data were analyzed for 5797 houses in 926 postcodes. These properties had more than 9000 repeat sales, of which over 700 bracketed at least one flood episode. Flood exposure was assessed using the percentage of each postcode area falling within flood zone 3 (in the UK, this land has greater than 1% chance of flooding from rivers in any year). Sales years account for property aging and appreciation effects.

Four scenarios were considered for changes in the price of properties. These were (1) when none (0%) of the postcode lies within flood zone 3 (Scenario A); (2) when 100% of the postcode is in flood zone 3 (Scenario B); (3) as in Scenario B but with three or more floods since the last sale (Scenario C); and (4) as in Scenario C but the sale was three years after the last flood (Scenario D).

Results

The hedonic model was used to simulate the impact of the four scenarios (A, B, C and D) on property price changes. To maintain comparability, the same years of sales (2006 and 2014) and property type (semi-detached) were applied across the demonstration scenarios. Overall, location of a postcode entirely within flood zone 3 reduces property values by 2.5%. Other key findings of the analysis are as follows:

- Scenario A (base case) shows that the price of semi-detached properties increased on average by 64% from 2006 to 2014 in a postcode that was not exposed to river flooding.
- Scenario B shows that the average price of a semi-detached property would have increased by 50% in a postcode that lies entirely within flood zone 3, i.e. a much lower increase than in Scenario A.
- Scenario C reveals that the appreciation in value is further depressed to 32% if there were three or more floods in the postcode since the previous sale.
- Scenario D suggests that if the sale occurred three years after the last flood, a price rise of 59% is expected. This is moving closer to the price change for an unexposed postcode over the same period (i.e. 64% under Scenario A), hence the discount on prices recovers with time since the last flood.

Table 5.5: Variables and scenarios used for an illustrative hedonic pricing model analysis.

Independent variables/ Scenarios		Scenario A	Scenario B	Scenario C	Scenario D
House type	Repeat sale brackets at least one flood	✓	✓	✓	✓
	Detached				
	Semi-detached	✓	✓	✓	✓
	Flat				
	Terraced				
	Sale after 2002	✓	✓	✓	✓
Flood exposure and recovery in postcode	Percent of postcode in flood zone 3	0	100	100	100
	Sale 1 year after flood	✓	✓	✓	
	Sale 2 years after flood				
	Sale 3 years after flood				✓
	Sale 4 years after flood				
	Sale 5 years after flood				
	Sale more than 5 years after flood				
Flood history in postcode	Two floods since previous sale				
	Three or more floods since last sale			✓	✓
Sales history	Year of previous sale	2006	2006	2006	2006
	Year of sale	2014	2014	2014	2014
Change (%) in price between consecutive sales		+64	+50	+32	+59

The hedonic model used here was built for illustrative purposes only, using a small sample of publicly available information. No data on actual flood damages to properties or home contents were used. Moreover, high exposure to river flooding does not necessarily mean that individual properties were affected by floods; there could be an amenity value associated with proximity to a water body[66] and/or for houses protected by flood defenses.[67] Property prices are also known to reflect the severity and type of flooding (i.e. inland fluvial, sewer, surface, and coastal), and depend on price quantile.[16] Here, the effect of flood insurance was represented only crudely using a dummy variable for sales after year 2002 – the date when a new set of insurance principles were agreed between insurers and the UK Government.[68]

For the example city, the model suggests there is differential pricing of properties that are located in floodplains. Prices were found to be more sensitive to the history of flooding than to the physical hazard exposure (represented by fraction of postcode area within flood zone 3). Further analysis is needed to confirm these findings.

In summary, a key strength of repeat sales hedonic models is that they control for invariant characteristics whilst uncovering price signals associated with factors that are changing over time. Each property is assigned dummy variables to distinguish between these features and to denote the treatment (here, likelihood of exposure to river flooding). The price evolution of properties can then be statistically modelled in relation to these multiple fixed spatial and time-dependent factors.

6. **Banking for resilience:** Analysis of opportunities driven by physical climate risk

Phase I of the UNEP FI TCFD Banking Pilot provided a framework to assess the strategic opportunities for banks created by the adaptation and resilience responses counterparties may take in response to the physical impacts of a changing climate. The framework recognizes that an assessment of physical risk-related opportunities by banks requires a different approach to that used in a risk assessment methodology. An assessment of opportunities needs to include both qualitative and quantitative considerations regarding future market conditions for banks and their clients.

Physical climate change impacts are often considered as a risk management challenge. What is missing is a recognition of the banking sector's critical role in the implementation of the Paris Agreement by mobilizing financial flows to deliver adaptation and resilience. It is essential that banks assess and explore the opportunities to provide finance within their markets and to their counterparties. The opportunities framework has been designed to enable banks to explore how they can align their strategic and operational activities with the Paris Agreement and play a major role in the mobilization of private sector finance towards adaptation. This chapter explores several key drivers which will influence the demand for finance from counterparties as they respond the impacts of a changing climate. These are in addition to the drivers already discussed in Chapter 1. This chapter also providers a brief overview of the Phase I opportunities framework which was described in more detail in the Phase I report.

It is increasingly understood that a changing climate brings significant financial risks and that public and private investments in adaptation are needed. There are no accepted global estimates for either the loss and damage arising from a changing climate or the global costs of adaptation. Various sources provide qualified global estimates, but none are sufficiently robust to enable their use in investment decisions.[69] As each new study is released, the estimates increase significantly, as the understanding of climate change impacts on society, the economy and the environment improves. The amount of investment needed to meet adaptation demands over the next 10 years cannot be met by public budgets alone – both public and private finance are needed to meet this challenge.

Physical climate risk will have significant global economic, environmental, and societal impacts. Adaptation needs to be given urgent priority, not only to prepare for the changes underway and the impacts which are increasing, but also to eliminate the existing resilience deficit. Figure 6.1 shows that adaptation and resilience are poorly resourced. Global climate finance flows in 2017/18 were dominated by GHG mitigation projects ($537 billion), with only $30 billion for adaptation. The net effect is that, as the scale of the impacts arising from a changing climate increases, the resilience deficit continues to grow. The banking sector has a critical role to play in closing the gap, not least with regard to SME clients.

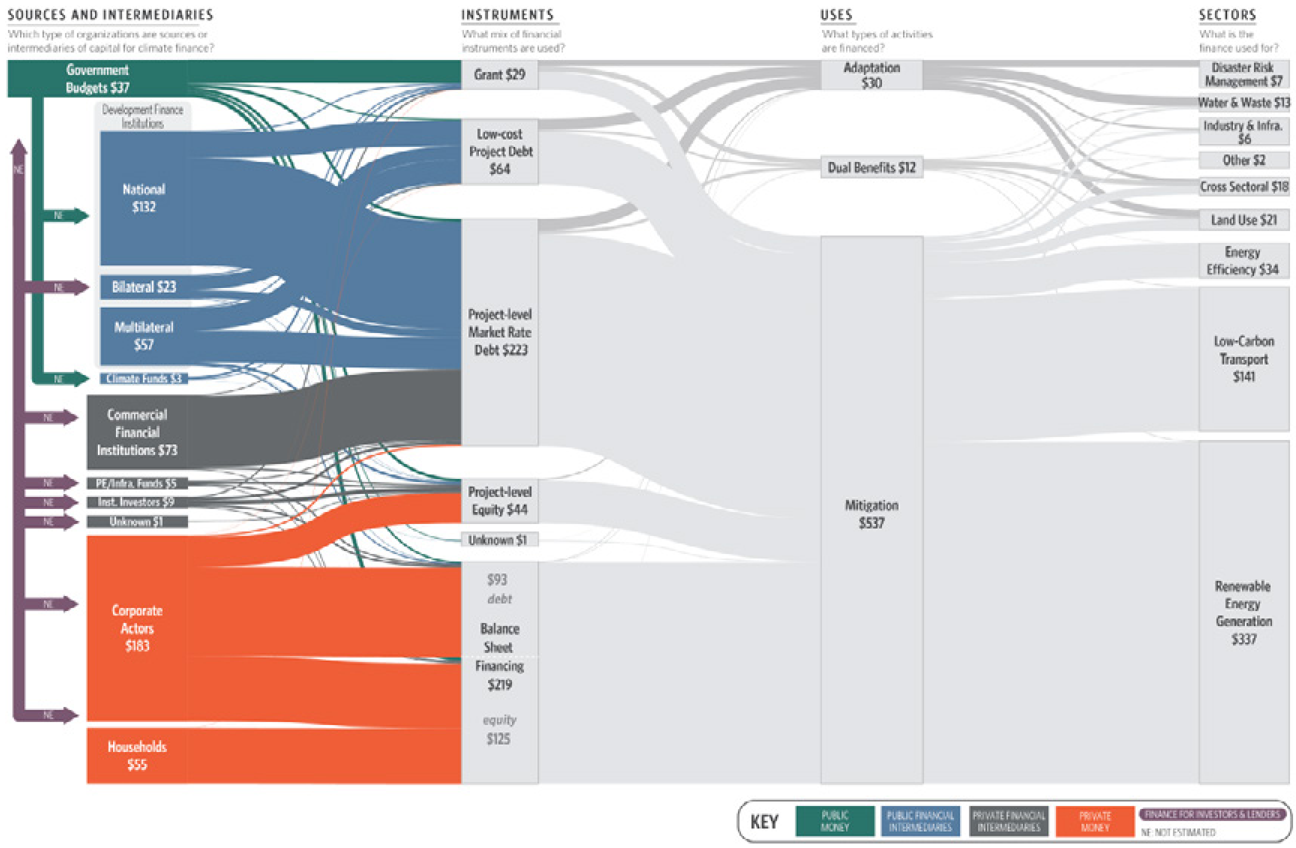


Figure 6.1: Climate finance landscape: Global climate finance flows along their life cycle in 2017/2018 (USD billion). Source: Climate Policy Initiative.[70]

6.1. What is meant by 'opportunities' in the context of physical risk?

The Task Force on Climate Related Financial Disclosures (TCFD) defines "climate-related opportunity" as "the potential positive impacts related to climate change on an organization". It also notes that efforts to "adapt to climate change can produce opportunities for organizations, such as through resource efficiency and cost savings … the development of new products and services, and building resilience along the supply chain".[71] The TCFD recommendations did not explore climate-related opportunities in detail, and focused more on transition and physical risks.

In the UNEP FI TCFD Banking Pilot Phase I report, a new definition of opportunities stemming from physical risk was created, specific to the banking sector. This has been further refined and the revised definition is set out in Box 6.1. It follows the key role of the banking sector to provide the finance needed to deliver adaptation and resilience.

Box 6.1: Physical risk-related opportunities for banks defined

'Opportunity' is defined as the potential increase in demand for finance, investment, insurance and advisory services driven by the direct and indirect physical impacts of a changing climate on clients and their adaptation and resilience responses.

New opportunities will develop for banks to support growth in horizontal and vertical adaptation solution providers.

Physical climate-related opportunities for banks to meet the needs of their clients will vary depending on the region, market and industry in which a bank operates. Understanding the changes taking place in business sectors and with clients as they are impacted by a changing climate, being aware of the responses they need to make to adapt and build resilience, and recognizing the challenges presented by the Paris Agreement and a green recovery from COVID–19 are critical.

A simple hierarchy is provided in the Phase I opportunities framework to characterize the reasons and timeframes whereby counterparties may demand new finance or investment. Namely, banks can evaluate climate opportunities associated with counterparties who are:

Managing existing risks
Anthropogenic GHG emissions and other human activities have already warmed the Earth's climate by around 1°C above pre-industrial levels.[72] Recent years have been the hottest since direct temperature observations began (in the 1880s), and the six warmest years on record have all occurred since 2010.[73] As a result of this warming, more frequent and more extreme weather and climate events are already being experienced, along with gradual shifts in other climate and climate-related factors (e.g. rainfall patterns and sea levels).[74] Counterparties are already managing the risks associated with these hazards, which are affecting their revenues and costs. In many cases, these existing risks are requiring additional operational and capital expenditures. For example, additional OPEX and CAPEX is needed to make extreme event preparations, conduct contingency planning, help with event recovery, and to handle changes in operating performance.

Responding to emerging risks
Global mean surface temperatures are set to increase by a minimum of 1.5°C degrees by 2040.[75] After 2040, there is less certainty about the rate of change, as this depends on how quickly GHG emissions are curbed. A certain amount of change is already locked into the Earth's climate system over coming decades and centuries, regardless of the success and rate at which global GHG emissions are controlled.[76] This will mean chronic changes and acute climate events continue to happen, with unavoidable, far-reaching consequences on social, human and natural systems.[77] This 'locked-in' climate change will have adverse or beneficial impacts on counterparties and will drive new investment needs for decades to come.

Preparing for market shifts
What is currently understood as 'extreme' today, e.g. extreme weather and climate events, may become the norm tomorrow. For example, a study found that European heatwave events estimated to occur twice a century in the early 2000s are now expected to occur twice per decade.[78] These more extreme changes will perhaps cause the biggest shift in finance and investment needs for banks' counterparties, as they will present systemic risks. The acute and chronic changes will drive changes throughout the value chains of counterparties. Counterparties will require new finance as their supply chains shift and their clients demand new or different goods and services, and their overall operational conditions shift dramatically.

6.2. Drivers of physical climate risk-related opportunities

Chapter 1 highlighted some key drivers for banks to assess, manage and disclose physical risks and opportunities, which have emerged since the publication of the TCFD recommendations. These include the Network for Greening the Financial System and increasing regulation facing issuers. This section highlights drivers which are specifically related to opportunities for banks.

6.2.1. A changing climate will drive the need for new finance

Physical climate risk assessments undertaken by banks will show that a changing climate will impact counterparties in various ways over time. This will lead to shifting finance needs which present opportunities for banks. Banks can use the UNEP FI Phase I opportunities framework to better understand how counterparties will demand new finance as a result of a changing climate. Box 6.2 provides some examples of opportunities, noting that counterparties may need new finance or investment due to existing risks, emerging risks, and / or market shifts.

Box 6.2: Examples of new finance needs as a result of a changing climate

Banks can consider the range of clients who may face new finance needs including:

- **Retail customers** (e.g. shifting demand for home improvement loans to cool houses),
- **Private companies** (e.g. managing existing risks in supply chains; providing new products/technologies),
- **Start-up companies** (e.g. providers of new adaptation technologies and services, such as in the agricultural sector),
- **Local governments** (e.g. 'cool city' adaptation measures; support for climate-vulnerable communities),
- **National governments** (e.g. measures to slow the spread of infectious diseases which may become more prevalent due to climate change).

Banks' clients who are facing increasing physical risk may require investment in adaptation measures, and a recent report by the International Council on Mining and Metals (ICMM)[ag] illustrates some examples of adaptation where mining companies may have new finance needs over time. The report shows that ICMM member companies are already experiencing an intensification of weather and climate-related risks, which are affecting mining operations. Flooding, drought, storms and an increasing number of high-temperature days have led to reduced production or shut-downs. These events have also caused increases in capital expenditure and health and safety impacts, and made vulnerable communities more prone to social unrest. The ICCM report notes that future climate variability and climate change will likely exacerbate these impacts.

Mining companies will increasingly need to finance adaptation measures to address climate impacts. For instance, the yellow circles in Figure 6.2 indicate some new adaptation investments that mining companies may consider, as they manage growing risks associated with water scarcity for operations and local communities.

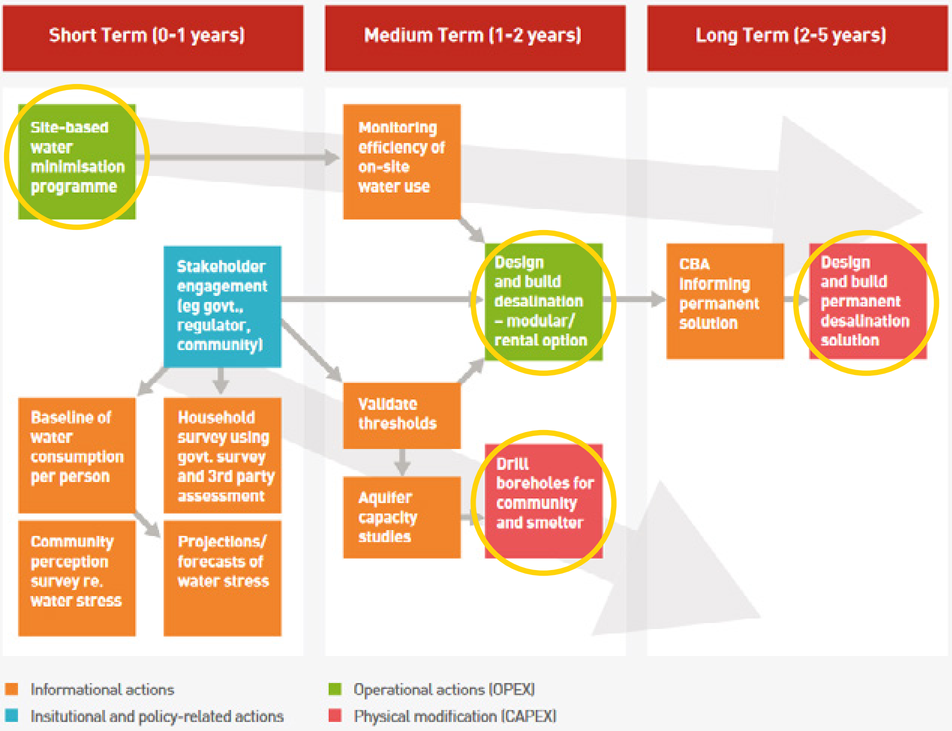


Figure 6.2: Examples of potential adaptation measures where mining companies may need investment to manage increased water scarcity. Source: Adapted from ICMM.[79]

ag ICMM is an international organization working on a safe, fair, and sustainable mining and metals industry. It brings together 27 companies and 36 regional, national, and commodities associations.

Banks may also identify opportunities to invest in, or lend to, new clients who are providing adaptation solutions, and the Global Adaptation and Resilience Investment (GARI) Working Group categorizes these into horizontal and vertical investments:[80]

- **Horizontal investments** include investments in companies who provide services (engineering, consulting, forecasting, modeling, monitoring and risk management), and data and technology development (climate and weather modeling, sector-specific data aggregation and analysis) to address physical climate risks, and
- **Vertical investments** include investments in companies that provide adaptation products and solutions in sectors such as water, agriculture, healthcare, energy, coastal areas, and finance.

6.2.2. Policy and market-led drivers

Policies and market-led initiatives are an important driver for banks on opportunities analysis and financing adaptation. Banks will increasingly need to align their lending and investment practices against relevant climate policies and frameworks, and some key examples related to opportunities are summarized here.

6.2.2.1. Paris Agreement

In 2015, at the 21st Conference of the Parties (COP21) in Paris, Parties to the UNFCCC[ah] reached an agreement (known as the 'Paris Agreement') to combat climate change and to accelerate and intensify the actions and investments needed for a sustainable low carbon future,[81] Three goals are set out in Article 2.1 of the Paris Agreement:[82]

a. Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this temperature increase would significantly reduce the risks and impacts of climate change;
b. Increasing the ability to **adapt** to the adverse impacts of climate change and **foster climate resilience** and low greenhouse gas emissions development, in a manner that does not threaten food production; and
c. Making **finance flows consistent with a pathway towards** low greenhouse gas emissions and **climate-resilient development.**

Though there is often an assumption that Article 2.1c of the Paris Agreement is primarily about transition risks and climate mitigation, the Paris Agreement also sought to mobilize financial flows into adaptation. Banks should seek to align with the Paris Agreement, and in doing so, will need to look closely at how they are financing both adaptation and low-carbon development. Many banks are now aligning with the Paris Agreement as a result of being signatories of the Principles for Responsible Banking (see later discussion in this chapter).

The Paris Agreement includes national commitments to cut emissions, known as Nationally Determined Contributions or NDCs. The UNFCCC's National Adaptation Planning (NAP) process provides an opportunity to inform the development of future NDCs and puts more emphasis on adaptation actions and the management of physical climate risks as part of countries' contribution.[ai] As the frequency and severity of natural disasters continues to rise, countries have started using their NDCs as a route to work towards reducing the risk and impact of these disasters. Over the last two decades, more than 90% of major disasters have been caused by floods, storms, heatwaves, droughts, and other weather-related events that are expected to increase in frequency and severity as a consequence of climate change.[83] Currently, 83 countries discuss disaster risk management options in their NDCs.[84]

ah The United Nations Framework Convention on Climate Change (UNFCCC) has near-global membership (197 Parties) and is the parent treaty of the 2015 Paris Agreement. Further information can be found here: https://unfccc.int/

ai Further information on how the NAP process can enhance adaptation in the NDCs by 2020 can be found here: http://napglobalnetwork.org/2019/03/how-can-the-nap-process-enhance-adaptation-in-the-ndcs-by-2020-weve-got-three-ideas/

Banks and other financial institutions can look to NAPs and NDCs as a starting point in their physical climate-related opportunity analysis as these documents set out clear investment needs associated with physical climate risks, i.e. adaptation investment needs.

6.2.2.2. EU Action Plan for Financing Sustainable Growth and the Sustainable Finance Taxonomy

The European Commission's Action Plan for Financing Sustainable Growth[85] established a Technical Expert Group (TEG) on sustainable finance in 2018 to assist in the development of proposals which advance the action plan. The TEG has developed the Sustainable Finance Taxonomy ('EU Taxonomy'). The Taxonomy sets performance thresholds ('technical screening criteria') for economic activities that can substantially contribute to climate change mitigation or adaptation, or other environmental objectives.

The EU Taxonomy differentiates between 'adapted activities' and 'activities enabling adaptation', and proposes three key guiding principles to identify economic activities that substantially contribute to climate adaptation:

1. The economic activity reduces all material physical climate risks to the extent possible and on a best effort basis,
2. The economic activity does not adversely affect adaptation efforts by others (it supports system adaptation), and
3. The economic activity has adaptation-related outcomes that can be defined and measured using adequate indicators.

In its final report on the EU Taxonomy,[86] the TEG has identified a list of 70 activities across eight sectors which are believed to make a substantial contribution to climate adaptation.

The EU Taxonomy will continue to be developed and implemented throughout 2020–2021. The European Parliament formally adopted the EU Taxonomy Regulation (TR) in June 2020. The TR creates a legal basis for the EU Taxonomy and sets out the framework and environmental objectives for the Taxonomy.[87] Delegated acts, which will contain detailed technical screening criteria for determining when an economic activity can be considered Taxonomy-aligned, will enter into force in 2020–2021.[88] By 31 December 2021, financial market participants, i.e. firms offering financial products in the EU, will be required to disclose against the Taxonomy covering their activities that substantially contribute to climate change mitigation and/or adaptation).[89] Further development of the EU Taxonomy will take place via a new Platform on Sustainable Finance, which is expected to be operating by autumn 2020.[90]

The EU Taxonomy is a tool to help plan and report the transition to an economy that is consistent with the EU's environmental objectives. Until disclosure requirements are mandatory, banks and others can use the Taxonomy to identify which of their activities are already contributing to climate adaptation, and to screen new investments, for example in their due diligence processes.

6.2.2.3. Other green or sustainability taxonomies

Globally, efforts to build green or sustainability taxonomies are proliferating as countries and organizations promote increased investment.[91] Countries such as China have already started to apply their own classifications and taxonomies to track spending on climate and green economic activities, while others such as Mexico and Chile have started to convene working groups to advance their own taxonomies. International Development Association (IDA) borrowing countries[aj] that are part of the International Finance Corporation (IFC) Sustainable Banking Network such as Mongolia, Bangladesh and Kenya have also started to advance the development of their own taxonomies.[92] In these areas, the support provided by the Climate Bonds Initiative (CBI) has played a leading role to generate standardized and comparable taxonomy frameworks. In addition, some individual financial institutions are developing internal taxonomies.

aj The International Development Association (IDA) is the part of the World Bank that helps the world's poorest countries. As at July 2020, some 74 countries are currently eligible to receive IDA resources.

With many taxonomies emerging, banks will need to consider how they use them to inform their opportunity analysis. Important challenges remain in aligning lending and investment practices with emerging taxonomies, particularly when they operate across multiple geographies. Not all adaptation-related activities will apply or transfer to other geographies. Harmonization of adaptation taxonomies globally is therefore most likely going to be guided by principles with common interpretation across geographies. The IFC is building a green finance review protocol, for example, which allows various green and sustainability taxonomies to be compared. The protocol is due to be released in the second half of 2020.

6.2.2.4. Principles for Responsible Banking

The Principles for Responsible Banking (PRB) were established by UNEP FI in 2019 and had over 180 signatories as of August 2020. The PRB provide the banking industry with a single framework that embeds sustainability at the strategic, portfolio and transactional levels and across all business areas.[93] Signatories are required to adhere to six principles, as shown in Figure 6.3. The Principles align banks with society's goals as expressed in the Sustainable Development Goals and the Paris Agreement. They require banks to be transparent and accountable, and to report publicly on their progress in implementing them.

The PRB may be an important driver for banks to assess and report on climate resilient investment/lending opportunities, primarily because the PRB framework signatories are committing to aligning with the Paris Agreement, and to conducting impact assessments and target-setting around positive impacts alongside negative impacts.

PRINCIPLE 1:
ALIGNMENT

We will align our business strategy to be consistent with and contribute to individuals' needs and society's goals, as expressed in the Sustainable Development Goals, the Paris Climate Agreement and relevant national and regional frameworks.

PRINCIPLE 2:
IMPACT & TARGET SETTING

We will continuously increase our positive impacts while reducing the negative impacts on, and managing the risks to, people and environment resulting from our activities, products and services. To this end, we will set and publish targets where we can have the most significant impacts.

PRINCIPLE 3:
CLIENTS & CUSTOMERS

We will work responsibly with our clients and our customers to encourage sustainable practices and enable economic activities that create shared prosperity for current and future generations.

PRINCIPLE 4:
STAKEHOLDERS

We will proactively and responsibly consult, engage and partner with relevant stakeholders to achieve society's goals.

PRINCIPLE 5:
GOVERNANCE & CULTURE

We will implement our commitment to these Principles through effective governance and a culture of responsible banking.

PRINCIPLE 6:
TRANSPARENCY & ACCOUNTABILITY

We will periodically review our individual and collective implementation of these Principles and be transparent about and accountable for our positive and negative impacts and our contribution to society's goals.

Figure 6.3: The six Principles for Responsible Banking. Source: UNEP FI.[94]

There are several Principles in particular, which may be driving banks to look at physical climate risk-related opportunities:

Principle 1: Alignment
The first Principle suggests that signatories should commit to align with frameworks including the Paris Agreement. Per Article 2.1c of the Paris Agreement, organizations aligning with the Agreement should finance climate resilience, i.e. investment/lending opportunities aimed at addressing physical climate risks.

Principle 2: Impact and target setting
The second Principle sets out expectations for signatories on how they will assess and manage both positive and negative impacts. Specifically, signatories agree to: 'continuously increase positive impacts while reducing the negative impacts on, and managing the risks to, people and environment resulting from our activities, products and services' and to set and publish targets where they can have the most significant impacts. This may include ways they can provide finance to clients who are addressing physical climate risks. Signatories should identify and report the areas where they have the most significant (potential) positive and negative impact, as well as strategic business opportunities in relation to the increase of positive impacts / reduction of negative impacts.

Principles 3 and 4: Engagement with clients and stakeholders to meet society's goals
The third and fourth Principles may also be relevant to physical climate-related investment/lending opportunities. These two principles ask signatories to engage with clients, customers and other stakeholders to encourage sustainable practices and meet society's goals. Banks should be engaging with their clients and other stakeholders to understand how they can encourage sustainable practices and develop related products. This may include practices and products that build climate resilience. Signatories should describe actions planned/implemented, products and services developed, and how engagement may improve the bank's impact.

As set out in the PRB Reporting and Self-Assessment Template,[95] signatories should identify and report on how the bank has met the Principles.

6.2.2.5. Innovative financial tools for climate resilience

Innovative financial tools are emerging to promote finance of resilient infrastructure and activities, such as resilience bonds, green bonds, social impact bonds (SIBs) and catastrophe bonds.[96] The European Bank for Reconstruction and Development's (EBRD's) first climate resilience bond was issued in September 2019. The proceeds from this five-year bond will be used to finance the bank's existing and new climate resilience projects. These will fall under three categories, including: climate resilient infrastructure; climate-resilient business and commercial operations; and climate-resilient agriculture and ecological systems.[97]

6.3. A framework for assessing opportunities associated with physical climate risks

The UNEP FI opportunities framework developed in Phase I helps banks identify where to focus their adaptation and resilience efforts. The framework is designed to provide a strategic market assessment within the context of a bank's institutional capacity and market positioning. Application of the framework will show where a bank is best-placed to assist its clients, supporting their adaptation and resilience actions.[ak]

Applying the framework involves analysis and completion of two scorecards to identify market segments with higher market potential and where the bank is well-positioned. The scorecards, which are provided in the Phase I report, cover:

1. Analysis of the market, by assessing sector finance demand and identifying the sectors with the most significant lending opportunities,
2. Evaluation of a bank's institutional capacity and market positioning.

The market analysis scorecard helps banks assess the potential drivers of investment in adaptation and resilience for each segment. These drivers include: policy and regulation impact; technology evaluation and relative performance; and value chain impacts on sector core financials.

The scorecard on institutional capacity and market positioning helps banks evaluate segments where they are better placed to take advantage of market opportunities. In view of physical climate impacts on markets over time, and the potential for market shifts as sectors respond to significant changes in their value chains, banks can assess their capacity and positioning to take advantage of opportunities. This scorecard reviews: the competitive landscape; the bank's risk appetite; and its institutional capacity.

ak A full description of the opportunities framework is provided in the Phase I report.

The two scorecards are brought together to help banks identify the most relevant opportunities for lending and investment, as shown in Figure 6.4. The framework can be further developed and modified by a bank using its market and counterparty data, and by accessing other socio-economic data to develop more sophisticated analysis.

When applying the framework, banks can refer to the hierarchy of opportunities to help understand the timescales when clients may require new finance or investment, namely:

- Managing **existing** risks,
- Responding to **emerging** risks, or
- Preparing for **future** market shifts.

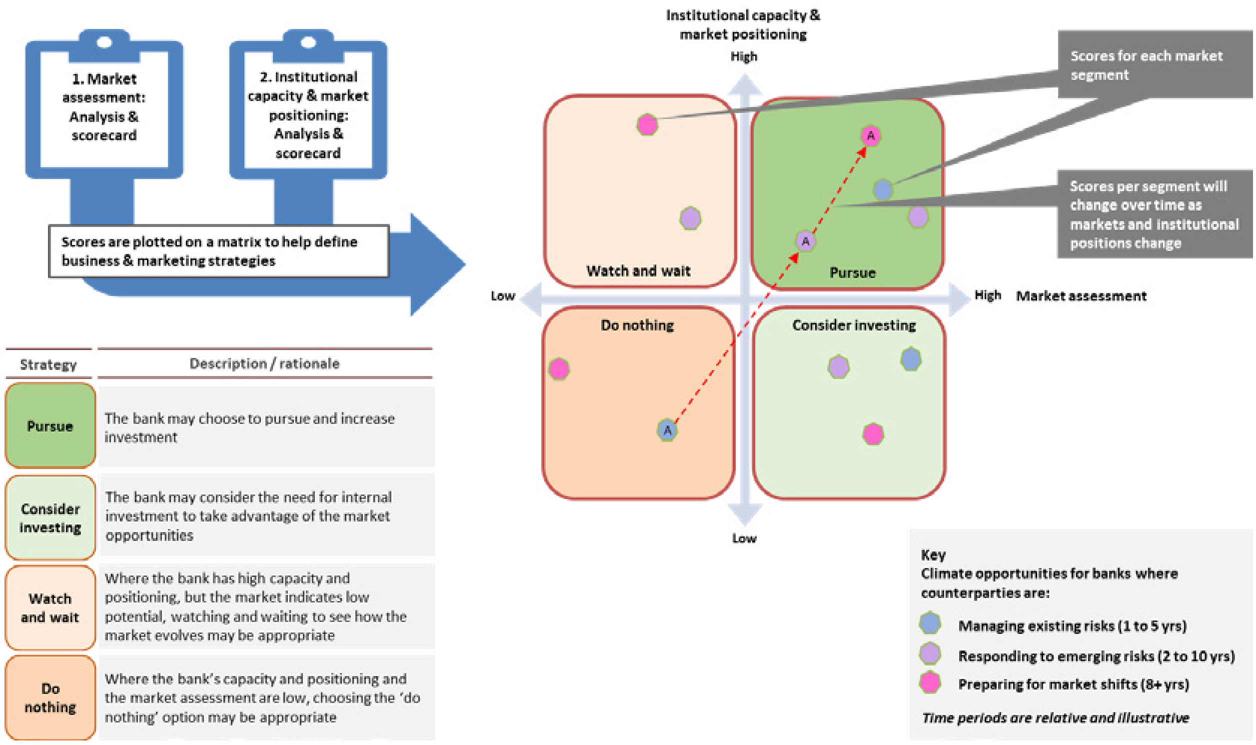


Figure 6.4: Overview of framework for banks to assess opportunities driven by physical climate risk. Source: Acclimatise.

NAB case study:
Identifying opportunities and supporting customers to become more climate-resilient

Understanding short-term and long-term risks of physical climate change has been a key focus of NAB's climate change strategy for some time now. The impacts of climate change and climate-related policy are having a growing effect on our business, our customers and the communities in which we operate.

Australia is particularly vulnerable to the physical risks of climate change.

We are integrating climate-related risks within NAB's Risk Management Framework and are expanding our understanding of the physical and transition risks we face.

Box 6.3: The Australian bushfires of 2019–20 in numbers

According to the Department of Home Affairs, to date **more than 12.6 million hectares across Australia** have been burned.

To put that in some perspective, **in New South Wales alone more than 5.4 million hectares** have been burned, said Ben Shepherd from the NSW Rural Fire Service.

"An average fire season here in New South Wales is typically at around 300,000 hectares," Inspector Shepherd said.

"So it has been extraordinary, it has been unprecedented, and hopefully it's one that none of us here will ever have to experience again."

From the beginning of September 2019 to February 23, 2020, the Australian **bushfires emitted 434 million tonnes of carbon dioxide** into the atmosphere.

This equated to over three-quarters of the 532 million tonnes Australian industry emitted in 2018–19.

11.3 million Australians were affected by smoke.

Over 1 billion animals were killed.

The insurance industry's loss footprint for the Australian bushfires of 2019/2020 is estimated at **AUD1.9 billion (US$1.3 billion)**, according to PERILS, the independent Zurich-based organization providing industry-wide catastrophe insurance data.

Sources:

https://www.abc.net.au/news/science/2020-03-05/bushfire-crisis-five-big-numbers/12007716 [Last accessed 3 August 2020]

https://www.insurancejournal.com/news/international/2020/07/07/574617.htm [Last accessed 3 August 2020]

We have witnessed and felt the devastating impact that physical climate risks like Australian drought and bushfires can have on businesses, communities and the environment, particularly when our customers and communities experience these events in quick succession.

This has highlighted the importance of identifying adaptation actions that can be undertaken by households, businesses, infrastructure owners, communities and all levels of government, to build resilience in the face of current and future climate-related extreme weather events and longer-term environmental change arising from the changing climate.

Understanding these risks creates a dual opportunity for NAB. Firstly, to provide capital to help fund the solutions that are needed and secondly, to take proactive action that reduces risk to our lending portfolio.[al]

To identify climate-related risks and opportunities, we have conducted a heatmapping exercise across our entire lending portfolio and operations. This assessment considers our relative exposures to key sectors across the Group's lending portfolio and their relative exposure to climate-related physical risk. It has helped us identify likely 'hot spots' of higher potential risk, so we can focus our attention in areas of mutual interest to our customers and our business. Agribusiness and property have been identified as two key sectors likely to experience more significant physical climate risk in the short-to-medium term. We can better support customers in these areas through this analysis.

al In FY2019, we supported farming customers through disaster relief packages and a moratorium on branch closures in affected regions and we made collective provision forward looking adjustments of AUD180 million to address the impact of extreme weather conditions related to drought.

When we speak to our agribusiness customers, they tell us the sustainability issues most important to their business include soil health, water scarcity, energy costs, and biodiversity and native vegetation. Analysis of the physical climate impacts also tells us that addressing these issues will help our customers to be more resilient, productive and profitable and represent less credit risk in the long-run. Given that drought was reported to have reduced the value of Australian farm production by around AUD6 billion in 2018–2019 compared to FY2016[98] and NAB banks one in every three dollars to the Australian agriculture sector, helping our agribusiness customers presents us with a significant opportunity.

Our work to date has also involved collaborating in two adaptation projects (one with IAG and the other with Climate-KIC) to identify and agree a definition of adaptation finance and identify potential projects that meet this definition. We undertook a stocktake of potential opportunities, with the end goal being to identify adaptation projects and develop a scalable approach to adaptation finance. We have also made available a green asset finance product to assist our agribusiness customers.

We consider physical risk as part of ESG risk assessment in our credit risk and due diligence process, where applicable, and assessment of the opportunities to help our customers was a key part of our Group strategy refresh and the decision to increase our environmental finance commitment, which we announced at the end of FY2019.[am]

We work collaboratively across a range of teams to understand the climate-related risks and opportunities facing our business. These include customer-facing teams, credit, sustainable finance team, ESG Risk and Social Impact (previously Corporate Responsibility).

NAB's refreshed strategic ambition is focused on serving our customers well and helping our communities to prosper, and it further states that we will take a long-term sustainable approach which includes implementing commercial responses to society's biggest challenges. This provides us with significant motivation to understand the risk and to find opportunities to help our customers adapt and build resilience to physical climate risk.

Key lessons learned through NAB's work to date and the TCFD Phase II pilot include the following:

- Internal and external collaboration is important to achieving the best outcomes and to getting access to the data and information to understand both physical climate risk and opportunities.
- Engaging with customers provides valuable insights that can help identify risk and opportunities – good risk management and analysis can in fact help identify opportunities to assist customers (they go together like two sides of a coin).
- Good data can be hard to access, but starting with what is available can provide useful insights and learning that helps decision making, while working towards identifying better data sources and methodologies for the future.
- Tools like the physical risk heat map and the outputs of the opportunities analysis framework can help achieve a shared understanding of the need for, and opportunities presented by, helping customers to adapt and build resilience to physical climate risk. The opportunities analysis framework provides an easy to use approach to structuring opportunities analysis.

am We increased our environmental finance commitment from AUD55 billion to AUD70 billion by 2025, by increasing our commitment to provide financing for green infrastructure, capital markets and asset finance from AUD20 billion to AUD35 billion.

The Standard Bank case study: Physical climate risk-related opportunities:

Introduction

Africa is extremely vulnerable to climate change, with major implications for agricultural production, food security, access to water, health and livelihoods. Many parts of the continent are already experiencing increased water stress as a result of prolonged drought, while yields from rain-fed agriculture are declining in many areas. Urgent measures are needed to support African countries to reduce vulnerability and build resilience to the impacts of climate change, and to facilitate the development of renewable sources of energy and energy efficiency across the continent. The UN Environment Programme reports that global warming of 2°C would put over 50% of Africa's population at risk of undernourishment, and that climate change is likely to lead to an equivalent of 2% to 4% annual loss in GDP in the region by 2040. Standard Bank is working with our clients, including governments, large corporations, smaller businesses and individuals, to help them mitigate and adapt to the impacts of climate change.

This case study summarises actions taken and to be taken by the bank to assist our clients in managing physical climate-related risks. In turn, these actions provide business opportunities to the bank which are aligned to our purpose of driving Africa's growth by meeting societies' developmental needs and doing business the right way. This case study includes references to disclosures made by the bank in publicly-available reports.

Standard Bank's *SEE* Value Driver

The bank has identified **seven** areas in which it believes it can best achieve its purpose of driving Africa's growth while making a positive impact on **S**ociety, the **E**conomy and the **E**nvironment. One of these areas is termed **Climate Change and Sustainable Growth** which the bank defines as *"work(ing) with our clients to develop appropriate solutions for mitigating and adapting to the effects of climate change…we develop innovative financial products and services that support the green economy and social development."*

The Climate Change and Sustainable Growth impact area is designed to address four of the Sustainable Development Goals (SDGs) – Clean Water & Sanitation (SDG6), Affordable and Clean Energy (SDG7), Sustainable Cities and Communities (SDG11) and **Climate Action (SDG13).**

To support the delivery of the bank's Climate Change and Sustainable Growth goals, and support our clients in adapting to the effects of physical climate risk, we have established Africa's first dedicated **sustainable finance business unit**. The unit works with our clients to develop bespoke solutions to help them achieve their social and environmental goals. An example of a successful deal originated by the unit and which brings adaptation benefits is:

- East Africa's first green bond, a R611 million bond for a Nairobi-based property developer to develop green-certified student accommodation. The bond has been certified as green by the Climate Bonds Initiative, as the accommodation will meet international green building standards for **water consumption**, energy use and construction materials.

Standard Bank's 2019 ESG Report

With respect to disclosures specifically on adaptation to physical risk,[an] the bank's 2019 Environmental, Social and Governance (ESG) report identifies the following short and medium actions, as well as sector assessments performed to date.

an The bank's ESG report covers mitigation-related disclosures, though this case study focuses on adaptation / physical risks, so mitigation-related activities are not covered here.

Short Term Actions	Medium Term Actions	Recent Assessments
▪ Our initial focus is on our existing clients in the **agricultural** sector, where diversification and medium- to long-term business plans need to include climate adaptation and resilience considerations. ▪ We will also be **identifying opportunities to finance infrastructure that improves adaptation and resilience, such as flood control, water efficiency and water storage**.	Based on an understanding of climate-related risk in our portfolio, we will assess opportunities for the bank to support adaptation action by clients in the following sectors: ▪ **Agriculture** (research and advice to clients, diversification of crops and products, food security, water efficiencies, flood mitigation, changing temperature/ecosystem mitigation) ▪ **Water-intensive industries**, including mining (water efficiency measures, desalination / water treatment projects) ▪ **Urban developments and infrastructure** (flood management measures, water efficiency measures) ▪ **Coastal developments** (coastal flood risk management measures to cope with rising sea levels, extreme weather events).	Our focus is on both **physical risk** and transition risk. Where we have significant exposure, we will develop short- and medium-term actions to manage this. In the short term, we'll be working with qualitative assessments of these sectors. In the medium term, we'll use scenario-planning and stress-testing methodologies to ensure risk management actions have sustainable outcomes. Management actions will cover physical and transition risk management and opportunity development.

Standard Bank's Sustainable Bond Framework

Standard Bank's **Sustainable Bond Framework** allows the bank to issue sustainable, green and social bonds that support its lending to green projects aimed at mitigating and **adapting** to climate change (including **physical risks** related to climate change), and social projects reducing economic and social inequality.

Standard Bank allocates the net proceeds of the sustainability bonds issued under this framework to an eligible loan/asset portfolio of new and/or existing loans/assets within categories aligned to the bank's SEE impact areas (including Climate Change and Sustainable Finance).

The **'Climate Adaptation' investment category of the Framework** includes eligibility criteria for the financing or refinancing of investments in projects (including assets or activities) that are intended to address physical climate-related risks. These criteria include projects that clearly demonstrate an understanding of the underlying climate-related risk that the investment is addressing. The investments also need to demonstrate that ongoing evaluation of resilience benefits is conducted, as well as external sustainability certification of agribusiness projects that seek to increase resilience against (physical-related) climate risks.

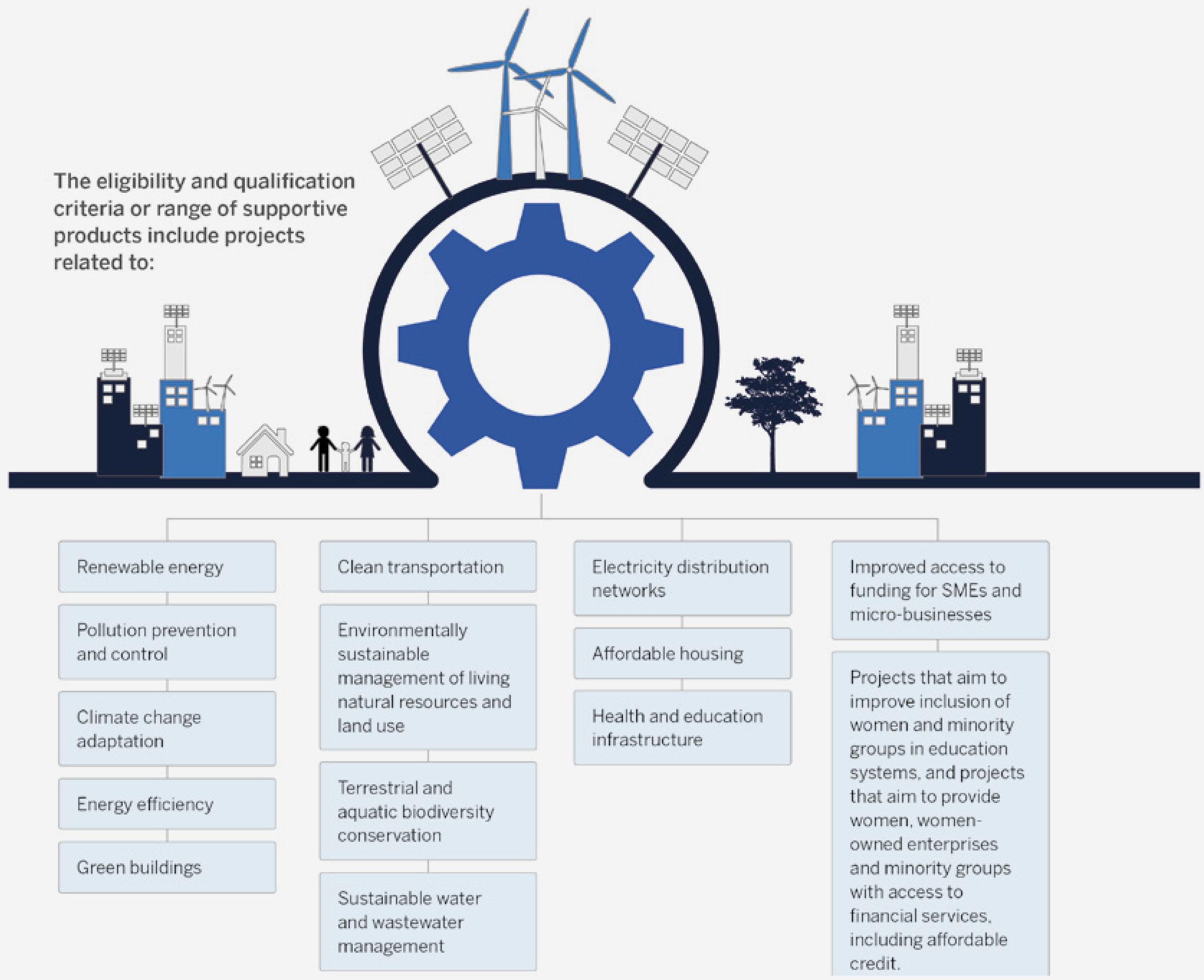


Figure 6.5: Projects which may be eligible for sustainable, green and social bonds under Standard Bank Group's Sustainable Bond Framework. Source: Standard Bank: https://sustainability.standardbank.com/documents/ESG-Sustainable-finance.pdf

Showcase on sustainable finance for climate adaptation and mitigation

- In March 2020 the Standard Bank of South Africa issued its first ever green bond, via private placement with the International Finance Corporation (IFC). This is a 10-year facility with the express purposes of raising capital for use in on-lending by Standard Bank Group's ("SBG") Sustainable Finance Business Unit.
- The USD200 million, London Stock Exchange-listed green bond is Africa's largest green bond and South Africa's first offshore green bond issuance.
- The capital raised will be used to finance eligible green assets, including in renewable energy, energy efficiency, **water efficiency** and **green buildings** aligned to SBG's Sustainable Bond Framework.
- The transaction addresses four of the UN's Sustainable Development Goals (SDGs) including Climate Action.

Additional information

Public sources available for further review.

1. Carbon Disclosure Project (CDP) public disclosures
2. Standard Bank Group – Environmental Social and Governance Report 2019
3. Standard Bank Group – Sustainable Bond Framework
4. Standard Bank Group – Report to Society 2019
5. Standard Bank Group-wide policy on lending to coal mining operations
6. Standard Bank Climate Change Resolutions 2020 – Press Statement
7. Standard Bank issues inaugural Green Bond – Press Statement

7. Future directions

7.1. Charting the way forward

The growing engagement on climate change among financial industry regulators has been the most notable development for the industry since the UNEP FI Phase I banking pilot. Regulators are developing requirements for banks to assess and disclose climate risks and opportunities, including through stress testing. Scenarios, tools and data for climate risk and opportunity assessments need to be aligned with these requirements. They also need to be transparent to provide assurance and comparability of results. Banks in the Phase II pilot have flagged that there is currently a misalignment between these emerging requirements and the status of physical risk tools and data. This tension will, not doubt, stimulate further innovation to bridge the gap. The past few years have already witnessed significant growth in the provision and application of scenario-based tools and data, as well as TCFD reporting by financial institutions. It is also noteworthy that banks have not yet focused sufficient attention on their pivotal role in financing clients' investments in adaptation.

The modules developed through the Phase II program have created a blueprint with tools and data to help banks make progress. They provide rich technical guidance and information to support forward-looking scenario-based assessments of physical risks and opportunities. Phase II has also flagged up practical constraints that remain to be overcome:

- **The portfolio physical risk heatmapping has demonstrated the benefits of looking across the whole portfolio to focus 'deep-dive' assessments of risks and opportunities where they are most needed.** Heatmapping has demonstrated how to handle the richness and complexity of physical climate risk in an efficient manner. However, discussions among the piloting banks revealed different opinions about the relative vulnerabilities of sectors and sub-sectors, and the extent to which counterparties were already positioned to cope with future climate change. Further work will be required if a consensus is to be reached.
- **Tools, analytics and geospatial data enabling physical risk assessment by banks have evolved a lot in recent years, but they require further development. Banks also need to understand and evaluate them, working with providers to ensure their needs are met.** The available tools and analytics lack depth and data across the entire value chains of counterparties as well as the macroeconomic environment. More sophisticated analytics and geospatial data are required to reduce the burden on banks undertaking assessments, and these will need to be supported by improved engagement between banks and counterparties:
    - Even where tools incorporate geospatial data on the locations of counterparties' physical assets, they do not take account of asset design characteristics, age and condition – all of which are relevant to understanding how climate hazards will affect asset performance. Initiatives such as the Spatial Finance Initiative and its GeoAsset project are helping to facilitate access to consistent geospatial datasets.
    - Physical risks to counterparties' supply chains and market demand are typically currently assessed by analytics providers using sector- or country-level trade data and sector input-output tables. These approaches reflect a lack of data on individual suppliers and customers of bank's counterparties, which prevents a thorough analysis of impacts on counterparties' value chains.
    - Climate risks facing unlisted companies / SME counterparties are often unknown, while these companies can make up a large share of banks' portfolios. They are not currently engaged in any form of public climate risk disclosure reporting and have often not undertaken assessments. Where assessments are done by unlisted companies / SMEs, there is no standardized reporting which limits the potential to collate and compare the outputs.
    - The ability of counterparties to adapt to and cope with physical risk is not often captured in tools and analytics, with the exception of sovereigns.
    - More effort is needed to reduce uncertainties about the scale of the macroeconomic impacts of climate change. Estimates of impacts on GDP need to be refined, and research is needed to improve understanding of how physical climate risks could affect other macroeconomic indicators such as inflation and interest rates.

- **Correlation analysis has proved to be a useful technique for exploring linear associations within data and is a first step towards more advanced statistical analysis of relationships between financial metrics and climate-related data.** Correlation studies have demonstrated that extreme events are already impacting financial portfolios. The Phase II pilot has identified a large body of research on correlation analysis and other statistical and modelling approaches for uncovering climate signals in financial data for the real estate and agriculture sectors. Banks can build upon this literature to develop their own analyses using empirical data on their portfolios. There is high potential for banks to use these techniques, which should be further explored.
- **Few banks have yet evaluated potential opportunities to support clients' investments in adaptation.** The Phase II pilot has flagged up the critical role of banks in mobilizing financial flows for adaptation, following their commitments to align with the Paris Agreement. Yet so far, banks have generally paid more attention to physical risks than to opportunities. Banks could be supported by more comprehensive market assessments of adaptation investment needs for sectors and countries, which identify the scale and timing of demand for finance, and whether it should come from private or public sources. Direct communication with counterparties on their adaptation investment needs, as highlighted below, could provide even better data.
  - Relatedly, with many green or sustainability taxonomies emerging, banks will face challenges in aligning their finance for adaptation with them, particularly where they operate in multiple geographies. Harmonization of adaptation taxonomies globally, guided by principles with common interpretation across geographies, can help to overcome this challenge.

7.2. Building the climate risk and opportunity ecosystem

UNEP FI is developing its next-generation TCFD programs with its banking and investor groups, including engagement with financial regulators, climate modelers and data providers. The programs aim to provide a platform for dialogue with financial supervisors to share perspectives on climate risk and financial stability, taxonomies, climate-related regulations and climate stress tests.

Banks will benefit from strengthening dialogue with counterparties on the nature and drivers of physical climate risks and opportunities, and counterparties' strategies to manage them. Given the challenges faced by banks in evaluating physical climate impacts and adaptation needs of counterparties, the Phase II pilot banks have flagged that engagement can help raise awareness of physical risks by both groups, improve the quality of risk assessments, and facilitate more effective climate-resilient investment strategies.

Corporate disclosures in line with TCFD recommendations can inform banks' own risk and opportunity assessments. There are emerging examples of new regulatory expectations for climate risk and opportunity assessment and disclosure by corporates in some jurisdictions (see the non-exhaustive examples in Box 1.1). As corporates disclose their climate-related risks and opportunities, banks and other financial institutions can look to these disclosures to inform their own.

Box 7.1: Examples of emerging regulatory expectations on disclosure for corporates

UK: The UK released a green finance strategy in 2019, which sets out the UK government's expectation for all listed companies and large asset owners to disclose in line with the TCFD recommendations by 2022.[99] The UK Financial Conduct Authority (FCA) has published proposals outlining disclosure requirements for premium listed issuers consistent with the TCFD recommendations on a comply-or-explain basis for premium listed issuers.[100]

Canada: The continuous disclosure regime set out in National Instrument 51-102 *Continuous Disclosure Obligations* requires reporting issuers in Canada to disclose material risks affecting their businesses and, where practicable, the financial impacts of such risks in their annual information form (AIF) and management's discussion and analysis (MD&A).[101] Furthermore, large companies receiving Canadian government support during the COVID-19 pandemic through the Large Employer Emergency Financing Facility (LEEFF) will be required to publish annual TCFD reports, including disclosures on how their future operations will support environmental sustainability and national climate goals for net zero by 2050.[102]

Australia: In August 2019, the Australian Securities and Investments Commission (ASIC) released its revised Regulatory Guides 228 and 247. The guides now incorporate the types of climate change risk described by the TCFD into the list of examples of common risks that may need to be disclosed in a prospectus. The prospectus highlights risks that may need to be disclosed in the operating and financial review in an annual report.[103] The Australian accounting and auditing standards boards have published guidance on climate risk assumptions in accounting estimates and in the financial statements, bringing climate risk disclosures within the remit of external audit scrutiny.[104]

Dialogue between banks, governments and insurers will help all actors to support each other in assessing and managing physical risks. This issue was flagged in the 'Navigating a New Climate' report which noted that, along with financial supervision roles, governments provide essential adaptation measures such as flood defenses, climate-related standards for infrastructure, disaster risk management systems, and financial backing for insurance schemes. Government policy and regulation on adaptation can therefore have profound impacts on the risks facing banks' borrowers. The future responses of the insurance industry to intensifying climate risk (e.g. regarding insurance availability and pricing) will also have a key influence – and will interact with adaptation actions taken by governments. Fora where banks can engage in dialogue with governments and insurers will help banks to understand and influence this agenda.

The Phase II program has facilitated engagement between banks, data and analytics providers, and climate science organizations which can be deepened in the future. The interactions have helped the banks to access and evaluate climate services providers. They have also enabled providers to have deeper insights into banks' needs, and to provide feedback on what can, and can't be delivered at present. Banks in the Phase II pilot have also connected with government agencies and research councils who can provide country-specific data and earth observation data from remote sensing instruments (e.g. satellites). It is hoped that these relationships will strengthen over time, driving further improvements.

Understanding and management of systemic risk must also improve if a robust response to climate change is to be achieved. This report is published in the wake of the COVID-19 pandemic which has led to a significant increase in systemic risk in the banking sector.[105] Like climate change, the COVID-19 virus has affected multiple geographies and sectors at the same time. COVID-19 has demonstrated the limits to current risk management practices, which are invariably focused on fragmented appraisal and management of risk. The World Economic Forum Global Risks Interconnections Map 2020 highlights the systemic nature of climate change and its interactions with other risk factors (Figure 7.1). The number and strength of the connections between 'climate action failure', other climate change-driven risks, and with the other risks identified in the figure emphasizes that a changing climate affects many aspects of the global economy. Its impacts will ripple through value chains and to banks providing working capital and finance for client growth and investment.

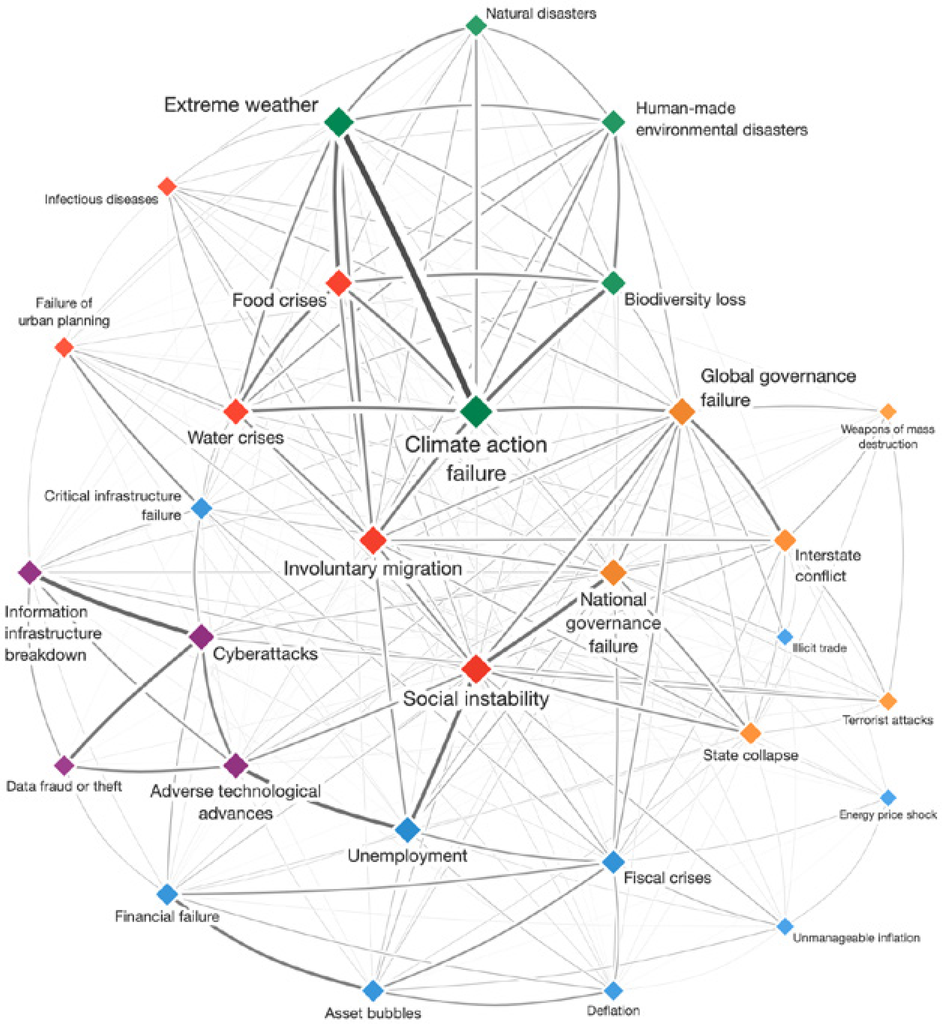


Figure 7.1: The Global Risks Interconnections Map 2020. Source: World Economic Forum.[106]

Banks have a key role in financing 'green' and climate resilient recoveries from the economic consequences of COVID-19 which fully integrate the obligations of the Paris Agreement and the urgency of action on climate change. Climate change remains the greatest threat to the planet, and recovery plans in the aftermath of COVID-19 must recognize the urgency to stabilize the climate and manage the impacts of climate change. Banks will play a pivotal role in financing the recovery.

Appendix A:
Correlation analysis studies for real estate

Table A.1 Studies of flood, wildfire and other climate impacts on real estate with method of analysis, input variables and financial indices.

Technique / Model	Variables	Predicted indices	Location	Ref
Before/after analysis	• Damage to property caused by Hurricane Harvey • Property location and reconstruction costs • Damage adjusted mortgage loan to value	90+ day delinquency rate (%) when compared to delinquency rates six months prior to the hurricane	Texas, California U.S.	107
Before/after analysis	• Most damaging 10 hurricanes • Apartment, industrial, hotel, office and retail property values	One- and two-year impact on property values (% change)	U.S.	108
Before/after analysis (regression)	• Mortgage and housing market data (mortgage applications and originations, payment history, credit risk score, rents and house prices) • Atlantic hurricanes between 1851 and 2018 (frequency and intensity) • At risk areas (identified from sea-level rise, elevation, and land use data) • Bank branch network and balance sheet information	Loan denial rates, price-to-rent ratios, delinquency and foreclosures post-hurricane	18 Atlantic States, U.S.	109
Discriminant analysis	• Flood depth, frequency and intensity • Frequency of severe floods • Distance to flood-prone river	Discriminating factors of flood insurance purchase and non-purchase for flood-hit residential properties	Malaysia	110
Generalized additive model	• Flood risk (location within flood-prone area and site 100-year flood depth) • Property characteristics (type, year built, living area, floors)	Property rents and value	Germany	111
Hazard index	• High water levels for minor (>0.50 annual exceedance probability), major (0.05 to 0.50 probability) and extreme (<0.05 probability) • Sea level rise scenarios (plus 1 to 10 feet) • Exposed property value	Cumulative exposure or cost of flooding due to minor, major and extreme coastal flooding under 10 sea level rise scenarios	11 coastal cities, U.S.	112

Technique / Model	Variables	Predicted indices	Location	Ref
Hazard index	• Sea level rise scenario • Wind speed, direction and fetch • Waves • Storm surge potential • Habitat and shoreline type • Elevation	Coastal hazard index / map showing residential property value and populations exposed to flooding with and without shielding by natural habitats	U.S. coastline	113
Hedonic pricing analysis	• Property price and geographical coordinates • Building and lot area, age category of the structure, number of bedrooms, bathrooms, undercover car spaces, levels • Distances to key spatial features (river, industry, train, bikeway, bus stop, parks, school, shops, waterway, central business district) • Land parcel height, 100-year flood level	Property price discounting (%) per meter below the 100-year flood level Impacts of sea-level rise on % of properties and price of properties exposed to 100-year flood events	Brisbane, Australia	114
Hedonic pricing analysis	• Property characteristics (age, living area, number of bedrooms/bathrooms, swimming pool) • Property location (Fire Hazard Severity Zone, wildland-urban interface, distance to national forest, distance to burn scar, elevation, slope) • Neighborhood characteristics	Change in property value (%) due to burn scar view	California	115
Hedonic pricing analysis	• Extreme weather event (unspecified) • Location-specific hazard function • Property-specific vulnerability	Expected annual loss ($) to property value	Europe	116
Hedonic pricing analysis	• Sites within the 500- and 100-year flood zone for inland and coastal areas • Time elapsed since last flood	Change in property value (%)	Global meta-analysis (mostly U.S)	117
Hedonic pricing analysis	• Flood hazard / flood-prone areas • Market price (price of lot, dimension of parcel, availability of public services)	Difference in price (per square feet) for lots with and without flood risk	La Plata, Argentina	118
Hedonic pricing analysis	• Property location (inside or outside coastal hazard zone) • Coastal erosion prediction map (published before or after sale) • Property characteristics (decade of construction, floor area, site area, interior/exterior quality, land gradient, sea view, lease)	Difference in property value ($) due to the disclosure of property-specific information about sea-level rise	New Zealand	119
Hedonic pricing analysis	• Flood affected and bushfire affected property characteristics (# of bathrooms, bedrooms, amenities e.g. carport, swimming pool) • Locality or neighborhood attributes • Environmental characteristics - pollution levels and distance to environmental risk area	Change in residential property value (%)	Queensland, Australia	120

Technique / Model	Variables	Predicted indices	Location	Ref
Hedonic pricing analysis	• Flood zone indicator • Home / property characteristics • 'Climate Attention Index' (frequency of mention of climate-related terms e.g. hurricanes or floods in for-sale listings)	Property and rental values	U.S.	121
Hedonic pricing analysis	• Price of residential coastal property • Property characteristics • Physical beach quality attributes • Distance from oceanfront • Width of beach at property location	Value ($) of beach width capitalized in property values	U.S., coastal	122
Hedonic pricing analysis (difference-in-difference)	• Wildfire characteristics (extent, ring zone, size, length) • Mortgage characteristics and performance • Mortgage geolocation and property characteristics • Weather (temperature, number of days with precipitation)	Change in 90-day delinquency and foreclosure 6 months after wildfire	California	123
Hedonic pricing analysis (difference-in-difference)	• Property sale date and price • Building type (e.g. single-family home, condo, etc.) and borough • FEMA building damage estimates, storm surge area, and flood depths • Hurricane evacuation zones	Change in property values (%) in flood zones before/after Hurricane Sandy	New York City, U.S.	124
Hedonic pricing analysis (repeat sales)	• Property type (detached, terraced, flat, rural, freehold) • Flood type (sewer, coastal) • Flood defenses • Flood history (duration, frequency) • Property price and sale dates	Change in property price (%) by flood type (inland, coastal) and years after flooding	England	16
Hedonic pricing analysis (repeat sales)	• Property price and sale dates • Building and lot area, year built, distance to central business district • 'Building footprint' (rather than property parcel) is within or intersects the FEMA 100-year floodplain	Difference in property sale price (%) depending on floodplain or tax lot designation	Portland, Oregon, U.S.	125
Hedonic pricing analysis (repeat sales)	• Floodplain designation (within or outside) • Repeat sales indices (same property) • Property details and locational variables • Flood history	Mean discounted growth rate for properties inside and outside the floodplain, and for frequently flooded locations	UK	126
Monte Carlo simulation	• Topography (elevation, slope, aspect) • Forest fire occurrence and burn probabilities (from multiple ignition points)	Potential loss of land value per parcel	Gyeongju, South Korea	127

Technique / Model	Variables	Predicted indices	Location	Ref
Regression (linear mixed effects) model	• Property characteristics (new build, type, leasehold, age) • Property location (elevation, proximity to coast, lake or watercourse, site has flooded) • Resident characteristics (ownership, education) • Community characteristics (population, health, greenspace, income, council tax band)	Change in property value (%) with proximity to water and location in floodplain	England	128
Regression analysis	• Property construction year and elevation • Property information (price, date of sale)	Price appreciation index by elevation band and jurisdiction	Miami-Dade, Florida, U.S.	129
Regression analysis	• High sea water levels (sea level rise projections, tide gauge trends) • Flooding (proportion of road surface and lot) • Property lot elevation and location • Property value (price per square foot)	Accrued loss ($) of property value due to recent sea level rise (2005–2016) for properties projected to be inundated by tidal flooding in 2032	Miami-Dade, Florida, U.S.	130
Regression analysis	• Sea level rise exposure • Property elevation • Distance from coast • Buyer / seller information • Property type	Change in property value (%)	U.S.	131
Regression analysis	• Temperature anomaly (36-month moving average) • Borrower characteristics (debt-to-income, income, and fraction of minority applicants) • Local economy (employment growth, wages growth, and population growth)	Change in mortgage approval rate (%) Change in loan amounts (%)	U.S.	132
Regression analysis	• Region (south, other) • City metrics (median house value, rental vacancy rate, rentals as percent of all housing, population size and growth rate, new rentals, racial composition, median income, unemployment, landlord professionalism, anti-war campaigning, same-sex households) • Climate (unspecified)	Monthly median rent price per city	U.S., cities	133
Stochastic dynamic model	• Beach erosion rates (with sea level rise, increased storminess) • Beach width (erosion and nourishment) • Coastal property value • Cost of beach nourishment • Storm return frequency	Change in property value (%) associated with removal of beach nourishment subsidies	North Carolina, U.S.	134
Vulnerability index	• Map of maximum flood extent during Hurricane Florence (based on FEMA high-water marks and radar remote-sensing data) • Property area and values exposed to a Florence flood (actual, 10, 50 or 100 years ago) based on year of construction	Total value of property exposed to flooding during Hurricane Florence (presently and historically)	Carolinas, U.S.	135

Technique / Model	Variables	Predicted indices	Location	Ref
Vulnerability index	• Indicators of flood exposure (elevation at 5 m spatial resolution, distance from the coast, and FEMA flood zones) • Indicators of readiness (stormwater drain locations, seawalls, green buildings, artificial reefs, monument locations, dune restoration areas, mangrove locations, and seagrass bed locations)	City vulnerability index (4 zones)	Miami, Florida	136
Vulnerability index	• Nature and experience of flooding, impact and recovery measures taken for risk reduction • Perceptions on flooding and its impact on vulnerability of property value (involving property usability, desirability and marketability indicators) • Demographic information related to the business and property ownership	Index of value of commercial properties based on flood risk perception	UK	137

Appendix B:
Correlation analysis studies for agriculture

Table B.1 As in Table A.1 but for extreme weather, average climate and non-climatic impacts on the agricultural sector.

Technique / Model	Variables	Predicted indices	Location	Ref
Canonical correlation analysis	• Yield, area harvested and value of six crops (cotton, corn, peanut, soybean, tomato, and tobacco) • ENSO phases and quarterly sea surface temperature anomalies in the eastern equatorial Pacific (Niño3 region)	Change in areas, yields and values of crops (%) with ENSO phase	Alabama, Florida, Georgia, South Carolina, U.S.	138
Correlation analysis	• Winter wheat and maize yields for selected sites in each country • Agrometeorological indices (e.g. number of days with extreme temperatures, dry conditions, snow cover characteristics, water balance, suitability for harvesting and sowing)	Correlations between crop yields and indicators of adverse weather during the growing period	Austria, Croatia, Serbia, Slovakia, Sweden	139
Correlation analysis	• Corn yields from 1982 to 2014 • Derived normalized difference vegetation index (NDVI) • El Niño and La Niña years	Detrended corn yield anomalies (bushels per acre) under El Niño and La Niña	Corn belt, Midwest U.S.	140
Correlation analysis	• National and state-level crop production (rice, wheat, sorghum, groundnut and sugarcane) • Indian monsoon rainfall index • Climate modes (Niño3, Indian Ocean sea surface temperatures, Darwin sea level pressure)	Correlations between crop production and variations in monsoon rainfall, and selected modes of climate variability	India	141
Correlation analysis	• Rain-fed crop yields (wheat and barley) • Weather data to calculate the aridity index (maximum and minimum temperature, sunshine hours, relative humidity, windspeed, precipitation) • Climate modes (AO, NAO and Niño3.4)	Detrended crop yields related to an aridity index and climate modes	Khorasan province, Iran	142
Correlation analysis	• Observed and simulated rice yields at provincial and field level • Daily weather variables and Niño 3 index	Correlation between de-trended rice yields and ENSO for irrigated and rain-fed systems	North and North-west, China	143
Correlation analysis	• State- and county-level corn yield data from 1895 to 2014 • Drought indices (e.g. Palmer Drought Severity Index, Standardized Precipitation Index, Palmer Z-index)	Correlations between de-trended state-level corn yield anomalies and drought indices	U.S.	144

Technique / Model	Variables	Predicted indices	Location	Ref
Generalized linear model	• Loan portfolio (by crop and geographical zone [altitude] of production) • Counts of exposures and defaults from loans • Unspecified macro-economic factors and product-specific price volatility • Climate variables (mean temperature and rainfall series by altitude group)	Frequency of default loans (%) in rural bank portfolios due to commodity price volatility and climate	Colombia	145
Hedonic pricing analysis	• Farmland revenue • Unspecified crop and farm variables for irrigated and non-irrigated counties • Unspecified climate variables	Change in farmland value ($ billion) under a 5°F increase in temperature and 8% increase in precipitation for dryland and irrigated counties	U.S.	146
Macro-agronomic model	• 'Field' level crop output based on the Global Agro-Ecological Zones project (50 countries, 10 crops) • Daily output from a climate model • FAOSTAT data on worldwide production and trade • National non-agricultural GDP • Determinants of trade costs	Change in GDP (%) from agricultural markets due to climate change	Global	147
Monte Carlo simulation	• Dairy farm budget (e.g. labor, fuel, feed, water, repairs, weed control) • Commodity prices (milk solids, cow beef, lamb, steer beef, mutton, wool and hay) • Annual rainfall	Economic risk profile ($) for irrigated versus non-irrigated farms	New Zealand	148
Monte-Carlo simulation	• Mean and variability of yields (wheat, barley, rapeseed) from samples of individual farms • Rainfall to design location-specific weather index insurance • Climate response functions for each crop, by country • Risk management policies (individual yield, area-yield, and weather index insurance or ex-post payments)	Optimal risk management policies and associated budgetary costs to manage crop yield variability under baseline, climate change and extreme events	Australia, Canada, Spain	149
Multivariate copula functions	• Mean winter wheat yields for five major wheat producing states • Climate indices (e.g. Niño3.4, Southern Oscillation Index, Indian Ocean Dipole)	Changes in wheat yield (%) with large scale climate indices	Australia	150
Regression analysis	• Average yields for corn, soybean and barley from field trials • Weather data to calculate crop heat units, effective growing degree days, water deficit and rate of accumulation of degree days (from maximum and minimum air temperatures and precipitation) • Climate change scenarios for 2040 to 2069	Change in average yields (%) of corn, soybeans and barley related to agroclimatic indices and climate change	Eastern Canada	151
Regression analysis	• Loans data (delinquent >30 days [%], delinquent> 90 days [%], total charge offs [%], non-real estate loans [%], real estate loans [%], total loans [$ millions]) • Assets data (total [$ millions], land value [$ billions]) • Farm data (number in state [millions], coverage ratio [state level], indemnity [$ millions, state level], farm output price / input price) • Other data (interest rate index, number of new loans) • ENSO index (Japan Meteorological Agency Multivariate ENSO Index)	Change in the share of delinquent loans (%) related to ENSO	Southeast U.S.	152

Technique / Model	Variables	Predicted indices	Location	Ref
Regression analysis (probit and logistic)	• Credit risk variables (repayment capacity, liquidity, solvency, profitability, financial efficiency, turnover) • Borrower data (age, gender, education, farm size, farming years, farm income, debt, debt-to-assets, assets, net worth, loan repayment) • Loan data (amount, interest rate, age, term, type, balance) • Lender data (region, ability to modify loan) • Macroeconomic data (unemployment rate, per capita income) • Climate data (annual mean temperature, annual precipitation)	Loan delinquency rates (%) linked to farm-level financial information on credit worthiness and repayment capabilities	Southeast U.S.	153
Regression analysis (probit)	• Risk management strategies (for price, climate, biological and financial) • Socio-economic variables (age, education, experience, off-farm income, farm size, proportion of own land) • Risk perceptions (for price, climate, biological and financial) • Management technologies • Access to information and credit (formal and informal)	Likelihood of adopting risk management strategies in cotton production	Punjab, Pakistan	154
Regression analysis (quantile)	• Farm business indicators (operating profit per hectare, retained profit per hectare, return on capital, business equity and debt-to-income ratio) • Wheat yield, percent of farm area in crop, operating cost per hectare • Drought incidence by production year and frequency over the decade	Changes in five farm business indicators related to annual and multi-year drought frequency	Western Australia	155
Ricardian analysis	• Farmland revenue • Seasonal temperature and precipitation • Farm soils, elevation, distance to cities and ports, rented, subsidies • Country	Sensitivity of land value (%/ha) to seasonal temperature and precipitation for rainfed, irrigated, specialized field crops and livestock farms	Europe	156
Ricardian analysis	• Farm variables (revenue, land value, agricultural area, share rented land, mean elevation, slope index, latitude, longitude, farmer age) • Climate variables (seasonal mean temperature and precipitation) • Socio-economic and geographic variables (population density and growth, density of conventional dwelling, density of tourist establishments) • Soil characteristics (gravel and sand fraction, nutrient status, pH) • Climate change scenarios (8 climate models, 2 emissions pathways)	Change in net revenues (%) due to seasonal changes in temperature and rainfall	Italy	157
Ricardian analysis	• Farm variables (crop net revenues, age, gender and education of household head, cultivated area and mode, size of household, irrigation water use, access to extension services and credit) • Climate variables (dry/wet season temperature and precipitation) • Adaptation measures • Climate change scenarios for 2050 and 2100	Change in net revenue (%) under climate change scenarios	Northwest Vietnam	158

Appendix C: Acronyms and abbreviations

AI	Artificial intelligence
AIF	Annual information form [Canada]
AMO	Atlantic Multi-decadal Oscillation
AO	Arctic Oscillation
API	Application Programming Interface
AR5	Fifth Assessment Report [of the IPCC]
BAU	Business-as-usual
BES	Biennial Exploratory Scenario [of the Bank of England]
BS	Balance sheet
CAPEX	Capital expenditure
CBI	Climate Bonds Initiative
CMBS	Commercial mortgage-backed security
CMIP5	Coupled Model Inter-comparison Project Phase 5
CML	Commercial mortgage loan
COGS	Cost of goods sold
COP	Conference of the Parties [of the UNFCCC]
CPI	Climate Policy Initiative
CRIS	Climate risk impact screening
CRT	Credit risk transfer security
CVaR	Climate Value at Risk
EAD	Exposure at default
EBRD	European Bank for Reconstruction and Development
ENSO	El Niño-Southern Oscillation
ESG	Environmental, Social and Governance
EU	European Union
FCA	Financial Conduct Authority [of the UK]
FD	Fire Danger [index]
FIRMS	Fire Information for Resource Management System [of NASA]
FSB	Financial Stability Board
GARI	Global Adaptation & Resilience Investment [Working Group]
GCM	General Circulation Model
GDP	Gross domestic product
GFDRR	Global Facility for Disaster Reduction and Recovery
GFH	Geospatial Financial Hub [of Airbus]
GHG	Greenhouse gas
GIS	Geographic information system
HVI	Home Value Index
ICMM	International Council on Mining and Metals
IDA	International Development Association
IFC	International Finance Corporation
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
ISIC	International Standard Industrial Classification
ISIN	International Securities Identification Number
KBDI	Keetch Byram Drought Index
KNMI	Koninklijk Nederlands Meteorologisch Instituut (Royal Netherlands Meteorological Institute)
LEEFF	Large Employer Emergency Financing Facility
LGD	Loss given default
LMF	Loss Modelling Framework [of Oasis]
LTV	Loan to Value
MD&A	Management's discussion and analysis [Canada]
MODIS	Moderate Resolution Imaging Spectroradiometer [of NASA]
NAO	North Atlantic Oscillation
NAP	National Adaptation Plan
NASA	National Aeronautics and Space Administration [USA]
NCEI	National Centers for Environmental Information
NDC	Nationally Determined Contribution
NGFS	Network for Greening the Financial System

NOAA	National Oceanic and Atmospheric Administration
NWG	NatWest Group
OPEX	Operating expenditure
P & L	Profit and loss
PAT	Portfolio Analysis Tool [from Climate Central]
PCA	Princeton Climate Analytics
PD	Probability of default
PDO	Pacific Decadal Oscillation
PRB	Principles for Responsible Banking
PREP	[The] Partnership for Resilience and Preparedness
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
REIT	Real estate investment trust
RoI	Republic of Ireland
RMBS	Residential mortgage-backed security
RWA	Risk-weighted asset
SBG	Standard Bank Group
SDG	Sustainable Development Goal [of the United Nations]
SIB	Social impact bond
SME	Small or Medium-sized Enterprise
SST	Sea surface temperature
TCFD	Task Force on Climate-related Financial Disclosures
TEG	Technical Expert Group
TR	Taxonomy Regulation
UN	United Nations
UNEP	United Nations Environment
UNEP FI	UN Environment Programme Finance Initiative
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	Now UNDRR - UN Office for Disaster Risk Reduction
VIIRS	Visible Infrared Imaging Radiometer Suite [of NASA]
WCRP	World Climate Research Programme
WMO	World Meteorological Organisation
WRI	World Resources Institute

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