Ceres

THE CERES ACCELERATOR FOR SUSTAINABLE CAPITAL MARKETS

FINANCING A NET ZERO ECONOMY

The Consequences of Physical Climate Risk for Banks

SEPTEMBER 2021

About Ceres

Ceres is a sustainability nonprofit organization working with the most influential investors and companies to build leadership and drive solutions throughout the economy. Through powerful networks and advocacy, Ceres tackles the world's biggest sustainability challenges, including climate change, water scarcity and pollution, and inequitable workplaces.

About the Ceres Accelerator for Sustainable Capital Markets

The Ceres Accelerator for Sustainable Capital Markets (the "Ceres Accelerator") aims to transform the practices and policies that govern capital markets in order to accelerate action on reducing the worst financial impacts of the global climate crisis and other sustainability threats. The Ceres Accelerator will spur capital market influencers to act on these systemic financial risks and drive the large-scale behavior and systems change needed to achieve a net-zero carbon economy and a just and sustainable future. For more information visit: ceres.org/accelerator.

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FOREWORD

Climate change poses systemic risks to our financial sector and economy. These risks are well known and highly probable, but they are inaccurately priced. That is due in large part to banks' historic tendency to treat climate change as a reputational risk, and address it through a lens of corporate social responsibility. They may phase out their financing of the most unpopular activities, like thermal coal or Arctic drilling, but these firms continue to underwrite, lend to, and invest in companies at every stage of the fossil fuel value chain. Climate change is not an exogenous shock. Banks cannot continue to finance the activities that accelerate climate change today and avoid the inevitable costs tomorrow.

There is no longer anything atypical about the intensity or frequency of climate-induced disasters. They will continue increasing in a nonlinear fashion, and the resulting economic and financial impacts will not be short term. Entire areas will become uninsurable and assets will face revaluation; banks will see both a higher probability of loan defaults, and higher losses in the event of default.

For banks and credit unions with more concentrated geographical footprints, these risks could be existential—and a wave of distress among these smaller institutions could, in itself, be systemic. The interconnectedness of our financial system means stress can spread quickly, amplifying and transmitting disruption throughout the economy. Our nation's largest banks should not assume, as they did in the 2008 crisis, that they are insulated from the reckless decisions of their peers, or nimble enough to avoid destabilizing losses from climate damages.

This report sets out a practical roadmap for banks to measure and mitigate their exposure to physical risks. Bank executives must start integrating climate change into their core risk management and strategic planning functions, rather than relegating climate considerations to sustainability divisions. This should include scenario analysis and stress tests to identify risks at the asset level and enable portfolio-wide decision-making.

But the market will only go so far on its own. It is the government's responsibility to establish clear expectations for what constitutes risk management, but U.S. regulators have long downplayed their responsibility for climate risks. Bank regulators like the Federal Reserve and the Comptroller of the Currency now acknowledge the severity of climate-related threats to financial stability, but they must incorporate climate risks into their day-to-day supervisory responsibilities. Climate-related stress tests on individual financial institutions should be an important component of this work.

Finally, addressing physical climate risks has the potential to be disruptive. The costs of such an accounting cannot fall disproportionately on the residents and business owners in vulnerable communities. I applaud the authors of this report for highlighting the importance of financing adaptation projects that will mitigate credit risk and maintain insurance affordability. Banks' efforts to address climate risks must take into consideration the needs of the communities they serve.

—U.S. Senator Brian Schatz

FOREWORD

Right now, someone's home is melting, a family is tossing its things in the car to flee a tornado or a wildfire, a person is being led to a shelter from the burning heat. The events of this summer have laid to rest the idea that climate induced damage is abstract, something future based that might or might not happen. Even speaking of it as a risk suggests that the cost and physical damage associated with climate events is something for another day, another government, another group of policymakers, or another set of business leaders to tackle. This summer we see that the costs and damage are with us now; they are not matters for another day. Solutions are no longer for just the future; they are needed now.

Fortunately, just at the moment when we wonder what form those solutions might take and how long we're going to have to wait for them to help put us out of harm's way, we are given the benefit of a new Ceres report, **Financing a Net-Zero Economy: The Consequences of Physical Climate Risk for Banks**. We turn the pages here to learn about the financial impact of specific climate hazards—seven in fact—and how these hazards are mapped onto the value of financial assets. Here we have the contours of an assessment of climate physical risk for our financial institution C-suites to consider, an assessment that permits them to reimagine the steps they can take in terms of measurement, mitigation, and pricing. This is an assessment that describes what happens to asset values when the force of hazards–floods, wildfires, storms, heatwaves, falling agricultural yields, energy supply losses—run roughshod, unpredictably, and wildly—over tangible things of value. This is an assessment that considers the conservation of asset values not merely as a "nice to have," but a "must have" as it pertains to a firm's total enterprise-wide value. This is an assessment that quantitatively reveals linkages between climate-related events and delinquencies, defaults, collateral values and the value of stranded assets.

Importantly, it's an assessment that is detailed and specific, ready for risk management teams at financial firms to read, consider, adapt and implement.

Our imaginations are being pushed forward. Realizing that there are costs and consequences of a climate altered society no longer implicates merely a financial firm's reputation. The costs and consequences are now of such import and magnitude to a financial firm's foundation that they demand a more thorough embedding within the firm's analytical and mitigation efforts. When it comes to physical risk, the report makes the call for action, and then shows firms how to heed that call.

This is a step forward—in imagination and in potential implementation. Here are solutions that our climate altered financial institutions can begin to embrace.

—Sarah Bloom Raskin
Professor at Duke Law School and
former Governor of the Federal Reserve Board

EXECUTIVE SUMMARY

As the lynchpin of the global economy, financial institutions have an essential role to play in minimizing the worst impacts of climate change. How banks respond to the climate risk that they individually and collectively face is critical. Whether banks act proactively and ambitiously or reactively and modestly is reflective of how they measure and analyze their exposure to climate risk.

In the fall of 2020, Ceres analyzed the risks banks face from climate transition risk. **Those findings indicated that banks that fail to prepare for the energy transition face far higher risks than what has been disclosed. The cumulative exposure could be over $500 billion from just the syndicated loan portfolios of the nation's largest banks.** The total balance sheet exposure is much larger, meaning that without a deliberate carbon transition, a future where well-prepared banks can thrive along with the rest of society will not be possible.

Transition risk, though, is only one part of the climate risk equation. The world is increasingly experiencing all-year forest fire seasons, catastrophic flooding, years-long droughts, and deadly heat waves. In fact, as this report was being finalized the National Oceanic and Atmospheric Administration reported that July 2021 was the Earth's hottest month on record. The physical impacts of climate change are already here and they are growing. Failing to take a proactive approach to the clean energy transition will turbocharge these physical risks that banks—and broader society—face. In addition to the human toll, these impacts have the potential to grind down our economy, challenge the stability of some bank portfolios, and punish us year after year, decade after decade, for our failure to take action. And, perhaps unsurprisingly, the burden of that failure will fall disproportionately on developing countries and historically marginalized communities in all countries, including the United States.[1]

In addition to their societal toll, these physical risks present major threats to banks' portfolios, some of which are already playing out through changes in asset prices and insurance premiums. Ultimately, these physical risks, combined with the potential transition risks, could impact the safety and soundness of certain financial institutions. Beyond the incentives banks have to support the transition and capture its enormous opportunity, the reality is they—and the sectors they finance—need to be prepared for an increase in physical climate risk that is already baked into our collective future.

So far, analyses of physical risk disclosed by banks have been piecemeal, covering only a few elements of the problem. This is in part due to model uncertainty, data limitations, and the long timescales involved. While these challenges are real, they don't change the fact that comprehensive analysis of physical risk is needed across sectors and asset classes. Banks must better understand how these risks fit together and—critically—how they can generate indirect, systemic effects across the economy, disrupting supply chains, national economies, and the lives and livelihoods of individuals.

This report presents a framework for this kind of comprehensive analysis of the physical risks being unleashed by climate change, as shown in Figure 1. Banks should prioritize the most important climate hazards, understand how climate change will affect them going forward, and convert economic impacts on physical assets, labor productivity, and agricultural yields into financial risk metrics. Additionally, the indirect economic impacts on supply chains and national economies must be accounted for—a difficult challenge that no U.S. bank has yet overcome.

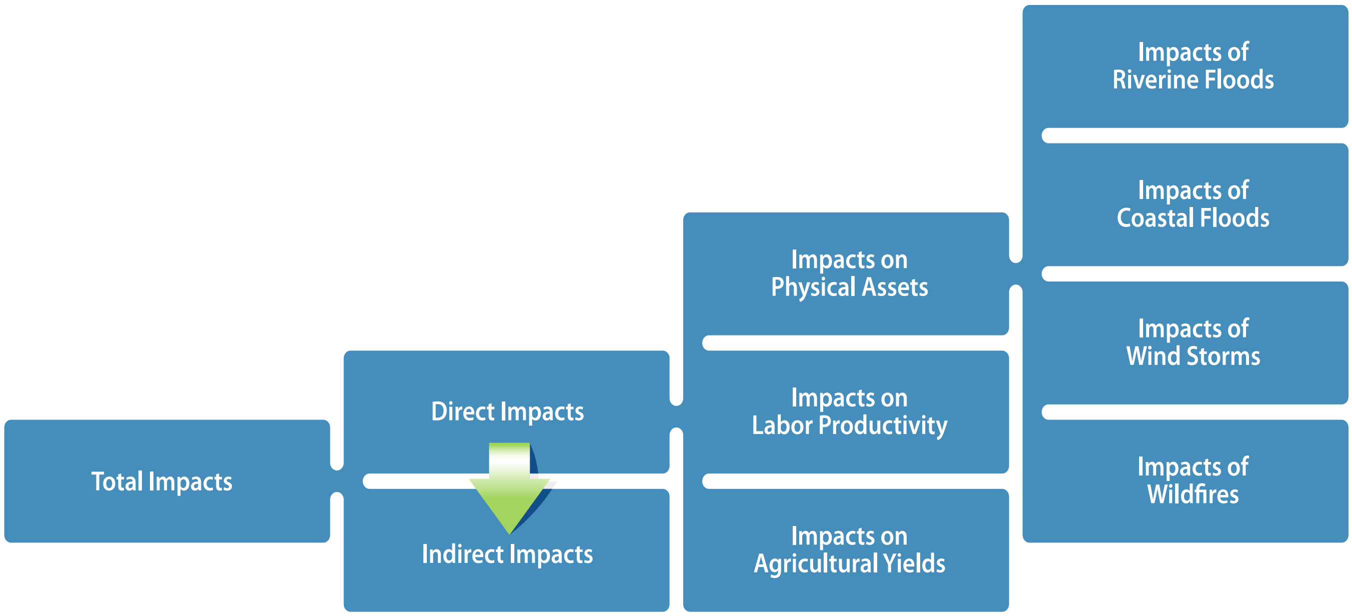


Figure 1: Flowchart of a comprehensive physical risk framework.

To give an idea of how the extreme weather impacts of climate change—more frequent and more devastating droughts, floods, heat waves, storms, and fires—could impact banks, Ceres and our partners at CLIMAFIN conducted an illustrative analysis that uses natural catastrophe and credit risk models adjusted for climate impact scenarios, downscaled macro-economic data, and publicly available syndicated loan information for major U.S. banks. As was the case in our transition risk report, these syndicated loans were used because there is abundant publicly-available data on them. It is important to note, however, that physical risk has potentially significant implications for other asset classes as well. This is another reason why this indicative analysis needs to be supplemented with further work based on banks' more complete understanding of their respective portfolios.

Looking at just $2.2 trillion of exposure for syndicated loans, the climate value-at-risk to 28 of the largest U.S. banks from physical risk could amount to more than $250 billion. This analysis echoes the findings of Ceres' first report on transition risk that identified $500 billion in potential risk exposure, underscoring the need for banks to collect better data, conduct risk assessments, and disclose the results in a harmonized and decision-useful way.

KEY FINDING

In a worst-case scenario, our analysis suggests that annual value-at-risk from physical climate impacts on the syndicated loan portfolios of major U.S. banks could approach 10%, even if adaptation measures are taken. About two-thirds of this risk comes from indirect economic impacts like supply chain disruptions and lower productivity, with coastal flooding (driven by sea level rise and stronger storms) representing the largest source of direct risk.

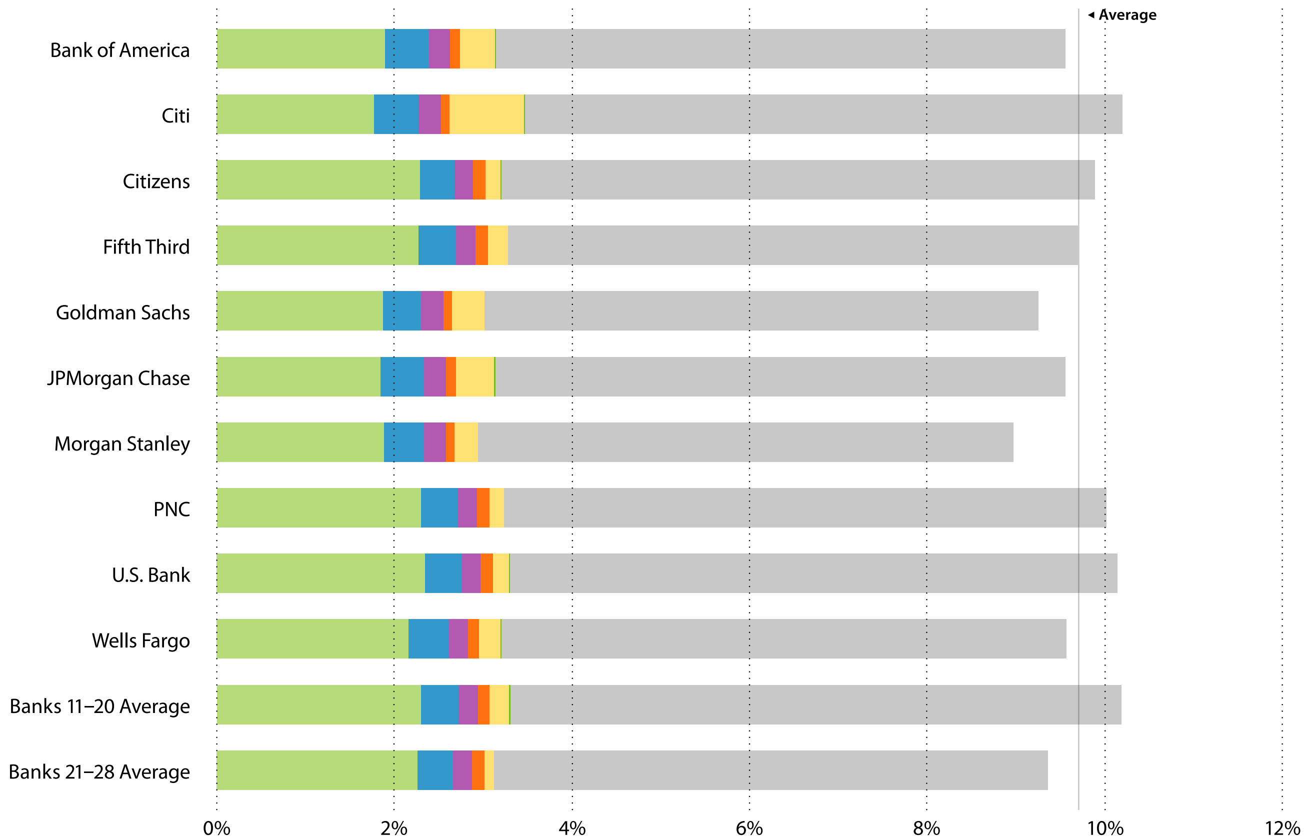


Figure 2: Illustrative analysis of 2080 value-at-risk as a percentage of each bank's portfolio by hazard for a worst-case climate scenario.

The magnitude of this risk, and significant remaining uncertainty around the specifics of indirect risk in particular, means banks and bank regulators have work to do. The Federal Reserve, the U.S. Comptroller of the Currency, the National Credit Union Administration, and a few state banking officials have taken initial steps in their regulatory oversight of these issues. Ceres is actively working with these financial regulators to address their responses to the increase in climate risk. But banks should not wait to take action. This report focuses on the voluntary measures banks should take in addition to navigating the evolving regulatory landscape.

Banks and their regulators should also work to understand the systemic nature of these growing risks. While insurance can mitigate some direct risk, this only spreads out the costs across the financial system. This risk will come back around to affect banks in several ways, including increased cost of insurance for clients, lower property values, and an increasing number of uninsured assets that ultimately increase default probabilities and therefore increase non-performing loans and potential risk.

While physical risk generates hundreds of billions of dollars of financial risk for banks, it also leads to significant opportunities in adaptation finance. Those banks that are leading in this work can create significant new value for their institutions, their clients, and the broader economy. As they capitalize on these opportunities, leading banks will also need to take into account the environmental and racial justice implications of these investments—including knowing which communities are most exposed and how resources should be allocated to avert harm where possible and mitigate impacts that do occur.

Fundamental change is needed to mitigate physical risk in the long term as the economy must rapidly decarbonize on a pathway consistent with the latest science. As with transition risk, individual banks, and collectively as a critical sector, have an important role to play in substantially changing this narrative.

Recommendations

Assess & Measure Physical Climate Risk

1. Assess all elements of climate risk and opportunity Banks should, as a first step, understand the risks that may affect their businesses and communities (including transition risk, physical risk, and litigation risk), and disclose an overall assessment to investors and other external stakeholders.

2. Measure the current impact of climate hazards on the value of financial assets Banks should build a strong framework for assessing climate physical risk that includes an understanding of how climate hazards affect their portfolios, both directly and through their indirect economic effects. Banks can then use this analysis to recalibrate their credit scoring and rating models so that they take these risks into account.

3. Project the future cost of climate change Banks should engage experts and develop internal expertise to estimate how disaster losses will increase due to ongoing climate change. This helps clarify the materiality of physical risks for each bank.

4. Perform climate stress tests Banks should perform climate stress tests (defined as a quantitative analysis of balance sheet resilience to risk). This should cover all asset classes in lending, underwriting, and other lines of business and all types of hazards that have been identified as potentially material. It is likely that climate stress tests will be a focus of prudential supervision in the future, so internal stress tests should be done with an eye on expected regulatory requirements.

5. Collect asset-level data about exposure and loss vulnerability Banks should seek out information about firms' exposure to and preparedness for future climate events. Unfortunately, local assessments of losses by sector and firm- and asset-specific data are still limited. Banks should address this by implementing a process to collect the relevant data from their clients as part of the lending process, as insurers do.

Take Action

6. Build connections with external experts Banks should cultivate internal issue expertise where appropriate but stay regularly updated on external developments by engaging with the scientific community, stakeholders (particularly those representing marginalized communities disproportionately affected by climate change), and state and federal financial supervisors.

7. Integrate climate into product and service pricing In addition to stress tests and scenario analysis covering the whole portfolio, banks should embed climate physical risk into client-level risk assessment and from there into pricing. Changes in firms' probability of default and financial risk metrics are highly sensitive to the choice of the climate scenarios. Thus "tail risk" climate scenarios should not be neglected.

8. Engage clients on physical risks Banks should engage clients on the increasing risks they are facing (and contributing to) and help them design solutions to reduce that risk. After integrating climate into credit risk assessment, banks should provide incentives to their clients to reduce risks by increasing the availability of capital for sustainable activities and lowering its cost.

Capitalize on Opportunities

9. Understand the changing insurance landscape Banks should work to understand how physical climate risks are driving changes in the insurance industry. Premiums and uncovered risk are already increasing. This will affect the most vulnerable bank clients and also hurt banks' loan metrics. Banks should learn from the insurance industry's more sophisticated physical risk assessment tools but not rely primarily on insurance to mitigate their own risk.

10. Focus on adaptation projects to mitigate credit risk Banks should know that because physical risk cannot be mitigated in the short and medium term, adaptation is one of the only avenues available for reducing their risk, though it is often a neglected part of banks' sustainable finance programs.

11. Develop innovative adaptation financing solutions Banks should recognize that financing public investment in adaptation has strong positive externalities for the banking sector as it reduces the risk for everyone, especially those in disadvantaged communities. Some of these adaptation investments can even come at a negative cost by limiting the physical impacts of climate change on workers, assets, and insurance premiums. Because adaptation finance is still in its infancy in the private sector, banks need to develop innovative approaches that are attractive to clients and structure the corresponding products in ways that are attractive to long-term investors.

12. Advocate for smart financial regulatory and policy actions on adaptation
Banks should seize on adaptation finance as a big opportunity. Without smart policy, however, the scope and scale of the opportunity could be reduced. Banks have a financial interest in promoting policy change that incentivizes the development of new infrastructure and the remediation of industrial pollution, which would reduce risk for banks and also benefit disadvantaged communities and society broadly.

Meet the Moment

13. Set and disclose financing portfolio targets Banks should align their strategies with the goals of the Paris Agreement and include detailed interim targets and specific timelines for sectoral portfolios to reach net-zero emissions—some sectors as soon as 2030, others by 2040 or 2050.

14. Publicly commit to and begin work on the 13 recommendations above within the next year.

Introduction

In October 2020, Ceres published **Financing a Net Zero Economy: Measuring and Addressing Climate Risk for Banks**. This report provided a blueprint for how banks and investors should think about one of the two major climate risks they face: transition risk—that is, the economic and financial risks arising from the policy, regulatory, consumer preference, and reputational impacts of a transition to a net zero economy. Ceres' analysis showed that banks are far more exposed to transition risk than was previously understood or disclosed.

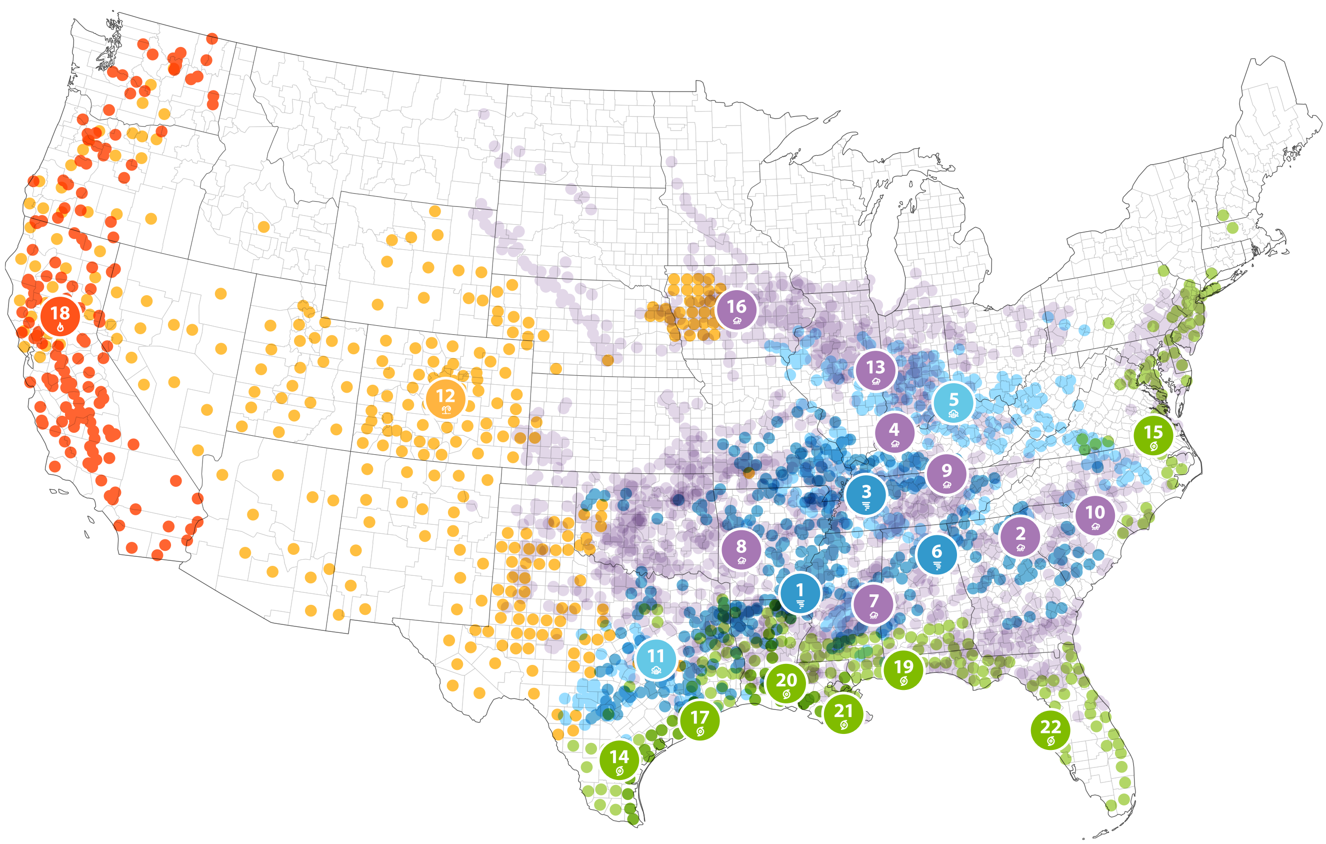
Since then, bank action has ramped up considerably. The largest U.S. banks and many banks around the globe have made commitments to align their financing with the goals of the Paris Agreement, with most adopting a more specific target of net zero emissions before 2050. The launch of the Net-Zero Banking Alliance has created a framework for banks across the globe to make commitments, develop the supporting details that are necessary to turn those commitments into reality, and work together to develop the tools and methods to appropriately price climate transition risk into financial markets worldwide.

Now banks need to show measurable, science-based progress against the commitments they've made. Absent concerted dedication of capital—economic, political, and leadership—banks will fall short of their commitments and fail to make the changes in strategy that are required to decarbonize the global economy and prevent the worst impacts of climate change. This could lead to a worst case scenario where the other major risk the financial system faces— the physical impacts of severe weather events, including flooding, droughts and fires, alongside rising seas—could devastate our economy and society. We could also face a world impacted by both physical and transition risks as the economy makes a delayed, disorderly shift to a more sustainable pathway.

The task is made even harder and more urgent by entrenched, long standing social, environmental and economic inequities, which must be overcome to ensure that the transition to a net zero economy is just, equitable, and sustainable. While global inequality continues to decline,[2] the U.S. is more unequal than it has been for a hundred years. Because of the legacy of systemic racism, the social and economic impacts of climate change fall disproportionately on historically disadvantaged and underrepresented groups. Efforts to tackle climate change must promote democracy and drive equitable economic growth. Local communities bring unique perspectives, skills, and knowledge to the challenges of strengthening resilience and addressing climate change at the micro level. They should be engaged as partners in resilience-building rather than being regarded merely as beneficiaries.

It might go without saying, given the above, but banks (and society) will all be safer and more stable in a world where there is less physical climate risk because an orderly transition has limited global warming to 1.5 C. The reason for this is that transition risk comes not from the transition itself, but from the failure to prepare for it—thus it can be mitigated. Individual and collective bank action (including client engagement, policy advocacy, and capital reallocation) could greatly reduce transition risk quite quickly, and, in the process, unleash a multi-trillion-dollar opportunity that could be a main driver of banks' (and broader) economic performance for decades.

Physical risk is different. If we miss the transition opportunity now, as difficult as it may be, there will be no easy way to mitigate the physical risks. Unchecked, these risks will only continue to accelerate and compound over time, impacting banks' balance sheets and financial stability in ways that are not yet fully understood. While adaptation and remediation finance could generate business for banks, these opportunities are significantly smaller than those presented by a successful energy transition. If U.S. banks do not put their full weight behind the transition, they could be among the main losers in the shattered world that we would face in high-physical-risk scenarios.



1	Jan 10–12	Southeast tornadoes and Northern storms and flooding
2	Feb 5–7	South, East, and Northeast severe weather
3	Mar 2–4	Tennessee tornadoes and Southeast severe weather
4	Mar 27–28	Midwest and Ohio Valley severe weather
5	Apr 7–8	North Central and Ohio Valley hailstorms and severe weather
6	Apr 12–13	Southeast, Eastern tornado outbreak
7	Apr 21–23	Southern severe weather
8	Apr 27–30	Central, Southern, and Eastern severe weather
9	May 3–5	Central and Eastern severe weather
10	May 20–23	South, Central, and Eastern severe weather
11	May 27	South Texas hailstorms
12	Summer–Fall	Western, Central drought and heat
13	Jul 10–11	Central severe weather
14	Jul 25–26	Hurricane Hanna
15	Aug 3–4	Hurricane Isaias
16	Aug 10	Midwest derecho
17	Aug 27–28	Hurricane Laura
18	Summer–Fall	Western wildfires and firestorms
19	Sep 15–17	Hurricane Sally
20	Oct 9–11	Hurricane Delta
21	Oct 28–29	Hurricane Zeta
22	Nov 8–12	Tropical Storm Eta

Figure 3: Distribution of billion-dollar disasters in 2020. Source: NOAA.

Understanding all the climate risks banks face—physical and transition—is necessary to navigate the global economy toward the low-carbon future we must achieve. As banks begin to map out how to deliver on their net zero commitments, assessing and addressing physical risk will need to be part of the equation.

Every bank must take into account physical climate risks across their business, understand the impact of specific climate hazards on financial exposures and vulnerabilities, and work to mitigate the risk. Providing a roadmap for banks to do this is the focus of this report.

The sections that follow outline the physical risks banks need to consider and the challenges they face in doing so. They outline a process for banks to conduct a risk assessment and present an example of such an analysis. Lastly, this report investigates the systemic implications of physical risk from the perspective of banks. Physical risk impacts all banks—smaller community banks and credit unions have greater risk in some ways, due to their greater geographic and sectoral concentration (see "Impact on Community Banks" box in Section 5). There are already examples of climate-related disasters that have fundamentally impacted the safety and soundness of community banks and credit unions.

CONTEXT

Climate physical risks refer to damages to physical assets, natural capital, and human lives that result in losses of productive capacity and thus output and GDP, as a result of climate-induced weather events. In addition to the potentially grave societal impacts, these risks are a key concern for the financial industry because the damages they will cause to economic actors and assets can generate credit, market, and systemic risk.

The Task Force on Climate-Related Financial Disclosures (TCFD) builds on this definition by adding that physical risks are the potential impact on the value of financial assets of:

(i) changes in the frequency and magnitude of extreme events (**acute** effects); and
(ii) shifts in climate-patterns: mean temperature, precipitation, and sea level (**chronic** effects).

Real-world impacts result from the interaction of these two effects. For example, coastal floods are influenced by both mean sea level rise and the increasing occurrence of storm surges. River floods are influenced both by changes in average and extreme precipitation. The TCFD also identifies two main ways these impacts manifest: damages to physical assets and disruption of revenues (see Table 1 below reproduced from TCFD).

ACUTE • Increased severity of extreme events such as tropical storms and floods **CHRONIC** • Changes in precipitation patterns and extreme variability in weather patterns • Rising mean temperatures • Rising sea levels	• Reduced revenue from decreased production capacity (for example, transport difficulties, supply chain interruptions) • Reduced revenue and higher costs from negative impacts on workforce (such as health, safety, absenteeism) • Write-offs and early retirement of existing assets (for instance, damage to property and assets in "high-risk" locations) • Increased operating costs (e.g., inadequate water supply for hydroelectric plants or to cool nuclear and fossil fuel plants) • Increased capital costs (for example, damage to facilities) • Reduced revenues from lower sales/output

Table 1: Financial impacts of physical risks according to the TCFD.

These effects are likely to be severe and have large impacts on the global economy. Climate impact assessments with a global or continental focus can provide useful benchmarks for the financial industry to consider the economy-wide effects of physical risk. The details of some key studies are provided in Figure 4 below and Table 2 on the next page.

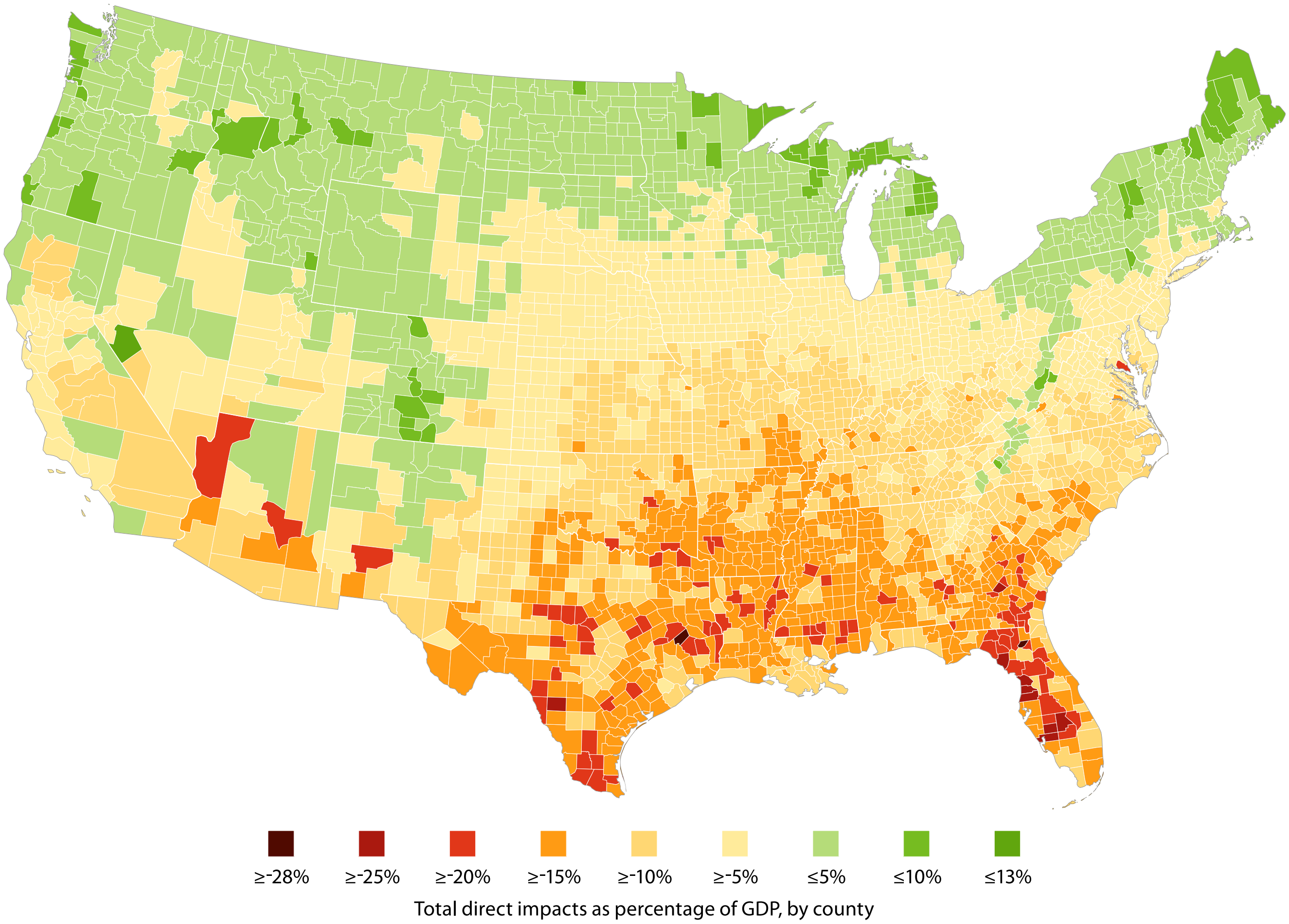


Figure 4: U.S. GDP long-term impacts of a worst-case physical risk scenario at the county level. Average 2080-2099 projections compared to a "Historical" scenario. (After Hsiang et al 2017.)

Study	Scope	Region	Key results
Hsiang et al (2017)[ii]	Agriculture, crime, coastal storms, energy, human mortality, and labor	U.S.	▪ Combined value of market and nonmarket damage is 1.2% of gross domestic product per +1°C on average. ▪ Risk is distributed unequally across locations and increases economic inequality. ▪ By 2100, the poorest third of counties will experience damages between 2 and 20% of county income.
JRC PESETA III (2019)	Coastal floods, river floods, droughts, agriculture, energy, transport, water, habitat loss, forest fires, labor productivity, and mortality due to heat	Europe	▪ Losses associated with heat-related mortality represent a very significant share of damages. ▪ Remaining impacts in order of importance are coastal flooding, labor productivity, agriculture and river flooding. ▪ Small welfare gain thanks to lower energy consumption.
Kahn et al (2019) [iii]	Impacts through labor productivity (macro-model)	Global	▪ GDP per capita loss of 7.22% by 2100 . ▪ GDP per capita loss of 1.07% by 2100 under a 2°C scenario. ▪ U.S. data shows a long-lasting adverse impact on real output in various states and economic sectors, and on labor productivity and employment.
IMF (2017)	Aggregate effect of temperature (macro-model)	Global, low income country focus	▪ Macro-economic impacts are uneven across countries, affecting more low-income countries in hot regions. ▪ For representative low-income country, by 2100, output drop of 4 % in moderate scenario and 9% in severe scenario.

Table 2: Survey of recent large-scale climate impact assessment studies and their key characteristics. [i]

Recent research shows that a statistically significant trend in negative economic impacts from climate hazards is already observable.[3] This raises concern among scientists about the possibility of catastrophic climate events.[4,5,6] Consequently, central banks and financial regulators are increasingly concerned by the impact of climate risks on financial stability. In response to this risk, regulations on the disclosure and management of climate risks have emerged at the global scale—with every indication of more to come, including from the U.S., that banks need to be aware of:

In 2017, the Task Force for Climate-Related Financial Disclosures released its recommendations, which have since become the standard for climate risk disclosures by financial institutions.

A group of financial regulators and central banks launched the Network for Greening the Financial System (NGFS) in late 2017. Since then, the NGFS has grown to include over 90 members representing almost all major economies. The core objectives of the NGFS include “the development of environment and climate risk management in the financial sector.”

In 2021, the Federal Reserve announced the creation of the Supervision Climate Committee and the Financial Stability Climate Committee, groups with the mandate to build the Fed’s understanding of the implications of climate change on financial institutions, infrastructure, and markets.

The United Nations Environment Programme (UNEP) has put forward a finance initiative (UNEP-FI) to catalyze climate action within the financial industry and launched the Principles for Responsible Banking in 2019.

Under the auspices of UNEP-FI, the Glasgow Finance Alliance for Net Zero (GFANZ) has been formed to specifically accelerate the progress of the financial sector towards a net zero future.

The Net-Zero Banking Alliance (NZBA) is the part of the GFANZ structure that is specifically focused on banks - a group that all large U.S. banks should consider joining in order to collaborate and accelerate action.

Climate change is an element of the assessment of EU financial institutions' risk and, going forward, will be part of stress-testing exercises. The European Central Bank recently released a comprehensive and valuable report on the topic.

Given this intense interest from regulators, banks need to be familiar with the complexities of physical climate risk so they can prepare for potential changes in regulation. However, as with Ceres' recommendations on transition risk, the potential impact of physical climate risk on banks' financial results is such that banks should act on the recommendations of this report regardless of regulatory pressure. By doing so, they will have an informational advantage over their competitors and valuable expertise that can help guide internal decisions, clients, and the global economy through a successful low-carbon transition.

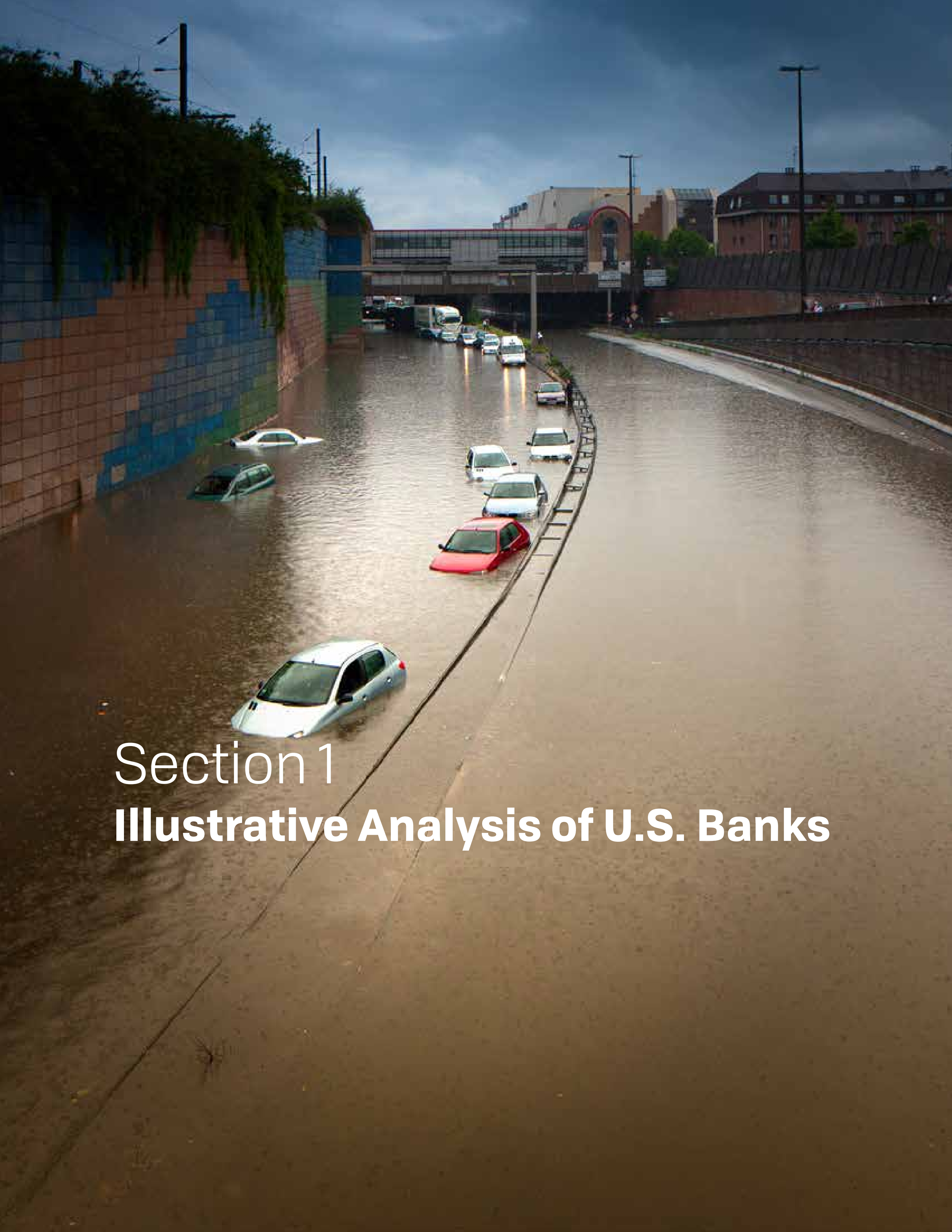
Climate Stress Testing by the European Central Bank

The European Central Bank (ECB) is currently conducting preliminary climate stress tests on the banks it supervises and is in the process of asking European banks to conduct climate self-assessments and draw up action plans on that basis. The ECB will then benchmark the banks' self-assessments and plans, and challenge them in supervisory dialogue.

The ECB climate stress test will examine the resilience of companies and banks to a range of climate scenarios. These scenarios set out plausible representations of future climatic conditions while also accounting for the impact on businesses of measures taken to limit the extent of climate change, such as carbon taxes. The ECB scenarios are based on those provided by the Network for Greening the Financial System (NGFS) but have been adjusted to capture the relationship between transition risk and physical risk more thoroughly.

These scenarios, together with a unique dataset that identifies and quantifies transition and physical risk exposures for millions of companies worldwide, provide the background for analyzing the impact of climate change on businesses and banks.

The ECB's preliminary results show that, in the absence of further climate policies, the costs to companies arising from extreme events increase substantially. The results also show that there are clear benefits in taking action early: the short-term costs of adapting to green policies (for example a carbon tax) are significantly lower than the potentially much higher costs arising from climate hazards in the medium to long term.[7] Along with transition risk (see our related report), physical climate risk also represents a source of systemic risk (see Section 5 of this report), particularly for banks with portfolios concentrated in certain economic sectors and geographical areas.



Section 1
Illustrative Analysis of U.S. Banks

Examining part of the industrial and commercial loan portfolios of 28 large U.S. banks gives a directional estimate of the extent of the climate physical risks they are exposed to, both directly and indirectly. As a top-down exercise without the benefit of asset- and firm-specific data, this analysis is illustrative. Its goal is to demonstrate the need for banks to undertake and disclose their own risk assessments with client-level data and customized parameters and the processes they can use to assess that climate risk.

KEY FINDING

In a worst-case scenario, **annual climate value-at-risk from physical climate impacts on the syndicated loan portfolios of the largest U.S. banks could approach 10%,** even if adaptation measures are taken.

Analysis in Brief

The analysis is based on the CLIMAFIN physical risk assessment model, which embeds natural catastrophe models used in the insurance industry (see Section 3).[7,8] However, the hazards it considers are projections of future climate impacts, while the exposure is determined by the sectoral and geographical characteristics of the assets in a financial portfolio, and the vulnerability metrics it uses are the outcome of financial valuation models.[9,10] See Appendix A for the formal mathematical details of the model.

- The analysis assesses the risk-adjusted value of each asset in the portfolio across four channels by analyzing:
  - (1) Direct impacts of extreme weather events on physical assets, including the impacts of river floods, coastal floods, wind storms, and wildfires
  - (2) Direct impacts of extreme temperature on labor productivity
  - (3) Direct impacts of changes in temperature and precipitation patterns on agricultural yields
  - (4) Indirect impacts through global supply chains and macro-economic dynamics
- It is calibrated at the country level for the purpose of the exercise, i.e., all firms are assumed to be impacted by the country-level distribution of hazards irrespective of the specific location of their facilities.
- The analysis assumes that risks induced by climate change are not accounted for in the baseline probability of default.
- It is built around three scenarios (See Appendix B for more details):
  - A benchmark scenario without further climate change
  - An "orderly transition" scenario aligned with a 1.5C temperature rise (RCP 2.6)
  - A "hot house world" scenario aligned with a 4C temperature rise (RCP 8.5)
- All three scenarios assume that global socio-economic trends follow their historical pattern (SSP2-Appendix B).
- It considers two time horizons:
  - 2030, which is the earliest date usually considered in impact assessments, focused on actual impacts on the value of existing assets whose maturity is past 2030. It also serves to highlight the importance of the next decade in terms of climate action.
  - 2080, in order to assess the full effect of today's decisions on the global climate (since those effects manifest over several decades). In terms of action, 2080 will be too late.
- It considers both a "no adaptation" and a "constant protection scenario."
  - In the no adaptation scenario, no investment (except maintaining current infrastructure) is assumed to occur.
  - In the constant protection scenario, investment in protection infrastructure is assumed to occur at the level sufficient to maintain protection at roughly current levels. This does not imply that the magnitude of "unprotected" hazards is constant, as the magnitude of events in the tail of the distribution generally increases with climate change.
- This example uses the climate value-at-risk as its primary output (value-at-risk, or VaR, is a measure of the potential for financial loss in a portfolio and the probability of occurrence for a defined loss. VaR is perhaps the most widely used risk measure in financial institutions). However, the CLIMAFIN methodology can readily be used to produce a broad range of risk metrics (e.g., conditional value-at-risk, distance to default, rating notches, expected shortfall).

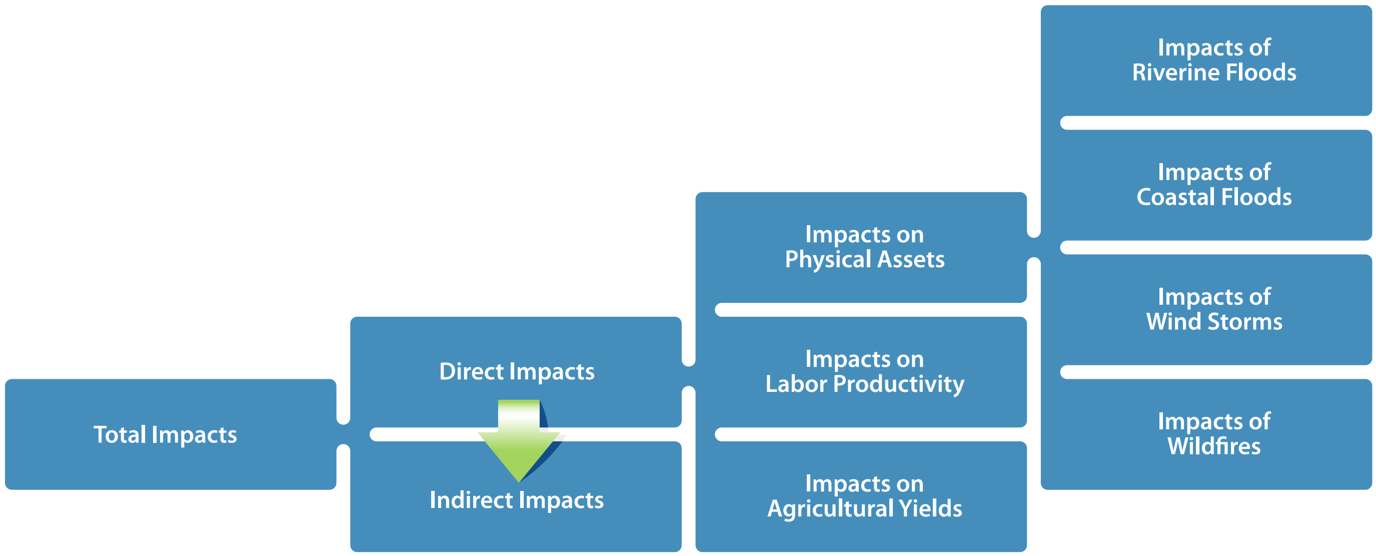


Figure 5: Structure of climate impacts.

Who is CLIMAFIN?

The technical analysis in this report was developed by CLIMAFIN (which also conducted the analysis used in our transition risk report), a consulting firm founded by three leading researchers, each with deep expertise in the relationship between banking and climate change:

Stefano Battiston
SNF Professor of Banking, University of Zurich

Antoine Mandel
Professor of Applied Mathematics at the Sorbonne and the Paris School of Economics

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The CLIMAFIN methodology (both for physical and transition risks) is the outcome of more than 10 years of scientific research and is notably being used by European regulators, including the European Central Bank (ECB) and the European Insurance and Occupational Pensions Authority (EIOPA).[12]

Our analysis examines 28 U.S. banks with 60,737 loans totalling $2.2 trillion. (These are syndicated loans from the Refinitive DealScan Loan Connecter database, see also Appendix C.) As was the case in our transition risk report, these syndicated loans were used because there is abundant publicly-available data on them. It is important to note, however, that physical risk has potentially significant implications for other asset classes as well, which is another reason why this analysis is indicative of the risks banks face but more work is needed, based on banks' more complete understanding of their respective portfolios. More than 80% of these loans have a U.S. counterparty, with the remaining mostly concentrated in other developed economies. As highlighted in Figure 6, outside of financial services, the sectors with the largest exposure are capital-intensive industries (oil and gas, technology, utilities, real estate, and manufacturing), which are the most exposed to direct climate impacts.

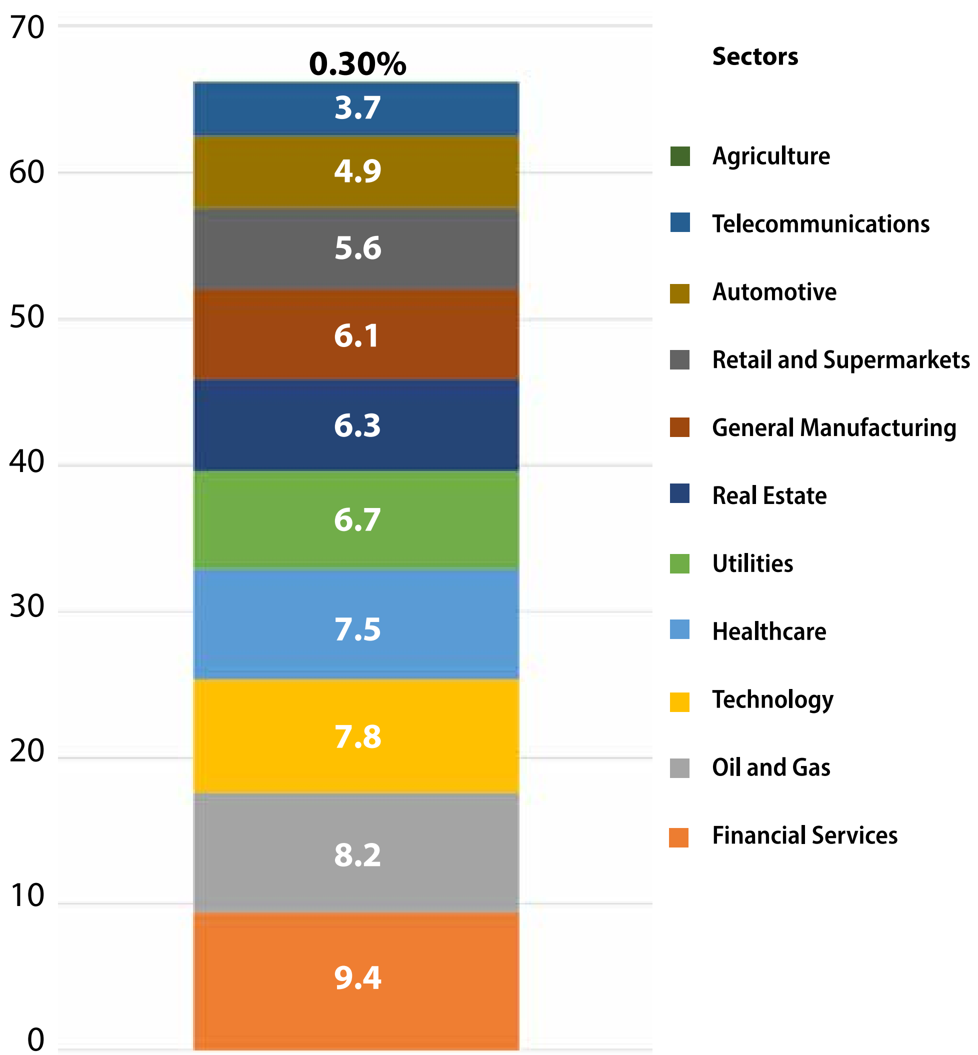


Figure 6: Percentage exposure per economic sectors (top 10 + agriculture) of the sample of loans considered in the analysis.

SECTION 1.1 Results - Direct Impacts

When considering the direct impacts of physical risk on banks, there are a number of different ways to look at the outputs of CLIMAFIN's work :

- Figure 7 compares the 99% value-at-risk (VaR) to each bank (meaning that in 99% of cases, annual losses will not exceed the amount shown) in the three different scenarios - "Historical", "Orderly Transition" and "Hot House World" at the end of the time horizon (2080). Adaptation measures are included (the "constant protection" scenario described above).
- Figure 8 shows the 99% VaR for only the "Hot House World" scenario at different times, to see how the risk increases over decades. Adaptation measures are included.
- Figure 9 shows what Figure 8 would look like without adaptation measures. The 2080 data point from Figure 8 (with adaptation) is included for reference.

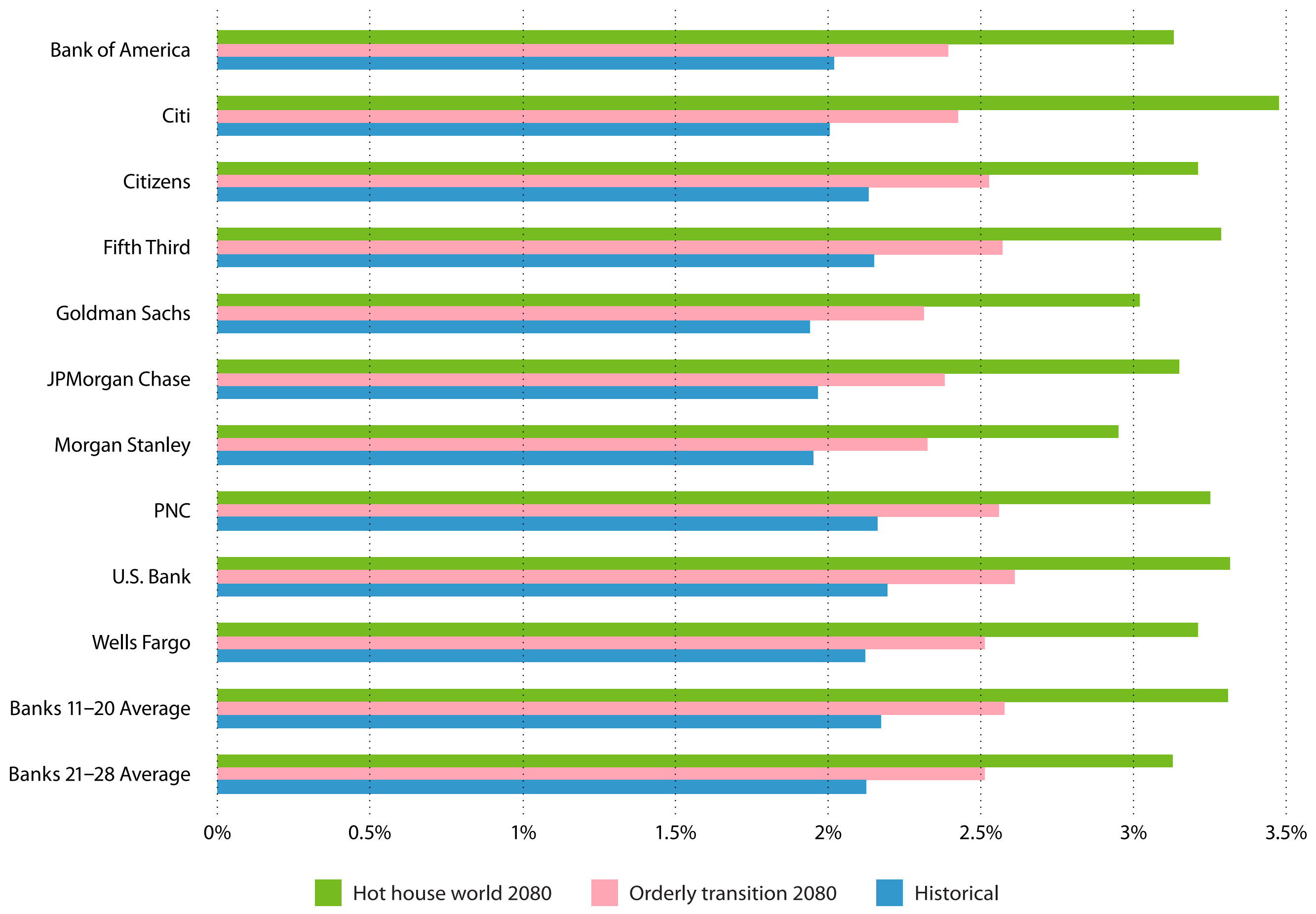


Figure 7: 99% VaR from direct impacts of physical risk, expressed in percentage of the portfolio, with adaptation.

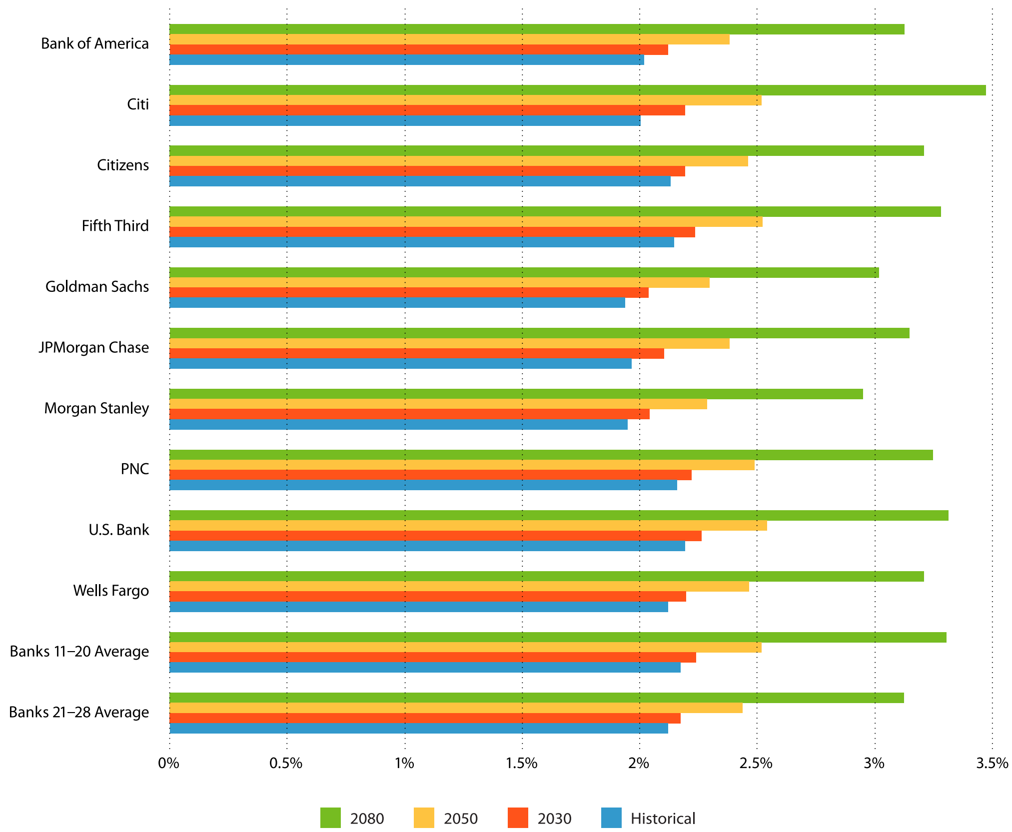


Figure 8:
99% VaR from direct impacts of physical risk, for the Hot House World scenario with adaptation, across time.

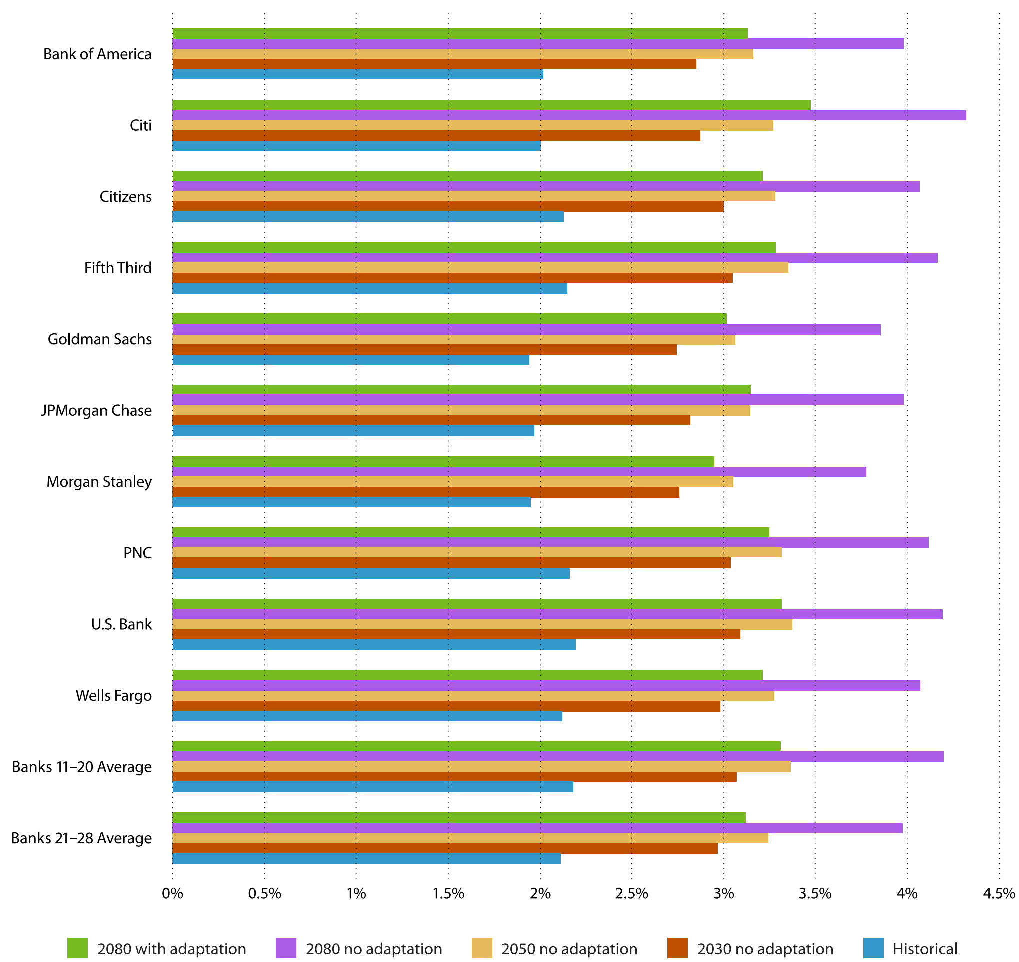


Figure 9:
99% VaR from direct impacts of physical risk, for the Hot House World scenario without adaptation, across time.

The dynamics are extremely clear.

- First, financial impacts increase substantially in the more adverse scenarios. In 2080, the average VaR across all banks increases from 2.1% of the value of the portfolio in the "Historical" scenario, to 2.5% in the "Orderly Transition" scenario and to 3.2% in the "Hot House World" (Figure 7).
- Second, the magnitude of financial impact increases over time. In the "Hot House World" scenario, the average VaR reaches 2.2% in 2030, 2.5% in 2050, and 3.2% in 2080 (Figure 8).
- Third, the presence of adaptation policy can smooth financial impacts. Without adaptation, the average VaR reaches 3% in 2030, 3.3% in 2050, and 4.1% in 2080 (Figure 9).
- Lastly, the increase in physical risk will be sustained over a long period of time, meaning that relatively smaller annual impacts (compared to transition risks, which are more likely to manifest all at once) will add up to a serious problem for banks—to say nothing of broader society. Additionally, many of these risks, for example, droughts and wildfires, exacerbate one another.
- Something not shown in the graphs is that the financial impacts can be substantially reallocated through the use of insurance. When the insured part of the losses is subtracted (from total losses), the VaR decreases to 0.99% in the "Historical" scenario, 1.3% in the "Orderly Transition" scenario, 1.61% in the "Hot House World" 2080 scenario with adaptation and 2% in the "Hot House World" scenario without adaptation. This assumes that insurance company losses do not directly affect banks, which they could if any insurance companies were to default.

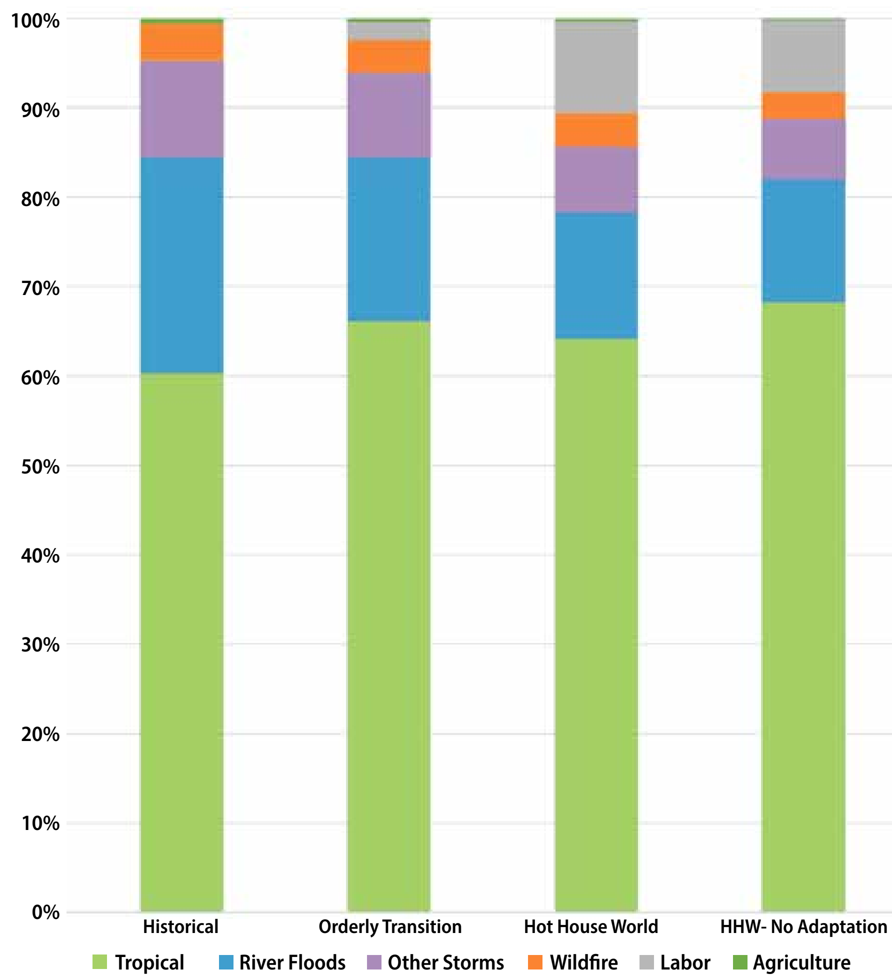


Figure 10: Percentage contribution to total value-at-risk in 2080 per type of impact for a range of climate scenarios, with adaptation except where noted.

Figure 10 highlights the relative importance of different hazards in the 2080 timeframe. Each hazard and its impacts are discussed in detail in Section 2. Tropical storms (including associated coastal flooding) are by far the largest source of risk. River floods, other storms, and wildfires also have impacts in all scenarios. Agricultural impacts appear minor because very few syndicated loans are made to the agricultural sector. However, for a bank with substantial exposure to agricultural counterparties, the agricultural sector would be a substantial source of risk. Although risk increases across all hazards, tropical storms and labor productivity become relatively more important in worst-case climate scenarios. Most of the increase in the impacts of tropical storms is due to increased coastal flooding, which is itself triggered by sea level rise. It's worth noting that in certain states, the relative risks could be very different. This is another reason why further analysis by banks and state banking regulators is vitally important.

Figure 11 illustrates the difference in risk across banks. The key driver here is the sectoral composition of each bank's portfolio. Banks with large exposure to sectors with a substantial share of physical (vs. intangible) assets and energy-intensive labor are more exposed. It should be noted that this illustrative analysis uses country-level estimates, which do not account for the impact of the geographical distribution of exposure within the U.S. Given the major contribution of tropical storms and coastal flooding to risk, banks with higher relative exposure to the southeast coast of the U.S. would face a substantially higher level of risk. Although quantitative data on the exposure of banks by state is not available, an analysis of the number of bank branches by county by the Federal Reserve Bank of Atlanta and proprietary research by Bank Street Partners highlight that some of the banks with a disproportionately high share of activity in the Southeast are Capital One, Truist, Regions, and Synovus. In addition to geographic considerations, there are social justice implications of the location-specific analysis that is ultimately needed. Different communities with varying affluence will be impacted differently. Consequently, they will require—and will be able to bring to bear—different resources to ideally avoid and at least mitigate physical climate impacts, and the financial sector will have an important role to play in helping ensure that these impacts are redressed equitably.

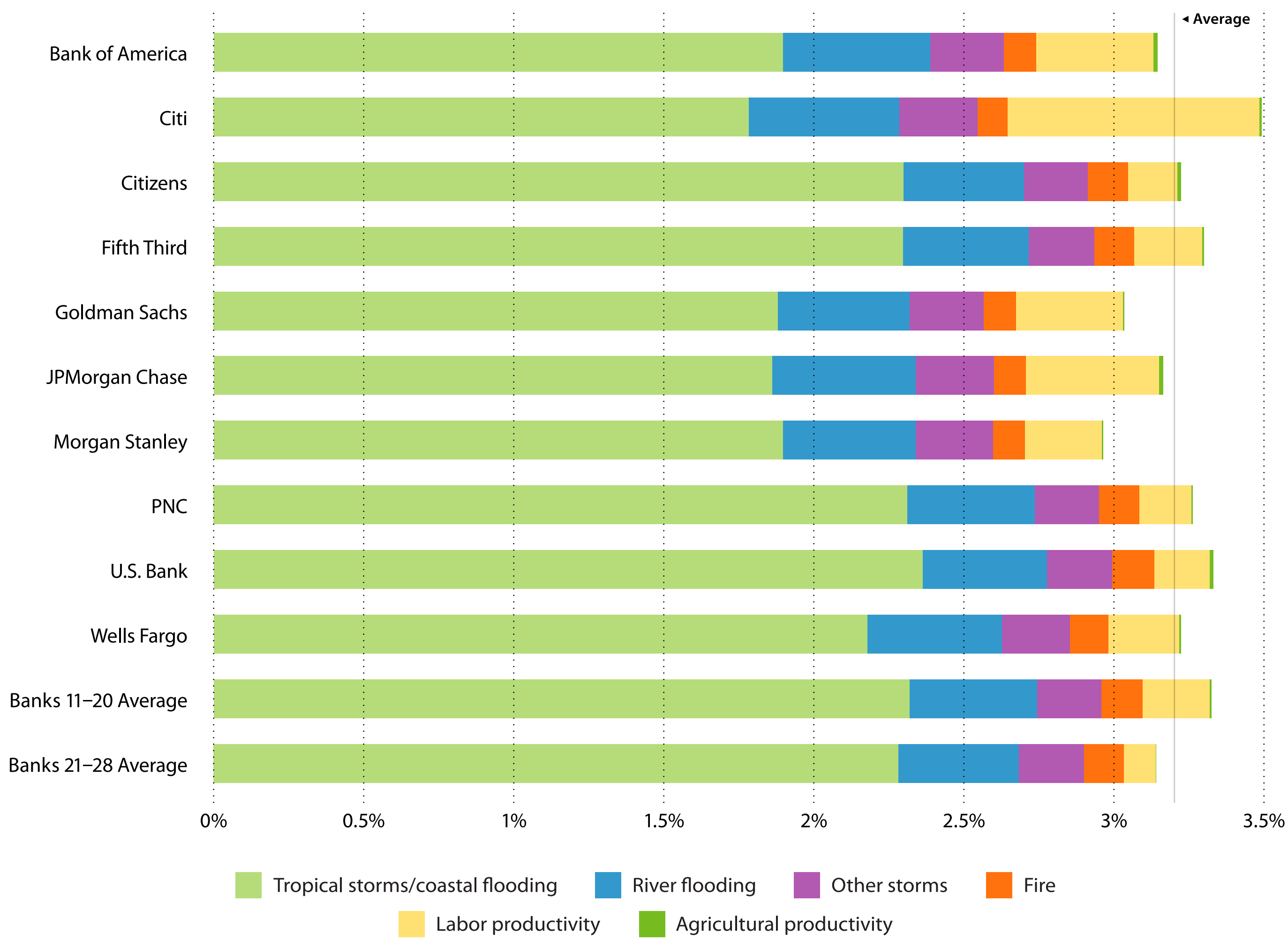


Figure 11: Decomposition of 99% VaR by hazard for Hot House World 2080 with adaptation.

SECTION 1.2 Results - Indirect Impacts

To analyze indirect impacts (including supply chain effects and changes in productivity, pricing, and demand), the direct impacts above are propagated through global supply chains using a computable general equilibrium model. This approach provides estimates of indirect physical climate impacts on the economic output of each country and sector. Note that there is very substantial model uncertainty related to the parameters of this analysis, which further emphasizes its illustrative nature.

The takeaway of this analysis is that indirect impacts are consistent across scenarios and across banks. The indirect impact approximately triples the total risk in most cases. This leads to very substantial risk in high-end scenarios, amounting to over 10% of the portfolio value (see Figure 12). As shown in Table 3, when those losses are thought of in dollar terms, $2.17 trillion of exposure for syndicated loans alone could generate annual value-at-risk of up to $263 billion.

Scenario	**Direct Impacts**		**Indirect Impacts**		**Direct + Indirect**	
Historical	2.1%	$46B	4.3%	$93B	6.4%	$139B
Orderly Transition	2.5%	$54B	5%	$108B	7.5%	$162B
Hot House World	3.2%	$69B	6.5%	$141B	9.7%	$210B
HHW -No Adaptation	4%	$87B	8.1%	$176B	12.1%	$263B

Table 3: 99% VaR of direct and indirect impacts for 2080 in a range of climate scenarios (in billions and a percentage of the portfolio).

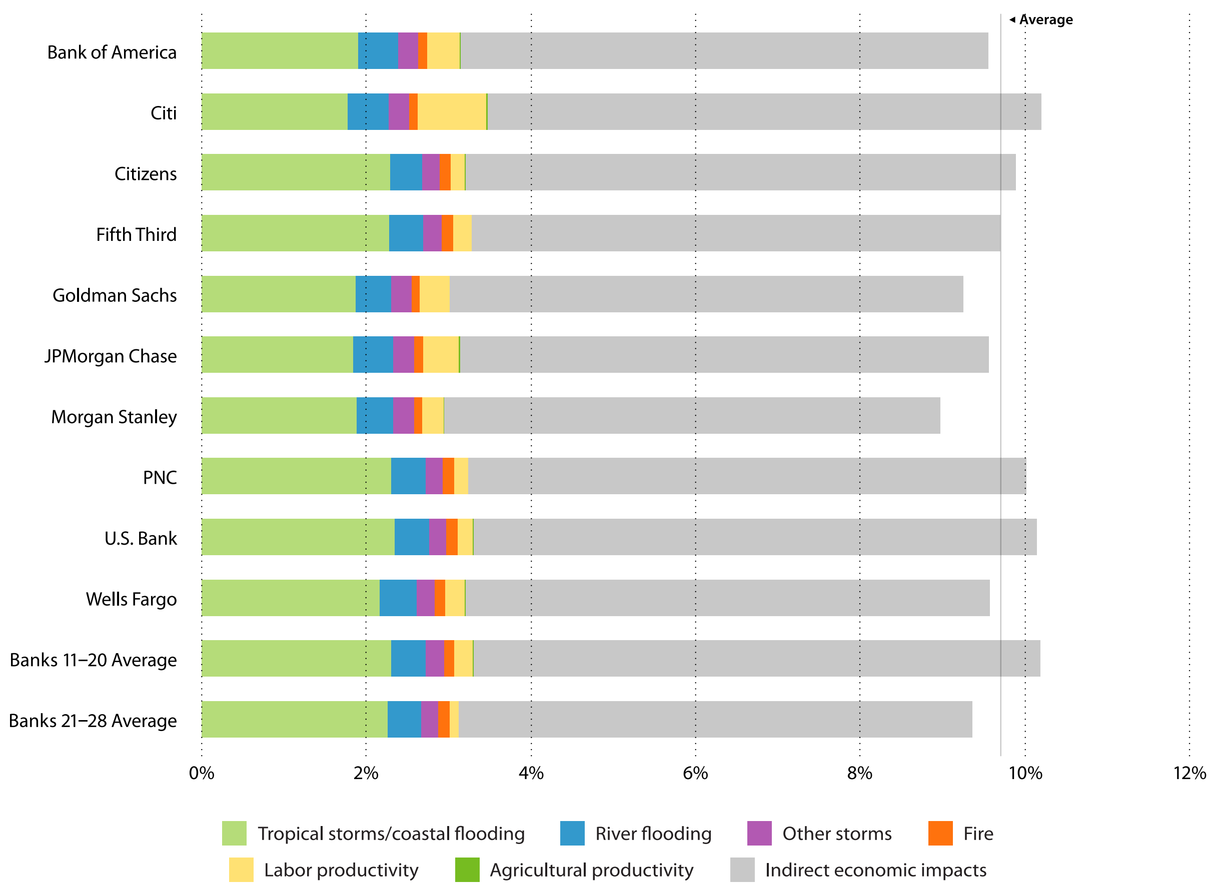


Figure 12: Decomposition of 99% VaR as a percentage of the portfolio by hazard for Hot House World 2080 with adaptation.

It is also instructive to look at the same data in terms of median annual losses in the 2080 timeframe (equivalent to a 50% VaR) to understand the shape of the loss distributions. While the losses in any individual year are modest, they will vary from year to year and accumulate over time.

Scenario	Direct Impacts		Indirect Impacts		Direct + Indirect	
Historical	0.5%	$11B	1.2%	$26B	1.7%	$37B
Orderly Transition	0.6%	$13B	1.4%	$30B	2.0%	$43B
Hot House World	0.9%	$20B	2.1%	$46B	3.0%	$66B
HHW -No Adaptation	1.1%	$24B	2.6%	$56B	3.7%	$80B

Table 4: 50% VaR of direct and indirect impacts for 2080 in a range of climate scenarios (in billions and as a percentage of the portfolio).

SECTION 1.3 Overall Results

Overall, the results lead to the following key findings:

1. Climate change can substantially increase direct physical risks to banks, roughly doubling them in high-end climate scenarios. The increase in physical risk will be long-lasting (rather than a one-off occurrence) and impacts will accumulate over time on the balance sheet of banks and their counterparties. Accumulated losses on the balance sheets of bank clients over time and correlations between different types of hazards (such as droughts and wildfires) might ultimately lead to much larger shocks on financial institutions. [11, 12]
2. While VaR on this scale would likely not threaten the stability of banks with diversified portfolios, experts often use a materiality threshold of 0.5-2% of total assets, indicating that physical risk on this scale is likely to become material and should be of substantial concern to banks and their regulators.[13]
3. Insurance could mitigate a substantial part of the financial risk for banks, but future insurability of assets is uncertain and insurance merely reallocates this risk elsewhere in the financial system (see Section 5).
4. Adaptation is a key lever to mitigate future risks: simple adaptation could reduce the financial risk by up to 50%. Optimal adaptation, from a cost-benefit perspective, would even entail further reduction of the risks (Hinkel et al. 2014).
5. Indirect impacts through global supply chains may roughly triple the risk, though further research is needed to narrow the associated uncertainties.

The level of financial risk shown in this analysis creates an imperative for all banks to conduct and disclose analyses (at least at a high level) based on far more granular, asset-level data to investors and other stakeholders. Existing evidence demonstrates that climate physical risks are on the rise and that they can impact banks' balance sheets and financial stability through multiple channels. If U.S. banks do not act now, they could be among the main losers of this "great risk reallocation." Adding firm- and asset-level data to the analysis will allow better risk management within banks, and should ultimately lead to proper pricing of physical climate risks in the market.

Recommendation: Perform climate stress tests. Banks should perform climate stress tests (defined as a quantitative analysis of balance sheet resilience to climate shocks). This should cover all asset classes in lending, underwriting, and other lines of business and all types of hazards that have been identified as a material risk. It is likely that climate stress tests will be a focus of prudential supervision in the future, so internal stress tests should be done with an eye on expected regulatory requirements.

Models and Data Sources Used

The above analysis builds on some of the data sources and methodologies discussed in Section 2. Further details of the specific models used can be found in Appendix D.

The models used provide direct estimates of impacts on labor and agricultural productivity at the country and sector level. To obtain estimates of impacts on physical assets, the damages from each hazard are combined with sectoral level asset data.[14] All this feeds a global economic model calibrated on the world input-output database.[15,16] This generates the following results:

(i) Estimates of direct climate impacts on gross value-added per country and sector.
(ii) Estimates, per country and sector, of the indirect impacts induced by the propagation of direct climate shocks through global supply chains.

Finally, the estimates of sectoral value-added are used to calibrate a credit risk model and consider the ability of each sector to repay its debts. This approach has been used by regulators like EIOPA and the Austrian National Bank.[17]

Data is used from a set of 28 U.S. banks (listed in Appendix C). It is important to note that any risk analysis using publicly available data can only provide a directional indication of exposure. This is because the only non-confidential credit data available for U.S. banks are on syndicated loans (sourced from the Refinitiv DealScan® dataset). Although syndicated loans make up a meaningful portion of banks' commercial loan portfolios, DealScan shows exposure at a single point in time—the time of issue—which may differ from what is held on banks' balance sheets at any point thereafter. High-level disclosures in financial filings suggests that the data is relatively representative of C&I lending in terms of sectoral distribution. But this is not the full picture—loans account for about 50% of U.S. bank holdings on average, of which C&I makes up only about 30% and syndicated loans only a portion of that. This is why it is so critical for banks to conduct and disclose their own analysis using complete data.

For each of the 28 banks in this analysis, a loan portfolio is constructed based on the syndicated loan data in the Refinitiv DealScan database for the set of active loans originated from 2010 to present for which the bank is indicated as lender. Thanks to increased data availability, the sample contains a much larger number of loans than that used in Ceres' past analyses. The larger number of loans means that the dataset is likely more representative of overall bank lending portfolios, but also that the numbers here are not directly comparable to Ceres' fall 2020 banking report. The percentage value-at-risk numbers used above partially address this—these can be notionally (but not precisely) compared to the 2020 report.

SECTION TWO
Understanding Climate Hazards and their Financial Impact

The example in Section 1 shows that all banks need to understand the impacts of physical climate risks on their business and that of their clients. These impacts ultimately derive from the different hazards that are influenced by climate change. In order to for banks to construct their own risk assessments, the first steps are:

1. Understanding the range of climate hazards that may present material risks.
2. Understanding (probabilistically) how the frequency and severity of those events may shift due to climate change.
3. Understanding, at a high level, the channels through which these hazards (individually and collectively) affect financial markets and asset values.

The first two items are covered in this section, the third in Section 3. Understanding and accounting for these hazards is not a simple task, especially for smaller banks, so banks should work together where possible, bring in external experts, and prioritize those hazards that have the most material impact (even if that assessment is initially qualitative).

Projected Changes in the Climate System

The Intergovernmental Panel on Climate Change (IPCC), created in 1988, is the key scientific body that assesses the potential impacts of climate change. In August 2021, it released the first piece of its AR6 assessment, its sixth major assessment of climate science, which includes updates to its previous special report Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Together, these reports represent the best available data on the physical science of climate change, which can be supplemented by additional recent research. Overall, this research finds that:

Temperature There is a greater than 99% chance that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur through the 21st century at the global scale. A recent report of the World Meteorological Organization further emphasizes that there is about a 40% chance of the annual average global temperature temporarily reaching 1.5°C above the pre-industrial level in at least one of the next five years and a 90% likelihood of at least one year between 2021-2025 becoming the warmest on record.

Heat waves There is a greater than 90% chance that the length, frequency, and intensity of warm spells or heat waves will increase over most land areas. Heat waves are the hazard that have the highest increase in frequency, duration, and intensity in a warming climate. Countless studies have shown this in observations as well as projections across the world and, more recently, an increasing number of individual heat waves have been attributed to anthropogenic climate change.

Heavy precipitation There is a greater than 90% chance that the frequency and intensity of heavy precipitation will increase in most regions. At the global scale, extreme daily precipitation events are projected to intensify by about 7% for each 1°C of global warming. A recent survey of existing projections of future U.S. extreme precipitation emphasizes that observed extreme rainfall magnitudes have increased since 1950 and that these increases will continue throughout the 21st century in many areas in the U.S.[18] Projections suggest that high-end extremes will increase more (between 10% and 50%) than low-end extremes.

Sea level rise There is a greater than 90% chance that sea level rise will continue throughout the 21st century. Consequently, extreme sea level events that historically occurred once every 100 years are projected to regularly inundate more than half of all locations by 2100. The U.S. Interagency Sea Level Rise Taskforce recently updated its sea level rise scenarios, estimating that global sea level is very likely to rise at least 12 inches (0.3 meters) above 2000 levels by 2100 even on a low-emissions pathway and up to 8.2 feet (2.5 meters) in a high-emissions scenario.

Droughts With 1.5°C of global warming, some regions will experience more frequent and severe droughts in every continent except Asia. At 2°C global warming and above, the level of confidence in the magnitude of the change in droughts increases further. Recently updated global drought projections estimate a greater than 66% probability that drought hazards will increase, with remarkable agreement across models.[19]

River flooding With 1.5°C of global warming, heavy precipitation and the flooding it unleashes are projected to intensify and be more frequent in most regions in Africa, Asia, North America, and Europe. At 2°C global warming and above, heavy precipitation and associated flooding are projected to become more intense and frequent in the Pacific Islands and across many regions in North America and Europe. These changes are also seen in some regions in Australasia and Central and South America. At 4°C global warming, countries representing more than 70% of the global population and global gross domestic product will face increases in flood risk in excess of 500%.

Tropical storms, cyclones, and hurricanes ("tropical storms" used hereafter) There is a greater than 66% chance that the global frequency of tropical storms will either decrease or remain essentially unchanged.[20] The proportion of intense storms (categories 4-5) and peak wind speeds of the most intense tropical cyclones, which are the primary driver of damages and corresponding risks to banks, are projected to increase across the globe.

SECTION 2.1 Current and Future Climate Hazards

This is a complex and fast-changing area of study and may not make sense for all banks to have internal expertise. In addition to potentially building their own capabilities, banks should assess the existing datasets and expertise and engage externally in a way that matches their portfolios and business strategy.

Recommendation: Build connections with external experts.
Banks should cultivate internal issue expertise where appropriate but stay regularly updated on external developments by engaging with the scientific community, stakeholders (particularly those representing communities disproportionately affected by climate change), and state and federal financial supervisors.

There are **seven key hazards** for banks to consider when assessing risk. These seven hazards are both potentially material for banks and closely linked to climate change. Further details on the models that are available for each of them is provided in Appendix D. The following list is ordered (and banks should prioritize risk assessment) based on the following criteria:

- The potential magnitude of the hazard and the range of impacts it can have
- The direct vs. indirect nature of the impact
- The uncertainty associated with existing quantitative assessments and climate sensitivity

Needless to say, depending on the location of the bank or credit union, this order may be different.

Hazard #1
Floods

THE BOTTOM LINE

At current levels of climate change, floods are causing, on average, $20.3 billion in losses every year to 5.7 million properties across the continental U.S. In a future that is 2 to 3 degrees warmer, these annual losses jump by 67% to $34 billion.

The direct impact of coastal and river floods on physical assets is among the most quantitatively relevant hazards—it has a direct and unambiguous financial impact on the balance sheets of many bank clients, especially those in low-income communities. As this report was being finalized, both Germany and China faced record-breaking floods that caused significant loss of life and enormous economic costs. The impact of floods is also widely felt: every economic sector and geography is potentially exposed, although sectoral vulnerability varies depending on the percentage of a given sector's value that is contained in real (as opposed to intangible) assets.

Working directly from the relevant scientific research on flood risks (see Appendix D) might be complex for financial institutions. Fortunately, there are a number of user-friendly platforms and datasets on flood risks that incorporate recent scientific research, including the Aqueduct global flood risk analyzer (see Figure 13). This is the most complete resource for banks to consider as it covers coastal and riverine floods at the global scale for multiple scenarios based on leading international research.

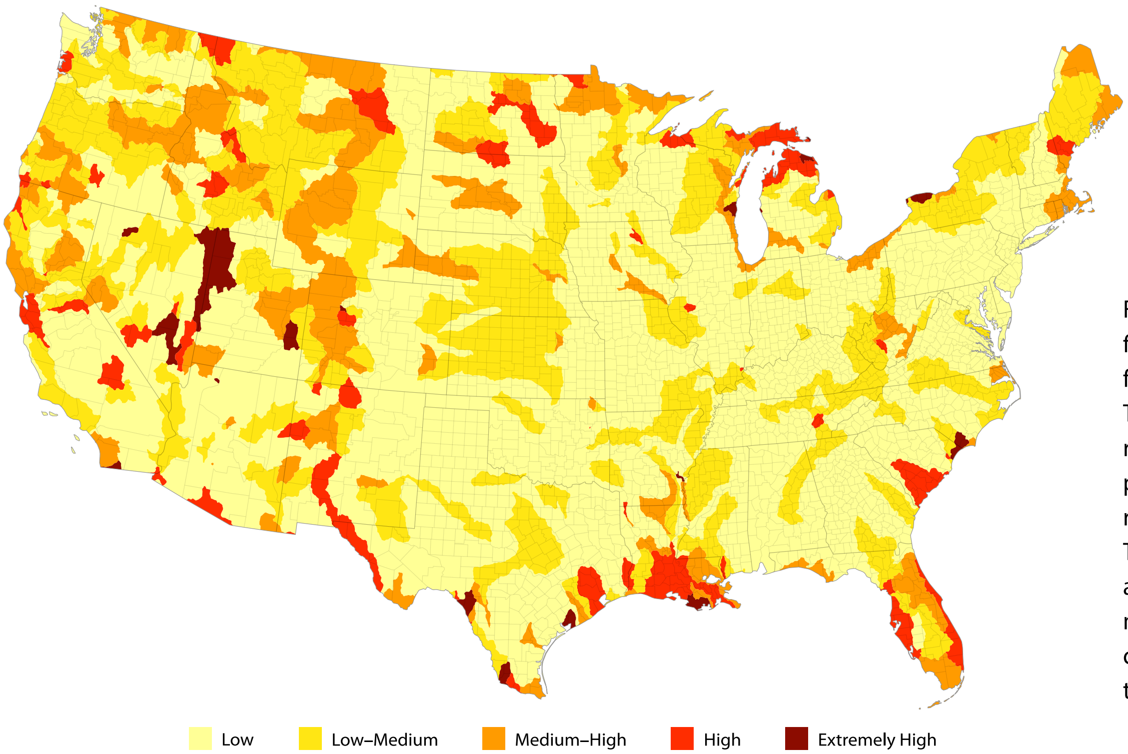


Figure 13: Riverine flood risk map adapted from WRI Aqueduct. The map summarizes risk in terms of yearly probability of occurrence of a flood event. The model provides a sequence of such maps for a range of climate scenarios and time horizons.

Hazard #2
Wildfires

THE BOTTOM LINE

The risk of very large fires could increase as much as sixfold by mid-century in certain counties in the U.S.

As this report is being written, the U.S. is witnessing another record-breaking fire season. The first six months of 2021 saw 2.8 million acres burned, compared with 1.9 million in 2020.[21]

Wildfires are very complex and are fueled by climatic as well as other factors, such as temperature, precipitation, humidity, and wind. Like floods, wildfires have a direct and unambiguous financial impact on client balance sheets. Again, all economic sectors and geographies are potentially exposed and sectoral vulnerability varies based on the percentage of sectoral value derived from tangible assets.

Quantitative impact assessments are produced using global historical datasets on total area burnt (see Appendix D). As for future projections, Barbero et al. provides a detailed assessment of the increased risks of very large fires in the U.S. by mid-century.[22] Knorr et al. also provides estimates of the evolution of burnt area for medium- and worst-case scenarios.[23]

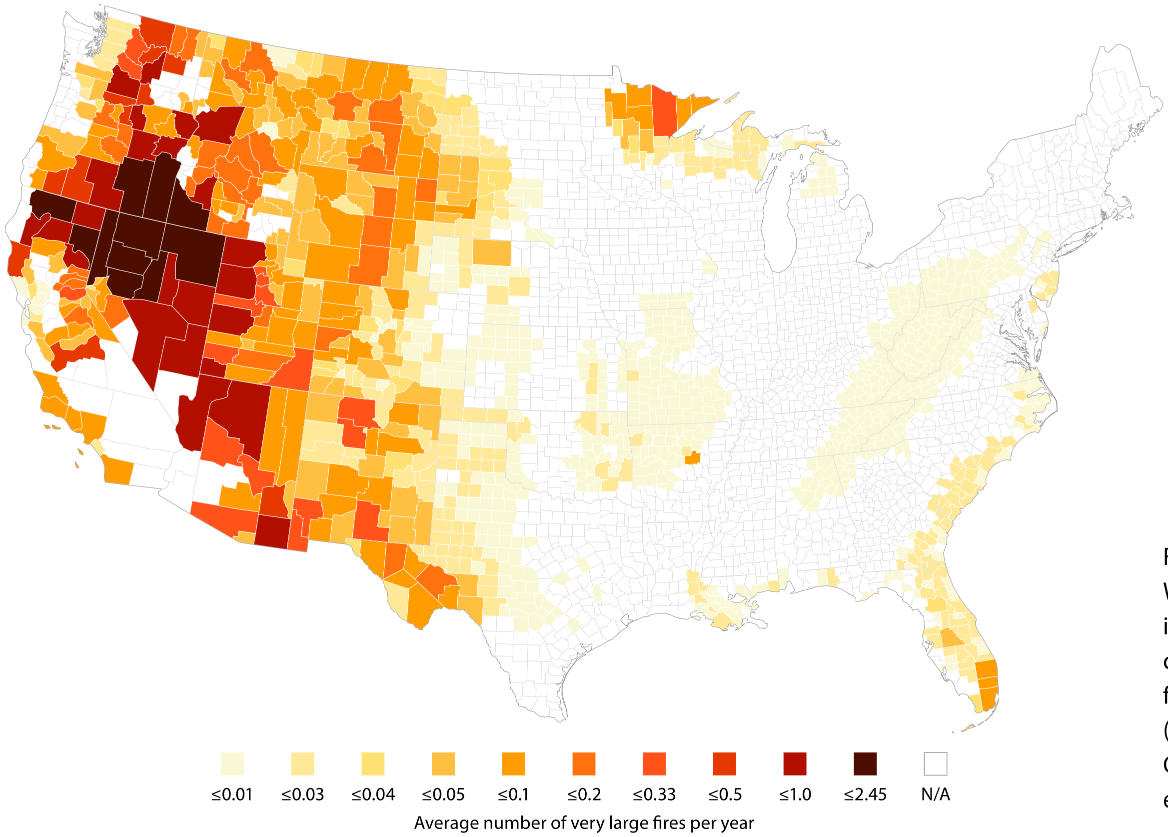


Figure 14: Wildfire prevalence in a worst-case climate scenario for 2040-2060. (After Rhodium Group and Barbero et al 2015.)

Hazard #3
Storms

THE BOTTOM LINE

The impact of climate-driven storm impacts is highly uncertain.
Like floods and wildfires, the impacts of tropical and non-tropical storms have wide-ranging direct impacts on physical assets and therefore the financial performance of bank clients. However, the range of geographical areas that are exposed is somewhat narrower and the influence of climate change on the distribution of such storms is unclear, except for the storm surge component that is directly linked to sea level rise and accounted for under coastal flooding (see above).

The state-of-the-art knowledge contains continued uncertainty about the effects of climate change on tropical storms, but:

1. The vast majority of studies predict decreasing global frequency of these storms.[24]
2. There is a 50-80% chance of an increase of the relative proportion of very intense storms.[25]
3. There is uncertainty, but some evidence points to an increase (in absolute terms) of frequency of very intense storms.
4. There is a 50-80% chance of an increase in the average intensity of storms.[26]

With respect to other types of storms, uncertainties are also very large.[27] Marciano et al. finds that the dynamics of non-tropical storms in the Northern Hemisphere are still unclear, with some studies projecting decreases and others projecting increases.[28] Precipitation associated with these storms is projected to increase with warming. For banks looking to make a quantitative assessment of storm risks, the main existing tools are synthetic storm track generators such as the Synthetic Tropical Cyclone Generation Model or the CLIMADA model. However, given the large uncertainties, these models generate distributions of storm events on the basis of historical observations but do not, by default, integrate climate change scenarios. Therefore, they should not be used for climate risk assessment on their own - an expert is likely needed to adapt them to bank needs.

Hazard #4
Heat Waves

THE BOTTOM LINE

10–15 extra heat wave days are expected per degree of global warming in the U.S.[29]

The direct impact of heat waves from an economic perspective is related to labor productivity. The role of climate change in increasing heat waves is clear. Most sectors and geographies will be affected.[30,31] Sectoral vulnerability depends on physical intensity of work in the sector and on working conditions (e.g., indoor vs. outdoor). The assessment of the resulting impacts on sectoral and firm revenues requires the use of an economic model and related assumptions.

Heat waves could also have an impact on annual mortality rates, raising them by ~5 deaths per 100,000 per degree of warming.[32] This mostly affects (from a financial perspective) the liability side of the balance sheet of pension funds and life insurers. These impacts will be most severe in low-and-moderate-income communities.

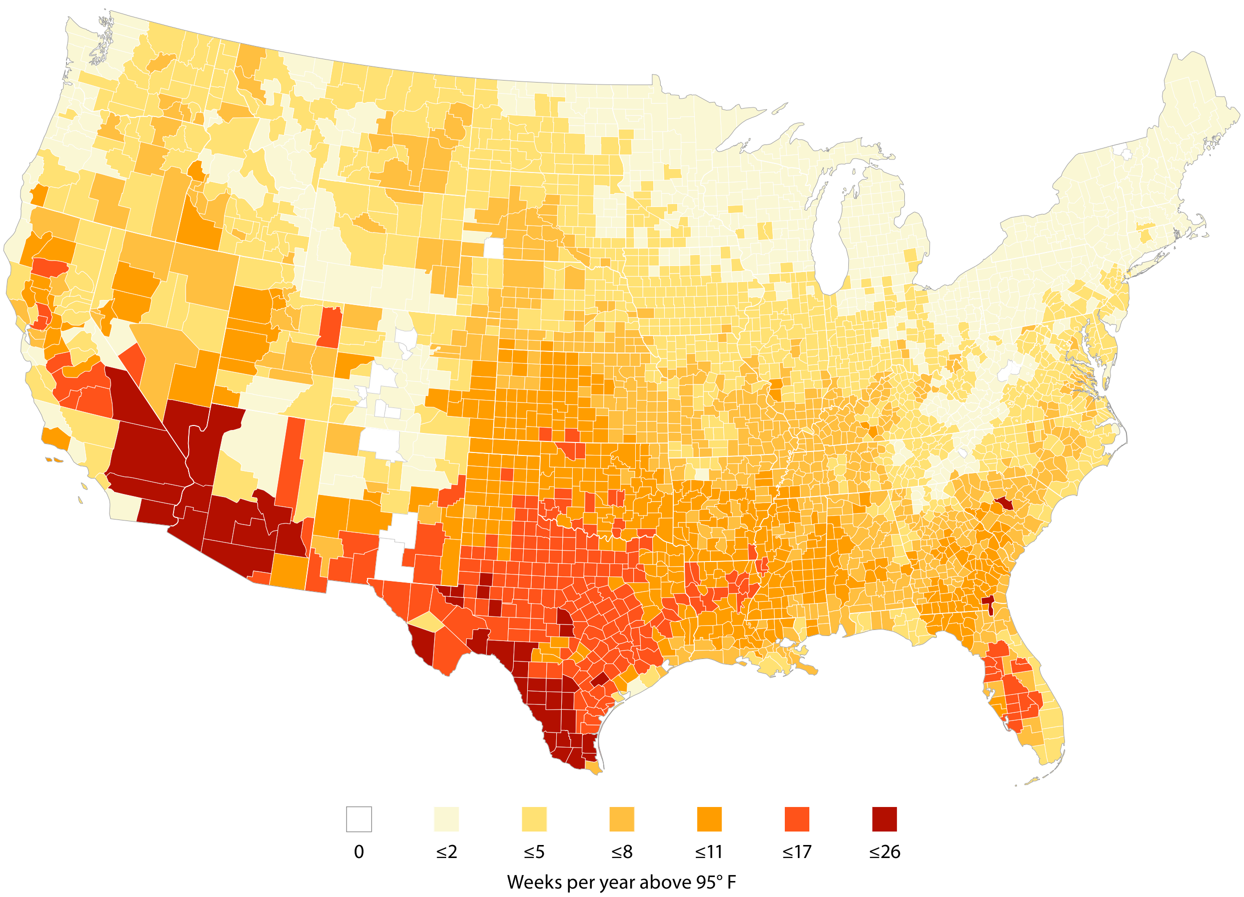


Figure 15: Long-term prevalence of extreme heat in a worst-case physical risk scenario at the county level. Average 2040-2060 projections. (After Rhodium Group).

Hazard #5
Falling Agricultural Yields

THE BOTTOM LINE

Some U.S. crop yields could drop 20-40% within 30 years.

The impacts of droughts and changes in the distribution of temperature and precipitation on agricultural yields is a key issue for the sector and could have implications for the broader economy as well. Assessing the related economic impacts involves substantial agro-economic modeling (and associated assumptions) for each type of crop considered. Both the magnitude and the direction of impacts might depend on the geographical zone.

The recent IPCC special report on Climate Change and Land provides an overview of the state-of-the-art knowledge on climate impact on agriculture. For banks looking to make a quantitative assessment, a few global analyses of climate impacts on agriculture are publicly available and can provide useful input for an economic and financial risk analysis (see Appendix D). AgCLIM50 is the most complete dataset and therefore likely the easiest for banks to use.

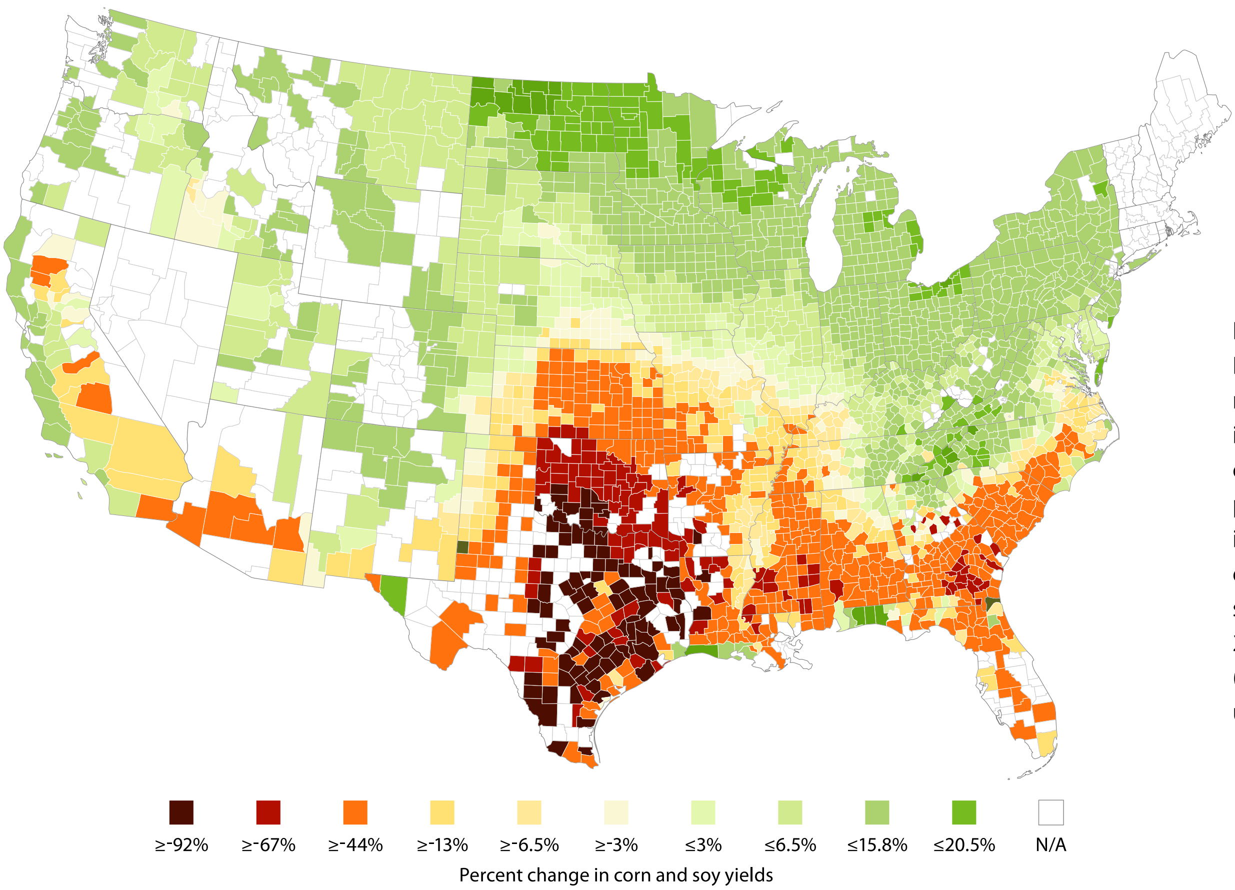


Figure 16: Regional climate change impacts on corn and soy production in a worst-case climate scenario, 2040-2060. (After Rhodium Group.)

Hazard #6
Energy Supply

THE BOTTOM LINE

Energy production losses may exceed 2% per degree Celsius for certain power plants.[33]

Energy supply could be impacted by changes in water availability (due to droughts and changes in the distribution of temperature) or by extreme heat (affecting both energy supply and demand). By definition, this impact directly concerns primarily the energy sector and involves very specific modeling (and associated assumptions).

Specifically, changes to the water cycle have an impact on hydropower while thermal power plants are adversely affected by high ambient temperatures.[34] Nuclear power plants are particularly vulnerable.[35]

Hazard #7
Indirect Economic Impacts

THE BOTTOM LINE

Indirect impacts approximately triple the financial risk of climate hazards, according to CLIMAFIN's analysis in Section 1.

Indirect economic impacts may result from any of the above hazards or their interaction with each other. These impacts can manifest as:

- **Supply chain effects:** production shortages initially triggered by extreme events propagating downstream as suppliers fail to deliver essential inputs.
- **General equilibrium effects:** changes in prices and demands of certain commodities due to reduced productivity or growing risk at certain producers.
- **Behavioral changes:** changes in demands of certain commodities due to changing environmental conditions or concerns about climate protection.

Recommendation: Project the future cost of climate change.
Banks should engage experts and develop internal expertise to estimate how natural disaster losses will increase due to ongoing climate change. This helps clarify the materiality of physical risks for each bank.

Ideally, an analysis of physical climate risk should cover all of these hazards. However, data availability, model uncertainty, and complexity might justify reducing the scope of the analysis. For example, the cost of a comprehensive analysis of the risk faced by an agricultural client with diversified crops might be prohibitive. In general, banks should start with the most general and direct impacts, and proceed to more specific and more indirect impacts. This approach is described in Table 5.

	General → Specific	
Direct ↓ Indirect	• Impact of coastal floods, river floods, wildfires on capital stock • Impact of heat waves on labor productivity • *Impact of tropical storms on capital stock*	• Impacts of drought, temperature, and precipitation on agricultural yields • Impacts of drought and temperature on energy supply • Impacts of changes in specific ecosystem services on specific economic activities (e.g. tourism) • Impacts of heat waves on mortality
	• Propagation of impacts through global supply chains • Propagation of impacts through general equilibrium effects (substitution and price effects) • Induced changes in demand	

Table 5: Classification of impacts along two dimensions: direct vs indirect, general or sector specific. Impact of storms italicized to emphasize the fact that the global frequency of tropical storms will either decrease or remain essentially unchanged.

SECTION 2.2 The Effect of Hazards on Financial Assets

Once a bank has determined the scope of the analysis it needs to conduct, it can estimate the extent of its current short- and long-term risks using historical data on the frequency and intensity of hazards and some of the tools described above and in Appendix D. While this will be a difficult task for many banks, beginning to assess financial impact should be the first priority for banks that have identified potentially material climate hazards.

Research shows that major climate hazards (tropical storms, fires, and droughts) have a direct short-term impact on the revenues of firms located in the areas where the disasters take place.[36] Exposure is widespread; a recent study found that 57% of the structures in the continental United States are located in hazard hotspots and about 1.5 million structures are located in hotspots for two or more hazards. Disaster impacts also spread throughout companies' supply chains, affecting the revenues of customers and suppliers.[37,38,39,40,41]

Evidence also shows that, in the short run, major disasters affect return on assets.[44,43] Research on the effect of natural disasters on firms' access to credit finds that stronger bank-borrower relationships (i.e., "relationship banking") tends to ease the post disaster credit crunch.[44] Data for more than 160 countries over the past 25 years indicates that large-scale natural disasters negatively affected companies' financial viability and increased commercial banks' likelihood of default.[45]

While there is broad scientific consensus about the negative short-term impacts and direct costs of climate hazards, this is not the case for the long-run macroeconomic and financial consequences. A substantial body of research shows that the medium- and long-term impacts of climate hazards on growth differ across types of hazards, sectors and economies.[46,47,48,49]

If climate risks were fully captured in market prices, banks would have less reason to be concerned from a financial perspective. However, there is strong evidence that this is not the case.[50,51,52,53] Regulators have been clear that they see market inefficiency with respect to this issue.[54] The NGFS' concludes "that there is a strong risk that climate-related financial risks are not fully reflected in asset valuations."

Given this mispricing of climate risks, once banks have estimated the total risk, their next step will be to identify how much of that risk is attributable to climate change. In general, this can be estimated by comparing the contemporary and historical distribution of each hazard (using the models described above, with and without climate effects incorporated). The illustrative analysis in Section 1 provides an example of how this can be done. For events that have already occured, the share of the damage attributable to climate change can be determined by an extreme event attribution analysis. Such analysis quantifies, using a large number of climate simulations, whether and how much past emissions contributed to the probability of an extreme event occurring.

Recommendation: Measure the current impact of climate hazards on the value of financial assets. Banks should build a strong framework for assessing climate physical risk that includes an understanding of how climate hazards affect their portfolios, both directly and through their indirect economic effects. Banks can then use this analysis to recalibrate their credit scoring and rating models so that they take these risks into account.

If current asset prices reflect historical hazards, then climate risks could be quantified based on the difference between the future and past distribution of hazards. Climate-related financial risks would then be the change in asset value implied by the change in the distribution of hazards.

However, given the abundant evidence that current asset prices do not fully integrate current hazards, the value of climate risks should be based more directly on the future distribution of hazards.[55,56,57] Climate-related financial risks can be approximated as the change in asset values implied by the complete integration of physical risks, i.e., the part corresponding to the current distribution of hazards, as well as the supplementary forward-looking risk induced by climate change.

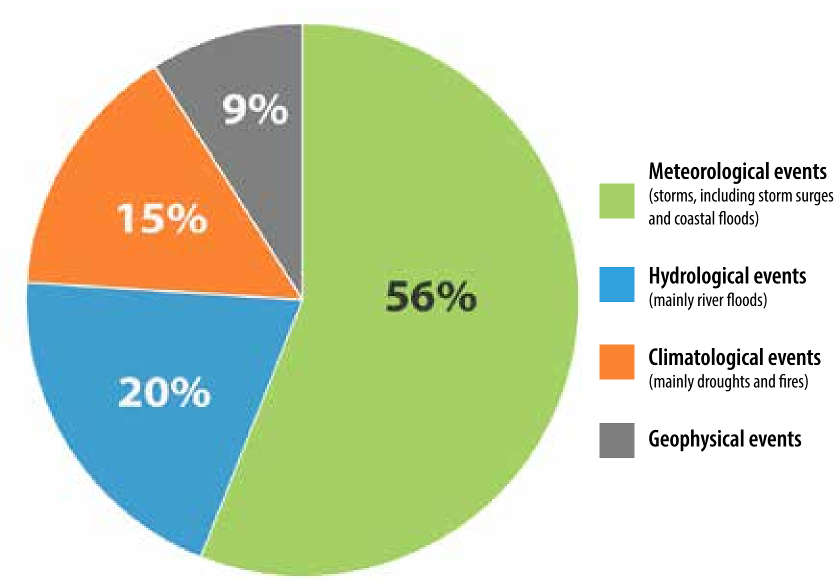


Figure 17: Disaster Types' Share of Global Losses (2013-2018). Source: Munich Re.

There are a number of studies that have tried to assess, in aggregate, the impact of climate-related natural disasters in financial terms. The share of overall losses for natural events worldwide by type of disaster are shown in Figure 17. Moreover, according to a recent congressional budget office report, approximately 60% of losses from tropical storms are due to coastal flooding. Overall, hydrological and meteorological events account for the vast majority (nearly 80%) of climate-induced impacts on physical assets. The main impact of climatological events goes through negative shocks on labor productivity and agricultural yields, as discussed above.

Another resource for banks is the National Oceanic and Atmospheric Administration database of billion-dollar events, which provides estimates of the costs of all the major drought, flooding, storm, and wildfire events. Between 1980 and 2020, the total (CPI adjusted) costs of tropical storms amounted to $997 billion, while other storms hit $336 billion, droughts reached $259 billion, floods amounted to $151 billion, and wildfires were $102 billion. Figure 18 further highlights that most extreme costs are due to storms (including coastal flooding).

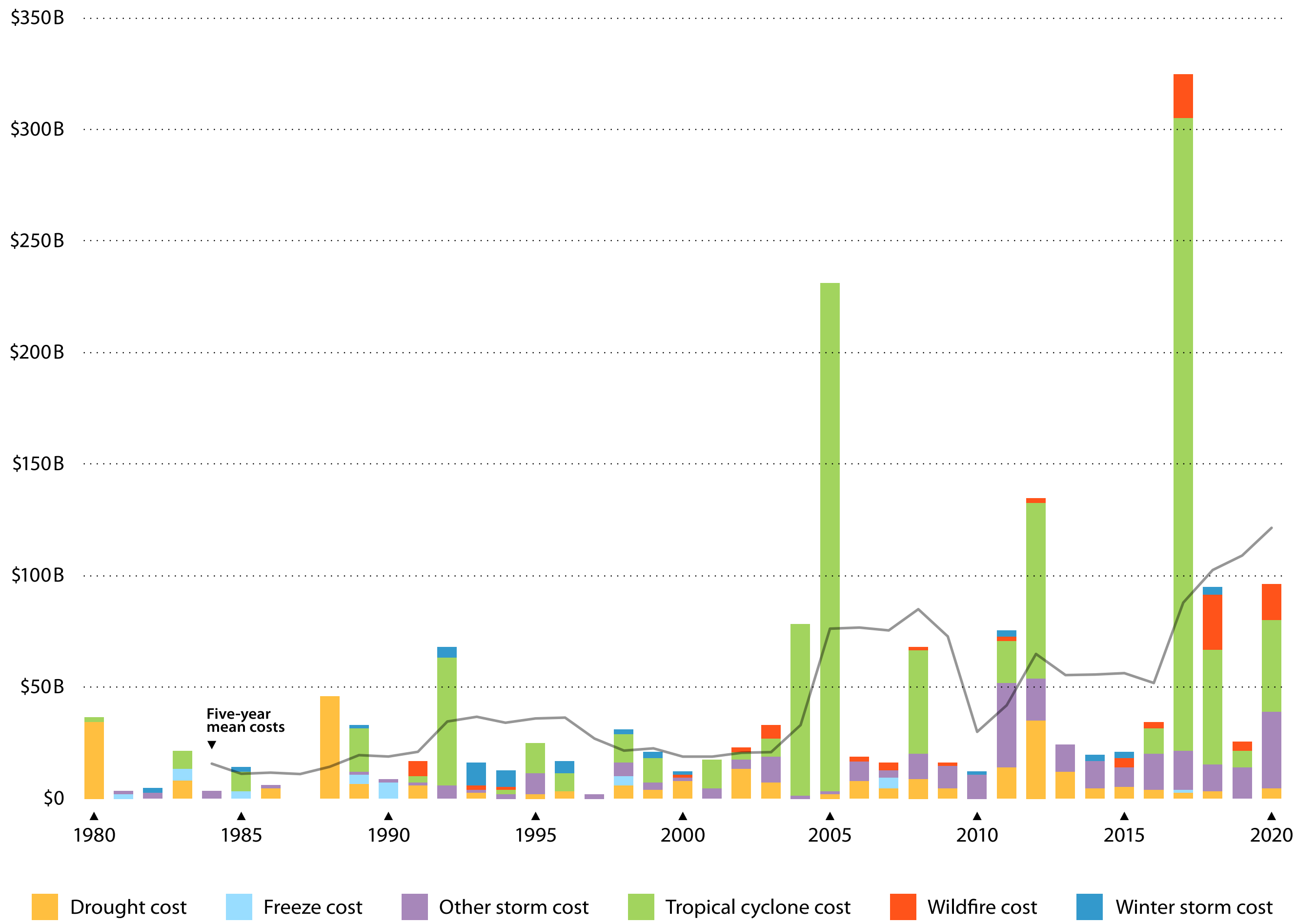


Figure 18: Time series of billion-dollar event damage by hazard type. Source: NOAA.

Section 3
Creating a Physical Risk Assessment

To conduct a climate-sensitive risk assessment, banks need to integrate the expertise developed in the insurance industry and elsewhere on the costs of disasters with the information from Section 2 on physical climate hazards and their macroeconomic impacts. Additionally, as with transition risk, banks need to prepare for the possibility that a discrete shock could propagate—sending a "second-round" shock through financial networks (see Section 5).

To combine forward-looking climate information with historical exposure and loss data, three existing processes need to be put together:

1. The assessment of disaster risks in the insurance industry using natural catastrophe models
2. The economic assessment of future climate impacts by the scientific community
3. The translation of economic impacts into financial risk for specific firms and securities

Natural Catastrophe Models

Natural Catastrophe models are used by the insurance and reinsurance industry to estimate the losses that could be sustained due to catastrophic events. There are three main proprietary models of this kind: RMS, AIR Worldwide, CoreLogic EQECAT, and an open-source model called the Oasis Loss Modelling Framework. There are other firms like KatRisk providing valuable information. These models create estimates of potential losses by combining data on hazards, vulnerability, and the geographical, physical and financial characteristics of client exposures. These models thus implement a workflow similar to what is needed for the banking industry to assess climate financial risks. However, the existing models currently lack two main features needed by banks: (i) they mostly focus on current distribution of hazards rather than on projections of risks induced by climate change, and (ii) they assess impacts on physical, not financial, assets. Building a climate financial risk assessment model for banks can be done by adding these two features to a NatCat model (see Section 1).

The large body of evidence produced on future climate impacts (see Section 2) has led economists to develop models that assess the impact of climate change on economic actors. The most useful models assess both the direct and indirect economic impacts of climate change. Figure 19 illustrates this distinction.

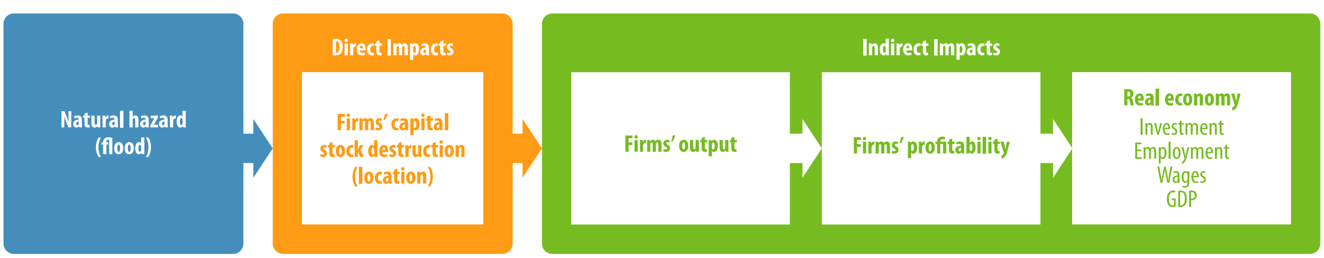


Figure 19: Disaster risk transmission channels to the economy. Adapted from Dunz et al (2021). Dunz, N., Mazzocchetti, A., Monasterolo, I., Essenfelder, A., Raberto, M. (2021). Compounding COVID-19 and climate risks: the interplay of banks' lending and government's policy. Journal of Banking and Finance, forthcoming.

Direct and Indirect Economic Impacts of Climate Change

The definition and analysis of direct and indirect impacts is relevant to assessing the magnitude and transmission channels of physical climate risks. The direct impacts of climate hazards affect physical assets and labor productivity and are calculated at the sectoral level based on damage estimates for specific types of disasters. Disaster risk modeling provides important tools for assessing the direct economic losses climate hazards can inflict on sectors of economic activity in a given area, region and country. In turn, these direct impacts affect firms' production and profitability, leading to lower investments and lower output, as well as losses on the value of financial contracts and instruments (loans, stocks, corporate bonds).

Indirect impacts depend on:

1. How the risk is transmitted to other actors in the economy
2. How economic actors are connected to each other (via a model of macrofinancial networks)
3. Supply and demand dynamics from the reaction and interaction of economic actors
4. Feedbacks from the economy to finance (and vice versa)

For instance, the impact of natural disasters on a particular sector may translate into lower production, driving higher unemployment and lower wages, leading to lower household income, which reduces consumption and, in turn, firms' sales. This may reduce firms' investment plans as a result of lower sales. A drop in firms' investment further decreases employment, driving a feedback loop in which the direct impact of a shock propagates and amplifies, affecting the overall magnitude and duration of economic shocks. This dynamic was seen in New Orleans following Hurricane Katrina in 2005. Climate hazards like Katrina have a disproportionate impact on communities of color, which are underserved by U.S. banks, both before and after these community-altering events.[58]

The economic models discussed above are similar to what is required for the assessment of climate financial risks by the banking industry. However, climate impact assessments are missing two key elements needed by bank risk professionals:

1. They are based on downscaled macro-economic data rather than on micro-level/firm data.
2. They assess the economic impacts and thus need to be further processed by a financial valuation model in order to provide an assessment of the impact on the value of financial assets and bank portfolios.

While there are several approaches to adding these missing pieces, it is possible and useful to think of the assessment of climate-related financial risk in terms of the general framework shown in Figure 20. This framework breaks down complex firms into individual business units that have specific exposures to specific physical risks. This allows a bank to transform macro-level data into a firm-specific profile that can be fed into a financial valuation model, helping to address the challenges discussed above.

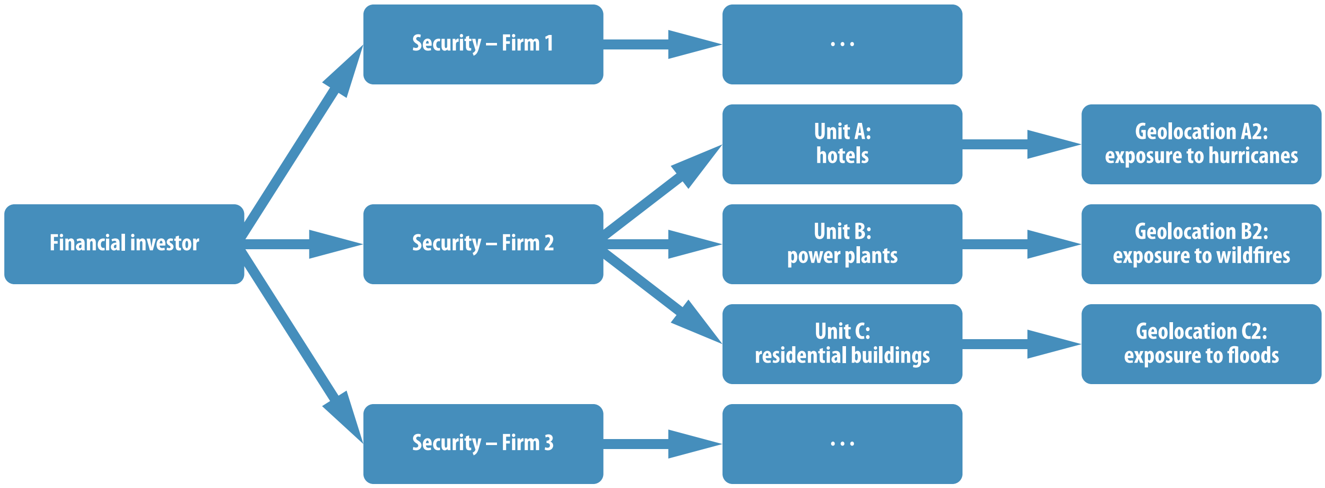


Figure 20. Example illustrating a portfolio of three securities (or loans), in which the second security is issued by a firm with three business units in three different geolocations and exposed to three different types of climate hazards.

In the example above (and in real life), financial portfolios are made up of securities and financial contracts associated with particular firms. Each firm can be thought of as a portfolio of business units (for example, manufacturing plants, installations, etc.), each contributing to the revenues and costs of the firm. Business units are characterized by their sectors of economic activities (e.g., under the NAICS classification system) and their location. This representation of the firm holds both for small- and medium-size enterprises with one or more production lines or plants, as well as for large corporate groups with consolidated balance sheets.

In this framework, the overall economic impact on a firm of a climate event depends on the extent to which each business unit is affected, weighted by the relative contribution of each business unit to the total costs and revenues of the firm. The overall shocks on revenues and costs of the firm translate into adjustments to financial metrics such as EBITDA and return on equity (ROE). These can then be fed into financial valuation models in order to assess the adjustment in the financial value of the firm's security or contract. The details of the valuation model depend, of course, on the type of security and contract (equity, bonds, and loans), as discussed further below.

Figure 21 adds this financial framing to the direct and indirect impact channels shown in Figure 19. Changes in firms' profitability are transmitted to the financial value of the firms' assets, to credit risk (via the adjustment in the probability of default (PD), and in its financing costs). These adjustments are then transmitted to financial institutions' risk profile (leverage, banks' Non Performing Loans, Capital Adequacy Ratio), investors' risk metrics (climate Value at Risk, Expected Shortfall), and to investors' portfolio value. Finally, the climate shock can aggregate to economy-wide impacts through firms' cumulative decline in profitability, creating sovereign risk via a fall in fiscal revenues, which in turn affect sovereign bonds' spread, debt service, and sovereign risk.

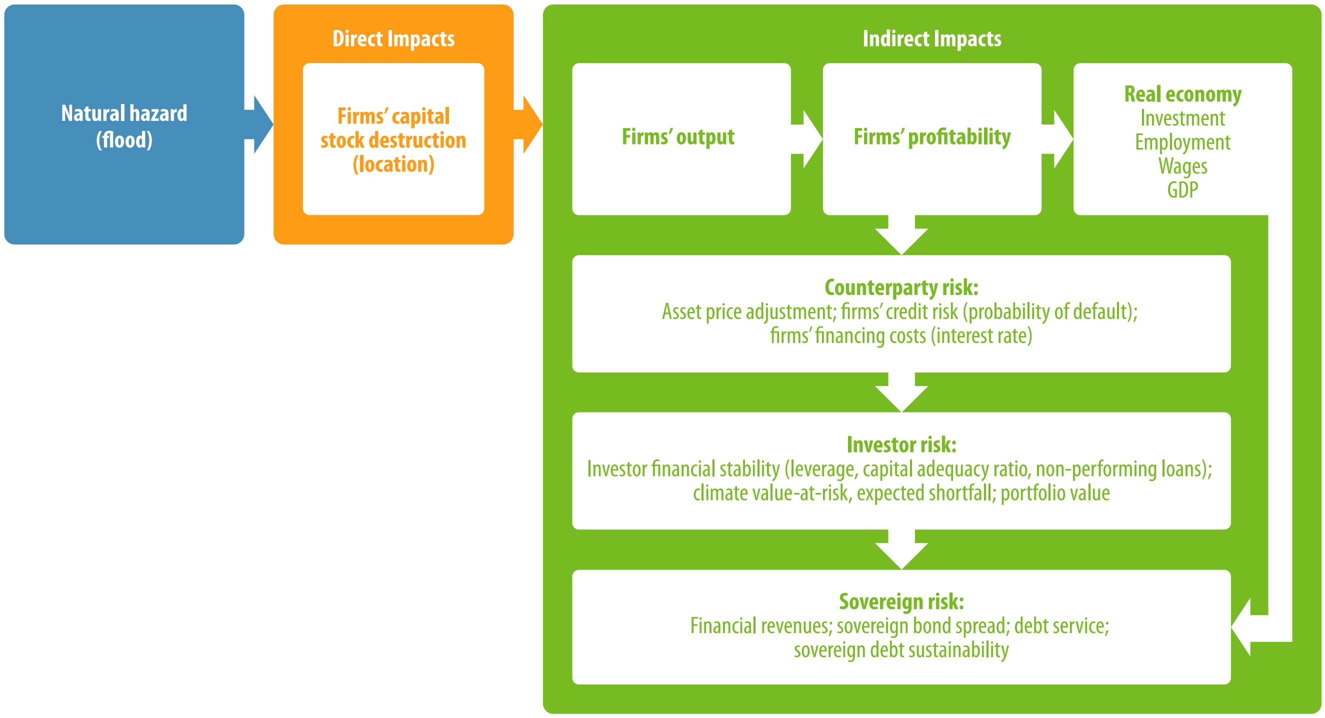


Figure 21: Disaster risk transmission channels to the economy, private and public finance. Adapted from CLIMAFIN.

This general scheme is conceptually simple. However, practically it poses a number of challenges that need to be resolved in order for the resulting analysis to be granular enough to inform decision making:

1. Large firms may be made up of hundreds of subsidiaries, across many countries, each having dozens of business units. The specific location and economic activity of these units, and their contribution to revenues and costs, is typically not easily accessible from outside the organization. The good news is that this data is the same data that the firm's risk managers should collect to monitor operational and financial risk in general. Non-financial firms should adapt their climate risk disclosure to include this information alongside emissions data, and banks should take steps to get more of this information through bilateral and collective engagement.
2. Global climate models break the Earth down into sections of about 3,000 square kilometers. In order to take into account the location of firms' business units at a more granular level, the use of regionally downscaled models is necessary.
3. Future climate events can only be estimated in probabilistic terms. Therefore, there is a degree of uncertainty that increases significantly with the time horizon considered. This uncertainty affects both climate economic and financial risk assessment exercises.
4. Climate events are generally correlated in time and place (for example, droughts and wildfires).[59,60,61,62] This means that multiple hazards could occur in the same location and year (for example, floods and droughts). Further, one or more hazards could affect multiple business units that are located in the same region and are in the same value chain (for instance, hurricanes over the Caribbean in a given year). If hazards are not independent but instead linked, the resulting economic shocks and distribution of impacts can be much larger than in the case of uncorrelated hazards.
5. Climate-financial risk assessment should also take the potential for systemic risk into account (see Section 5). This risk is most likely to be driven by low-probability, high-impact events ("tail risk") because of the magnitude of those events, but also because most existing risk-management systems (notably in the insurance industry) are designed to handle conventional/historical risks and so might not be able to handle climate-related tail risks.[63,64,65]

Specific models also need to be developed to account for the characteristics of each asset class. This means that banks undertaking this analysis will have to:

1. Identify which climate hazards are material for which classes of financial assets.
2. Develop financial valuation models for all asset classes that account for the climate risks identified as material.
3. Empirically validate these models and quantify the share of risk currently attributable to climate hazards.
4. Integrate forward-looking projections of physical and transition risks.

Table 6 below provides a simplified view of the types of relevant hazards and models that can be used to assess physical risks for the main asset classes.

Asset class	Relevant hazards	Type of models[2]
Stocks	Direct + indirect (supply chains) + sector specific (e.g. agriculture, energy)	Structural credit-risk models
Corporate bonds		
Sovereign bonds	Direct + indirect impacts on fiscal revenues. Government insured hazards (floods++)	Structural approach à la Gray-Merton-Bodie
Mortgages	Direct (floods++)	Structural econometric models, survival models

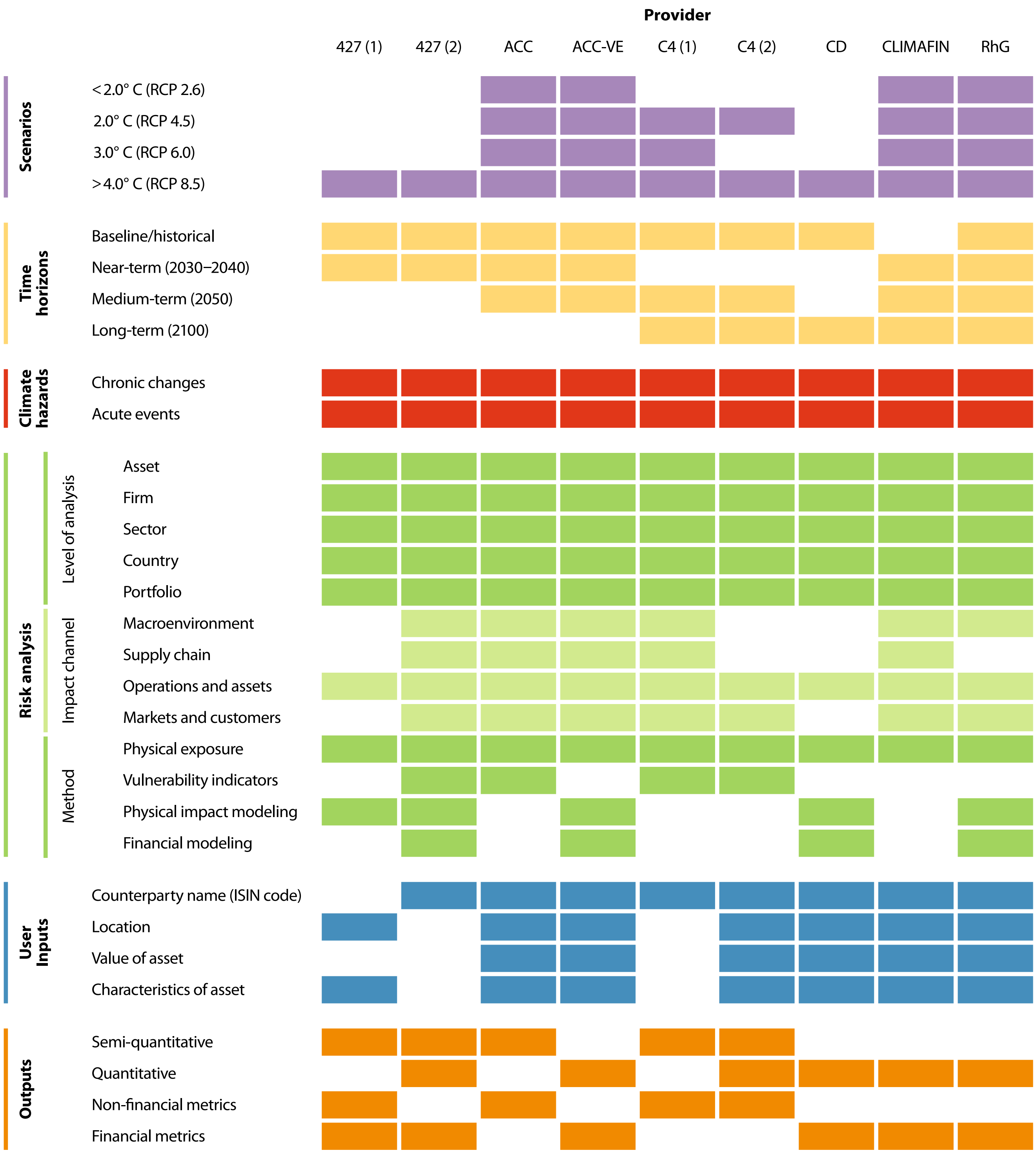
Table 6: Key hazards and type of models for the assessment of climate physical risks for the main financial asset classes.

Given these complexities, banks should consider academic and commercial analyses that attempt to address the issues discussed above (some examples are provided in Appendix D). Regardless of the methodology selected, the impacts to clients and the potential benefit to risk evaluation means that banks need to start somewhere with respect to the integration of physical climate risk into their existing enterprise risk management approaches.

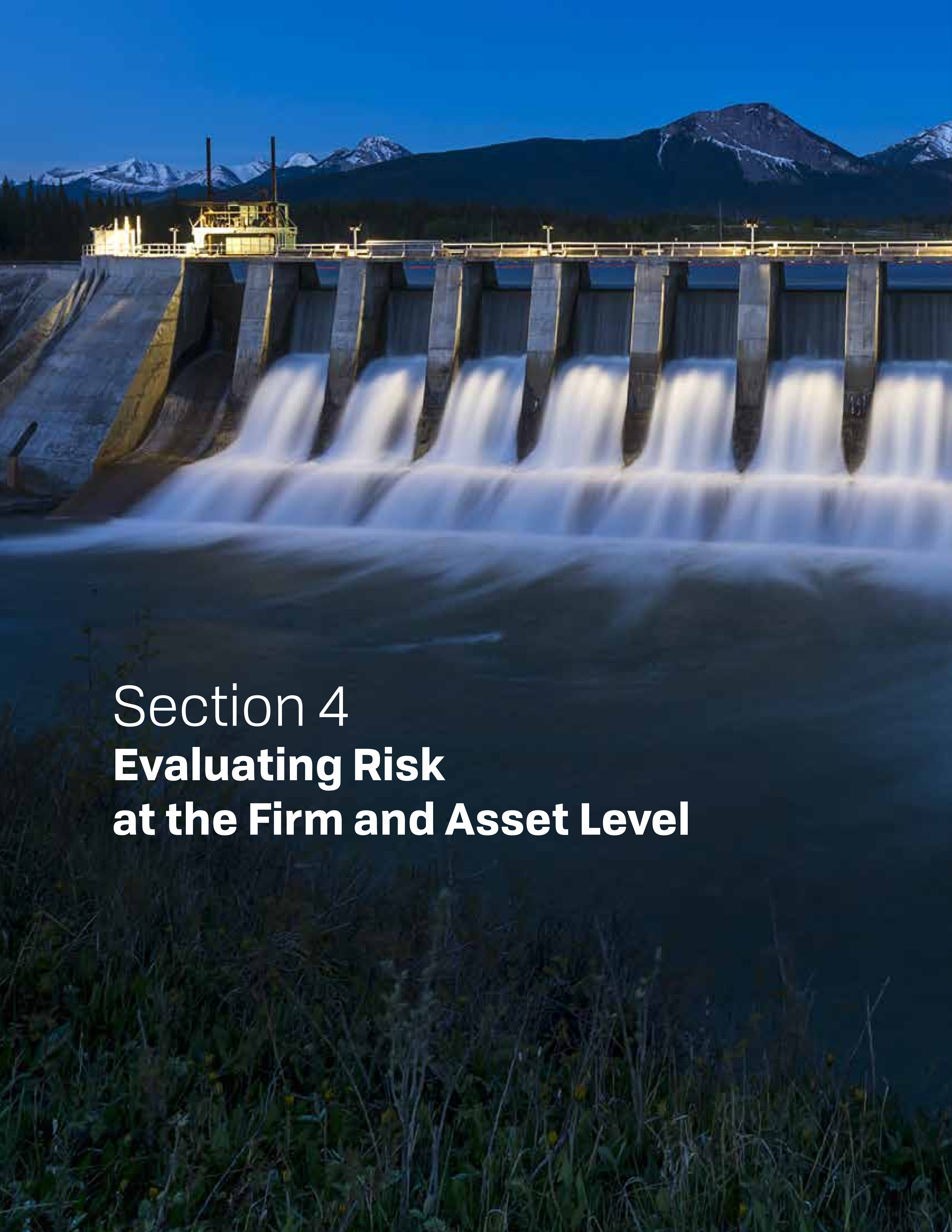
Since the field is still in its infancy, banks should focus on knowledge-building and pilot analysis at this stage. Banks should also consider piloting or adopting one or more of the commercial methodologies for climate financial risk assessment that have been developed in recent years. UNEP-FI in its **Climate Risk Landscape** report provides a comprehensive review of physical risk methodologies, including CLIMAFIN's, whose model is used in Section 1.

Banks should select the approach that best fits their individual risk management strategy. Unfortunately, this may be difficult to determine without directly engaging these commercial vendors as most provide very little information about their methodology, particularly regarding the scientific inputs and scenarios used.[66] This is problematic from both the perspective of scientific fidelity and the ease with which banks can compare these methodologies. Where possible, banks and civil society should press commercial vendors to be more transparent with regard to their models and assumptions.

Summary of Commercial Climate Risk Methodologies Highlighted by UNEP-FI



427 (1): *On-demand physical climate risk scoring application* 427 (2): *Physical climate risk scores for publicly listed companies*
ACC (Acclimatise): *Physical climate risk heat mapping 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*



Section 4
Evaluating Risk at the Firm and Asset Level

While data about the large-scale effects of climate events is increasingly robust and relevant for banks' risk assessments, firm- and asset-level information is critical for evaluating individual client relationships and potential transactions. The key gap that currently exists is a lack of information about how much exposure a bank's clients (firms and governments) have to physical risk and the specific losses the bank is exposed to as a result.

Recommendation: Engage clients on physical risks.
Banks should engage clients on the increasing risks they are facing (and contributing to) and help them design solutions to reduce that risk. After integrating climate into credit risk assessment, banks should provide incentives to their clients to reduce risks by increasing the availability of capital for sustainable activities and lowering its cost.

Fortunately, a model exists for firm-level analysis of these risks. Insurance companies have already developed much of the informational and analytical infrastructure needed for firm-level assessment of physical risks. Banks should (either individually or collectively through organizations like OS Climate) build or acquire similar systems to develop a robust climate risk assessment framework.

Of course, insurance companies have some built-in advantages that banks do not—a vast amount of information on their clients' exposure that is collected through the underwriting process. While banks collect some information about clients through due diligence, exposure is still the key data gap banks need to bridge for the assessment of climate physical risks. As discussed in Ceres' **Financing a Net Zero Economy: The Role of Time Horizons and Relationship Banking**, banks should leverage client relationships to obtain much more robust and granular data. Failing that, exposure can be approximated, from the bottom up, by third-party data providers.

For example, by incorporating (widely available) real-time weather data into scenario analysis, banks would be able to conduct industry and firm-level forecasting of material physical risks that could impact a borrower's creditworthiness. It could also share acute and "near miss" physical risk data with borrowers to help them assess and implement mitigation strategies. And since industry-specific climate risk factors are also widely available (such as the Discussion Topics provided by the SASB standards), banks could use this additional data to develop correlational databases between financial and climate-related factors to better inform their risk management practices.

Recommendation: Collect asset-level data about exposure and loss vulnerability.
Banks should seek out information about firms' exposure to and preparedness for future climate events. Unfortunately, local assessments of losses by sector and firm- and asset-specific data are still limited. Banks should address this by implementing a process to collect the relevant data from their clients as part of the lending process, as insurers do.

Some U.S. banks have already started to collect data and analyze it, although at present this is generally limited to ad-hoc analysis of particular sectors or types of assets. It is useful to look at some of these examples as a model for what banks might do across their portfolios once more complete data is available. Bank of America, for example, looked at the potential impact of 12 different hazards on a sample of its residential mortgages across the U.S. This is the baseline level of analysis that every U.S. bank should already be undertaking and disclosing to stakeholders.

Of the large U.S. banks, Citi has done the most public, in-depth work, through its Mexican subsidiary Citibanamex. Citi's analysis considered the impact of five physical hazards on Citibanamex's portfolio of commercial real estate and agriculture loans. What differentiates Citi from its peers is the extrapolation from potential losses to clients into bank-specific financial metrics, such as probability of default and credit rating. While still in the pilot phase, Citi's work provides a leading example of how firm-level data can be leveraged to understand the materiality of physical climate risk to the bank and its clients. Other banks like JPMorgan Chase, Goldman Sachs, and Morgan Stanley have also done pilot projects that produced estimates of financial vulnerability, but the level of detail provided in disclosures makes the usefulness of these exercises difficult to evaluate.

Upcoming Ceres Research

Data, especially public data, is hard to come by at the asset level. Ceres recognizes that some banks, particularly smaller ones, may need additional guidance about how to build a bottom-up physical risk analysis that could supplement the kind of top-down analysis Ceres and CLIMAFIN use in both this report and its predecessor. To that end, Ceres has partnered with the climate analytics firm FutureProof to look at the asset-level data that is publicly available for U.S. banks—that is, information about their physical offices and branches. FutureProof's analysis includes the impact of floods, hurricanes, wildfires, tornados, hail, snowstorms, wind, and lightning. Climate-linked losses reflect damage to physical structures, as well as lost revenue and other costs.

The analysis uses asset-specific data on losses to estimate these impacts and makes asset-specific projections of loss that take asset characteristics into account. AI techniques are used to estimate how the magnitude of physical perils interacts with asset characteristics in determining financial losses. By combining the projected probability of climate events with the estimated impacts they have on financial outcomes, the analysis projects how the climate will impact financial outcomes around the globe both now and in the future.

This asset-level analysis can be used as a proxy, in an illustrative sense, for the physical climate risk to banks' broader portfolios. In the absence of data on the geographic concentration of banks' portfolios, it may be reasonable to assume that the geographic concentration of banks' broader portfolios will in some cases follow the contours of the geographic concentration of their facilities, at least for smaller banks.

While the preliminary results of this work are consistent with the analysis in Section 1, the vastly different methodology used makes it logical to release it separately from this report, as Ceres did with our previous work on transition-related client engagement. Interested readers should expect to see this research on the Ceres website in the coming months.

While all of these examples are useful, they are incomplete. When it comes to the information that still needs to be collected, it is helpful to distinguish between three types of clients: non-financial firms, other financial firms, and governments:

Non-Financial Firms
The direct exposure of non-financial firms depends on where their physical assets are located. Financial and regulatory reporting of firms, such as 10-K filings, are the primary source for this kind of information. Some economic and financial data providers give access to datasets with geographical allocation of firms' activities (for example, S&P and Bloomberg). Firms also have indirect exposure through their suppliers and customers. Again, the primary source of information on the topic is the financial and regulatory reporting of firms and financial data providers. In the absence of micro-level data, indirect exposure can be estimated from global input-output tables such as the World Input-Output Database (WIOD) or the Eora global supply chain database.

Financial Firms
The exposure of financial firms to physical risk depends, in addition to their branches and other locations, on the composition of their balance sheets. This exposure is mostly indirect—a bank's exposure depends on the exposure of its clients. Micro-level data on the balance sheets of financial institutions is generally not available. However partial data is available or can be reconstructed from specialized data providers like Refinitiv, Bloomberg, IJGlobal, and Bureau van Dijk. At a more aggregate level, the Bank for International Settlements provides quarterly data on the outstanding claims and liabilities of internationally active banks located in reporting countries.

Governments
Exposure can be estimated based on the distribution of GDP throughout a given country, state, or city—areas with higher GDP per square mile will, in general, be the areas that are most exposed from a government finance perspective. Methods already exist to downscale GDP at high geographical granularity, so banks should be able to do this relatively easily.[67]

While these data sources are useful for banks, they are far from complete. Client engagement and partnerships with other banks, regulators, and the insurance industry will be needed to fill in many of the gaps. Regulators are already looking to help banks address these issues. Acting U.S. Comptroller of the Currency Michael Hsu recently said: "Prudently managing climate change risk is a safety and a soundness issue. The changes announced today will enable the agency to be more proactive in accelerating the development and adoption of robust climate change risk management practices, especially at the larger banks."

In the interim, one possibility could be for clients to voluntarily submit additional data to reduce a punitive risk premium that banks could otherwise apply based on sectoral risk assessments. In addition to working with clients to obtain data, it is also worth noting the importance of educating them about their risk exposure and potentially partnering with insurers to encourage reduced premiums if certain resilience measures are implemented. Banks that establish these practices could build a reputation for this work and potentially generate expanded business opportunities from it.

Recommendation: Integrate climate into product and service pricing.
In addition to stress tests and scenario analysis covering the whole portfolio, banks should embed climate physical risk into client-level risk assessment and, from there, into pricing. Changes in firms' probability of default and financial risk metrics are highly sensitive to the choice of the climate scenarios. Thus "tail risk" climate scenarios should not be neglected.

Section 5
From Individual to Systemic Physical Risks

As discussed in Ceres' fall 2020 report, climate transition risks have obvious and material systemic implications in the case of sudden changes in policy or investor sentiment, which affect many or all actors in the system simultaneously.[68,69] This has the potential to cause a financial crisis as or more severe than the 2008 housing crisis. The systemic impact of physical climate risks on a national basis, on the other hand, might be more "like diabetes than an asteroid," in that the risk slowly builds rather than hitting all at once. No single natural disaster is likely to destabilize the national financial system on its own (even the COVID-19 pandemic did not, despite historic levels of economic disruption). While there could be disaster-driven changes in investor sentiment, it is more likely that this sentiment would shift gradually over time based on multiple events, allowing banks time to adjust their portfolios and avoid a financial meltdown. But individual banks or credit unions, especially smaller ones that have a highly concentrated loan portfolio, could be wiped out by individual climate disasters.

Impact on Community Banks and Credit Unions

Community banks and credit unions typically focus on providing traditional banking services to their local communities. Generally, they obtain their deposits locally and make most of their loans to local businesses. Community banks represent the vast majority of banks in the United States (by some estimates over 90%). However, community banks represent only ~15% of total banking sector loans.

Based on their local expertise, community banks tend to focus on a few key sectors, such as residential mortgages, commercial real estate (CRE), small business financing, and agricultural sector loans. Given this focus, community bank loan portfolios are more exposed to the physical risks of climate change considering the vulnerability of these sectors to acute weather events in the near term and transition risks in the medium to long term.

The extent to which physical risk will impact the operations of specific community banks will obviously depend on the geographic distribution of their branches. However, in general, three factors make community banks and credit unions more vulnerable to physical risks than their larger counterparts.

- First, community banks tend to rely more on physical branches to deliver banking services.
- Second, larger banks can better use technology to enable a higher degree of resiliency in their operations. Community banks have challenges in adopting these new technologies relative to their larger bank peers.
- Finally, these banks have fewer staffing resources. As such, they may not be able to go as deep in their analysis of climate risks or climate-related new business opportunities.

Systemwide Implications of Climate Litigation

A significant legal ruling connecting carbon-producing companies to disaster liability could lead to a system-scale shock. While this possibility is not directly related to physical risk, climate litigation is a major policy and legal development that could dramatically broaden the scope of climate-related risks going forward. Linking scientific attribution studies of climate events to legal causality has been demonstrated in principle under U.S. law.[70] Accordingly, one possible source of an abrupt physical risk-related shock to the financial system would be a major court ruling holding carbon-producing companies liable for disaster damages, which would quickly shift the market value of many companies. Most recently, in a landmark ruling, a Dutch court has ordered Royal Dutch Shell to drastically deepen planned greenhouse gas emission cuts (by 45% by 2030 from 2019 levels). Although this decision does not order direct damage payments, it could imply drastic shrinkage of certain lines of business, according to Shell executives. A number of other signals also suggest increasing litigation risks. There is evidence that insurers are changing insurance policies for directors and officers at certain companies to reduce risk exposure and that companies at risk of such litigation are developing legal strategies to limit their future liabilities.

The increase in physical risks attributable to climate change will define how much compensation might be sought through litigation. Companies that may be liable face both financial and reputational risk. Banks face a direct liability risk as they could be held responsible for financing "undue investment" in fossil fuels: although the financial risk seems limited in this case, the reputational risk is real. Banks also face an indirect risk through the exposure of their clients to liability risk. In first approximation, this risk is proportional to the historical emissions of the client.

An avenue through which physical climate risks could cause a systemic crisis similar to what could result from the failure to prepare for an energy transition is if a major disaster in an at-risk country caused that country's political or economic system to collapse. CLIMAFIN conducted analyses estimating the exposure of the U.S. financial system to foreign counterparties and the potential for foreign flood risk to affect the U.S., and found that while the U.S. banking sector is very central within the global interbank network, its external financial leverage is limited (see Appendix E). Both analyses indicate that although the external risk is substantial, it is commensurate with domestic risks and, at the aggregate level, existing prudential requirements appear sufficient to handle such a shock.

Of course, systemic risks don't have to be catastrophic to be material. Large correlated shocks on a set of financial institutions, such as the ones induced by major disasters, can lead to systemic risks if they cause financial institutions to reassess the risk of their counterparties who have been directly or indirectly affected by the initial shocks.[71] The aftermath of Hurricane Katrina illustrates one way this could unfold. Research shows that the liquidations of bond holdings by property and reinsurance companies created a persistent negative price impact on bond prices.[72] Additionally, the uninsured property damages led to unexpected losses for banks, contributing to major rating agencies announcing close monitoring of these affected banks.[73] Further propagation, which didn't materialize in the case of Katrina, would occur if the loss-to-capital ratios (an important credit risk metric) had been sufficient to trigger massive credit downgrades.

Beyond the direct exposure to disasters, foreign and domestic, the physical climate risks faced by the financial system stem from how risks are allocated and diffused on a global scale. From a macro perspective, direct losses from climate hazards are allocated between the private sector (corporates and households as physical asset owners), the public sector (as a physical asset owner and as a formal/informal insurer), and the insurance sector.

As highlighted in Figure 23, a substantial share of damages to property (60% on average) is insured in the U.S. The insurance rate for flooding is substantially lower (around 40%) compared to other hazards. This is because standard property insurance policies, such as homeowners insurance, typically do not cover flood damage. Some flooding insurance is provided by the national flood insurance program and is mandatory only in FEMA-designated flood zones. Through the National Flood Insurance Program, the government plays an explicit insurance role but only meets a portion of the need for flood insurance. Through the disaster relief fund, it also plays an implicit insurance role, in particular through individual assistance programs.

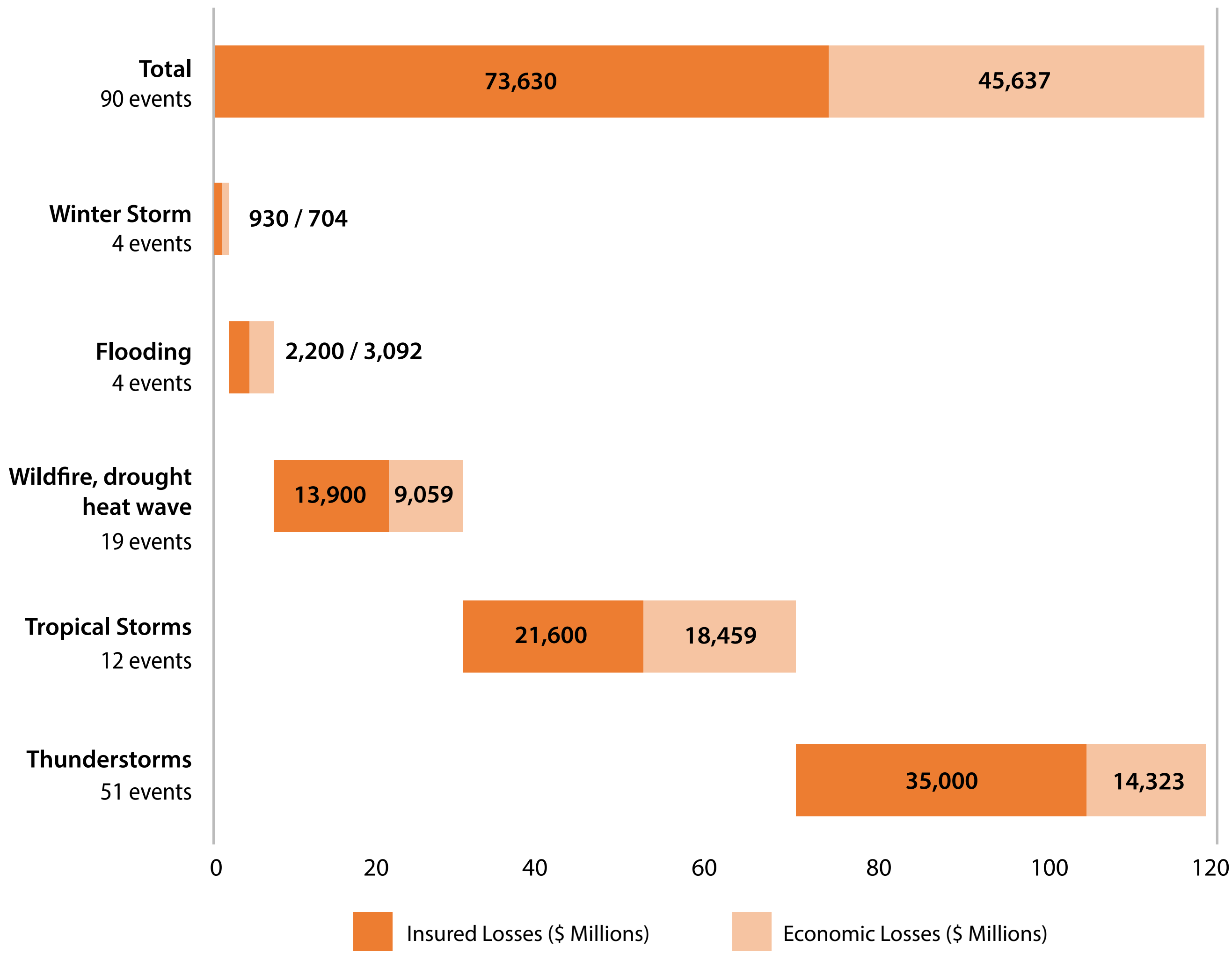


Figure 22: Natural catastrophe Losses in the United States, By Peril, 2020. Source: Insurance Information Institute.

By shifting part of the (extreme) risk away from banks' balance sheets, insurance reduces and smoothes the exposure of the banking sector to physical climate risks. But a substantial share of the risk remains uninsured. Beyond imperfect property insurance (see Figure 23), it has been estimated that only 30% to 40% of business owners carry some form of business interruption coverage and, according to FEMA, about 25% of businesses do not reopen after disasters. This risk, which mostly affects small- and medium-size businesses, can be very significant for banks with large exposure to this market segment. In order to mitigate this risk, banks should take into account in their credit risk assessment the disaster recovery plan implemented by their clients, and in particular their business interruption insurance. In addition to assessing clients' preparedness, banks could also help businesses in disadvantaged communities—which are often disproportionately affected by and ill-equipped to prepare for these events—build the capabilities to better plan and prepare for such disasters. Ultimately, insurance only reallocates risks and the exposure of a given bank depends on the type (and exposure) of its clients. After a natural disaster, pre-existing insurance policies:

- Decrease the risk associated with private sector clients
- Increase the risk associated with insurance and reinsurance clients
- Increase or decrease the risk associated with government clients, depending on their rate of insurance vs. self-insurance and their role as insurer

There is substantial evidence that, following major natural catastrophes, insurance premiums increase and insurers might exit the market for some risks.[74,75] Concern that climate change may cause certain risks to become uninsurable has been voiced by key institutions, including the European insurance regulator EIOPA, insurance industry associations, and leading insurance companies, such as IAG and AXA. Changes in the insurance and the insurability of climate-related risks can have substantial negative impacts on the banking sector in the following ways:

- An increase in the price of insurance will negatively affect the profitability and liquidity of corporate bank clients and the associated default probability.
- An increase in the price of insurance (and of the associated risk) will decrease the value of exposed properties. In the case of mortgages, this might substantially increase the loan-to-value ratio and thus increase default rates, and increase loss-given-default.
- In the absence of insurance and, in particular, business interruption insurance, climate-related hazards will lead to higher frequency of corporate and mortgage defaults.

Overall, it is unlikely that the insurance sector will shield the banking sector from the increase in physical risks induced by climate change.

Recommendation: Understand the changing insurance landscape.
Banks should work to understand how physical climate risks are driving changes in the insurance industry. Premiums and uncovered risk will likely increase. This will affect the most vulnerable bank clients and also hurt banks' loan metrics. Banks should learn from the insurance industry's more sophisticated physical risk assessment tools but not rely primarily on insurance to mitigate their own risk.

One possible solution to this problem is increasing support for insurance policies by governments through the National Flood Insurance Program or similar state-owned insurance corporations, such as Florida's Citizens Property Insurance Corporation. However, this solution could end up increasing risk to banks through other channels:

- At the federal level, increased government exposure to natural risks might first materialize through an increase in interest rate risk.
- At the state and local level, the credit risk profile of certain entities might substantially deteriorate if they end up covering a substantial share of physical risks in their jurisdiction.
- Inappropriately structured government flood insurance programs can also lead to rebuilding where it is not appropriate, further increasing risk in those areas.

In all cases, the value of long-term government financial assets could be impacted.

While insurance can currently cover a substantial portion of physical climate risk at the firm level, it comes at the cost of increased systemic risk since the risk is not actually mitigated, only spread out across the financial system. This raises the question of what exactly banks can and should do to mitigate their exposure to physical climate risks as those risks grow in the coming years. Unlike transition risks, which can be reduced in the medium term with concerted client action, actions taken today to reduce future emissions are unlikely to substantially affect the level of physical risk before 2040 (as that risk is already "baked in".)[76] Mitigation of the risks after 2040 is critical for financial and societal reasons, as the analysis in section 1 shows. Banks already have an overwhelming business case for this (through client engagement, sustainable finance and broad support for the energy transition), as highlighted in Ceres' 2020 report on transition risk. Furthermore, adaptation and resilience measures (as opposed to mitigation efforts) taken today do have a major impact and represent a key opportunity for banks.

Adaptation finance can be a major business opportunity as part of banks' sustainable finance work, and also substantially mitigates physical risk that banks and broader society could face. However, the last National Climate Assessment (NCA) emphasizes that adaptation is happening too slowly and that most organizations' planning is currently based on the assumption of a stationary climate.

Recommendation: Focus on adaptation projects to mitigate credit risk.
Banks should know that because physical risk cannot be mitigated in the short and medium term, adaptation is one of the only avenues available for reducing their risk, though it is often a neglected part of banks' sustainable finance programs.

Yet, as emphasized by the NCA, "Adaptation is a form of risk management." It is therefore in everyone's interest for banks to advocate for, incentivize, and finance adaptation measures. This would reduce risk across the system as well as for individual banks and create new business opportunities at the same time.[77]

Recommendation: Develop innovative adaptation financing solutions.
Banks should recognize that financing public investment in adaptation has strong positive externalities for the banking sector as it reduces the risk for everyone, especially those in disadvantaged communities. Some of these adaptation investments can even come at a negative cost by limiting the physical impacts of climate change on workers, assets, and insurance premiums. Because adaptation finance is still in its infancy in the private sector, banks need to develop innovative approaches that are attractive to clients and structure the corresponding products in ways that are attractive to long-term investors.

In the Section 1 analysis, adaptation is mainly related to the upgrade of flood protection measures (for example, dikes). However, there is much more that could be done, and which could be enabled by advocacy from banks. This could include:

1. The integration of adaptive measures into current policies or planning processes (for example, building codes).
2. An update to the regulatory framework for adaptation and land-use policies. Notably, this would include an update to FEMA flood maps.
3. The assessment and the reduction of risks by bank clients related both to operations and the value chain, in particular the adaptation of agricultural production to changing climate conditions.
4. More broadly, raising awareness and increasing scientific evidence about climate risks in order to improve market pricing of climate risk in financial assets, insurance contracts as well as physical assets.
5. Ensuring that adaptation finance takes into account the needs of underserved communities and follows principles of environmental justice.

Recommendation: Advocate for smart financial regulatory and policy actions on adaptation.
Banks should seize on adaptation finance as a big opportunity. Without smart policy, however, the scope and scale of the opportunity could be reduced. Banks have a financial interest in promoting policy change that incentivizes the development of new infrastructure and the remediation of industrial pollution, which would reduce risk for banks and also benefit disadvantaged communities and society broadly.

CONCLUSION

"There is no doubt that climate change poses profound challenges for the global economy and certainly the financial system."

Federal Reserve Chairman Jerome Powell

"Climate change also introduces new and increasing types of risk. The risks from more frequent and severe natural disasters—so-called physical risks—have, and will continue to become, more prominent."

Treasury Secretary Janet Yellen

To adequately address these physical climate risks, U.S. banks must answer the following questions:

- What physical climate risks need to be considered and in what order?
- What are the challenges in obtaining the required data?
- What is the process for conducting a risk assessment on this topic?
- What does an example analysis look like? What does it show?
- What are the systemic implications of the risk?
- How can the risk be managed in a way that reduces existing inequalities and promotes environmental justice?

This report begins to answer these questions, but much more must be done. Our analysis shows that banks and credit unions need to act now on physical risks because:

1. There already is a substantial share of climate-related risks on banks' balance sheets that are not properly managed.
2. These risks—to banks and broader society—will only increase with climate change.
3. Banks need to be prepared for state, federal, and international regulators to act on climate risk assessment, stress testing and disclosure.
4. Investors in the U.S. and worldwide, representing more than $41 trillion of assets under management, are demanding action to ensure a net zero future.
5. Banks lag behind the insurance industry in terms of physical risk assessment; they need to close this gap.
6. There are substantial business opportunities available in adaptation finance that will be taken up by others if U.S. banks do not move quickly.

Only by developing and acting on this comprehensive understanding of climate risks can banks ensure that their lending decisions reflect and respond to the reality that they, their clients, and broader society face from climate change. As the U.S. returns to climate leadership with its ambitious commitment to more than halve GHG emissions by 2030, U.S. banks must follow suit and become global leaders as they are in so many other areas.

Words are no longer enough, action is needed. Now.

Appendix

APPENDIX A: Mathematical Details of the CLIMAFIN Model

The analysis in Section 1 is based on the CLIMAFIN physical risk assessment model, which is similar to natural catastrophe models used in the insurance industry (see Section 3). However, the hazards it considers are projections of future climate impacts, while the exposure is determined by the sectoral and geographical characteristics of the assets in a financial portfolio, and the vulnerability metrics it uses are the outcome of financial valuation models.[78,79]

Hazard models (see Appendix D) provide estimates of the physical impacts from floods, storms, and wildfires and climate impact models provide estimates of the impacts on labor and agricultural productivity at the country and sector level. To obtain estimates of economic impacts on capital assets, the distribution of damages on physical assets obtained from the climate impact models is combined with sectoral level data on the share of tangible assets in fixed capital obtained from the EU KLEMS dataset.[80] These estimates of climate impacts are then inputted into the global economic model IO-NET calibrated on the world input-output database.[81,82] From there, one obtains:

(i) Estimates of direct climate impacts on gross value-added per country and sector
(ii) Estimates, per country and sector, of the indirect impacts induced by the propagation of direct climate shocks through global supply chains

Overall, for each country c and each NACE sector s, we obtain a decomposition of the random variable $\kappa_{c,s}$ representing the climate shock on gross value-added of the form:

$$\kappa_{c,s} = \kappa_{c,s}^{labor} + \kappa_{c,s}^{river} + \kappa_{c,s}^{coastal} + \kappa_{c,s}^{wind} + \kappa_{c,s}^{fire} + \kappa_{c,s}^{agri}$$

where the last term $\kappa_{c,s}^{agri}$ is non-zero only for the agricultural sectors.

CLIMAFIN then translates these country- and sector-level economic shocks into impacts on financial assets. The methodology first considers (for each asset in the portfolio) an assessment of the risk-adjusted value in absence of climate risk. This assessment can be expressed in reduced form as:

$$V_{benchmark} = (1 - PD_{benchmark}) * V_{nominal} + PD_{benchmark} * (1 - LGD) * V_{nominal}$$

where $V_{nominal}$ is the nominal value of the asset, $PD_{benchmark}$ is the probability of default associated to the idiosyncratic (i.e. non-climate related) risk on the asset, LGD is the ratio of loss given default and $V_{benchmark}$ is the risk-adjusted value of the asset (in absence of climate risk). The benchmark probability of default corresponds to the probability that the counterparty faces an idiosyncratic shock on its assets that leads to the crossing of the default threshold, that is:

$$PD_{benchmark} = Prob[(1-\theta)A < L] = \int_{1-\frac{L}{A}}^{1} f(\theta)d\theta$$

where A denotes the value of the assets of the counterparty, L the value of its liabilities (or more generally the default threshold), and θ is the idiosyncratic shock on the asset (with probability density f).

In line with the framework assumptions put forward by financial regulators, we assume that risks induced by climate change are not accounted for in these benchmark assessments of the probability of default and of the risk-adjusted value. More precisely, we assume that climate change induces a supplementary risk on the assets of the counterparty, which is independent of the idiosyncratic risk. Considering a given percentile (*k*a) of the distribution of the climate risk, one can define a range of indicators of climate risks such as:

- The default probability under climate risk: $PD^{\alpha}_{climate} = Prob[(1-\theta-\kappa_{\alpha})A < L] = \int_{1-\kappa_{\alpha}-\frac{L}{A}}^{1} f(\theta)d\theta$ (1)
- The climate-induced change in default probability:

$$\Delta PD^{\alpha}_{climate} = PD^{\alpha}_{climate} - PD_{benchmark}$$

- The asset value adjusted for climate risk:

$$V^{\alpha}_{climate} = (1 - PD^{\alpha}_{climate}) * V_{nominal} + PD^{\alpha}_{climate} * (1 - LGD) * V_{nominal}$$

- The climate value-at-risk at percentile α

$$VAR^{\alpha}_{climate} = V^{\alpha}_{climate} - V_{benchmark}$$

Climate value-at-risk is used as the default risk metric throughout the report.

APPENDIX B: Climate Scenarios Used

Scenarios have been used extensively in climate change research itself since the 1990s.[83] Since then, the IPCC has developed a reference framework to describe climate change scenarios and their physical and socio-economic impacts, on the basis of the future evolution of population, economic activity and GDP, lifestyle, energy use, land use patterns, technology, and climate policy. This framework is based on the following connected notions:

i) Representative Concentration Pathways (RCP)
ii) Shared Socio-Economic Pathways (SSP)

This general framework has been adopted worldwide, including by financial supervisors and regulators in many countries. Ceres' and CLIMAFIN's analysis uses the scenarios from the IPCC's Fifth Assessment Report (AR5), as AR6 has not yet been fully released (although the first AR6 report did launch in August 2021).

Representative Concentration Pathways (RCP)

RCPs are trajectories of yearly GHG emissions leading to target levels of GHG concentration in the atmosphere by 2100, or equivalently to target levels of cumulative emissions in the period 2010-2100. They can be mapped onto ranges in average global temperatures, as described below. The term "representative" means that each RCP provides only one of many possible ways that a given future could emerge. The term "pathway" emphasises that the trajectory taken over time to reach that outcome is as important as the ultimate endpoint. Four main RCPs have been used since the IPCC AR5 report was published (2014), of which this report uses the best- and worst-case scenarios (RCP 2.6 and RCP 8.5) to give a sense of the range of possible outcomes:

1. **RCP 2.6** is a stringent scenario of climate stabilization, named RCP2.6 because radiative forcing peaks at approximately 2.6 W.m^2 before 2100 and then declines. **This scenario corresponds to a 66% chance of global warming below 2 degrees C—the target set out in the Paris Agreement**. This can be considered as the optimistic scenario. Note also that in many modelled trajectories the 2 degrees C target is only reached assuming a certain level of negative emissions, i.e., the use of technologies to remove GHG from the atmosphere. This assumption has raised concerns in the community.[84]
2. **RCP 4.5** is an intermediate stabilization scenario where **warming is in the range of 1.7 to 3.2 degrees C**.
3. **RCP 6** is an intermediate stabilization scenario where **warming is in the range of 2 to 3.7 degrees C**.
4. **RCP 8.5 is** the pessimistic scenario, a scenario of unmitigated climate change with emissions increasing according to historical trends. In this scenario radiative forcing reaches a level above 8.5 W/m^2 by 2100 and continues to rise for some amount of time. **This scenario corresponds to increasing global warming likely above 4 degrees C in comparison with pre-industrial levels.** In terms of impact on socio-economic systems, under RCP 8.5 the following impacts are projected (with high level of agreement across experts):
    - Reduced renewable fresh surface water and groundwater
    - Irreversible regional scale changes in ecosystems, including mass extinctions, ecosystems services, and fishery productivity
    - Sea level rise leading to submersion, coastal flood, and erosion
    - Loss of food security, displacement of people, and conflicts
    - Negative impacts on economic growth, critical infrastructure, and territorial integrity in many countries

Shared Socio-Economic Pathways (SSP)

The financial assessment of the impacts of climate change requires long-term economic projections that are based on global socio-economic scenarios. The Shared Socio-Economic Pathways (SSPs) represent a set of narratives of future developments that consider the concurrent evolution of several socio-economic dimensions, such as demography, technology, energy use, and economic growth, as well as the outcome of international negotiations about climate mitigation.[85] SSPs are formulated in terms of levels of challenges (low/medium/high) to climate adaptation and mitigation. They are also compatible with RCPs, with the relations (in the absence of mitigation) represented below:[86]

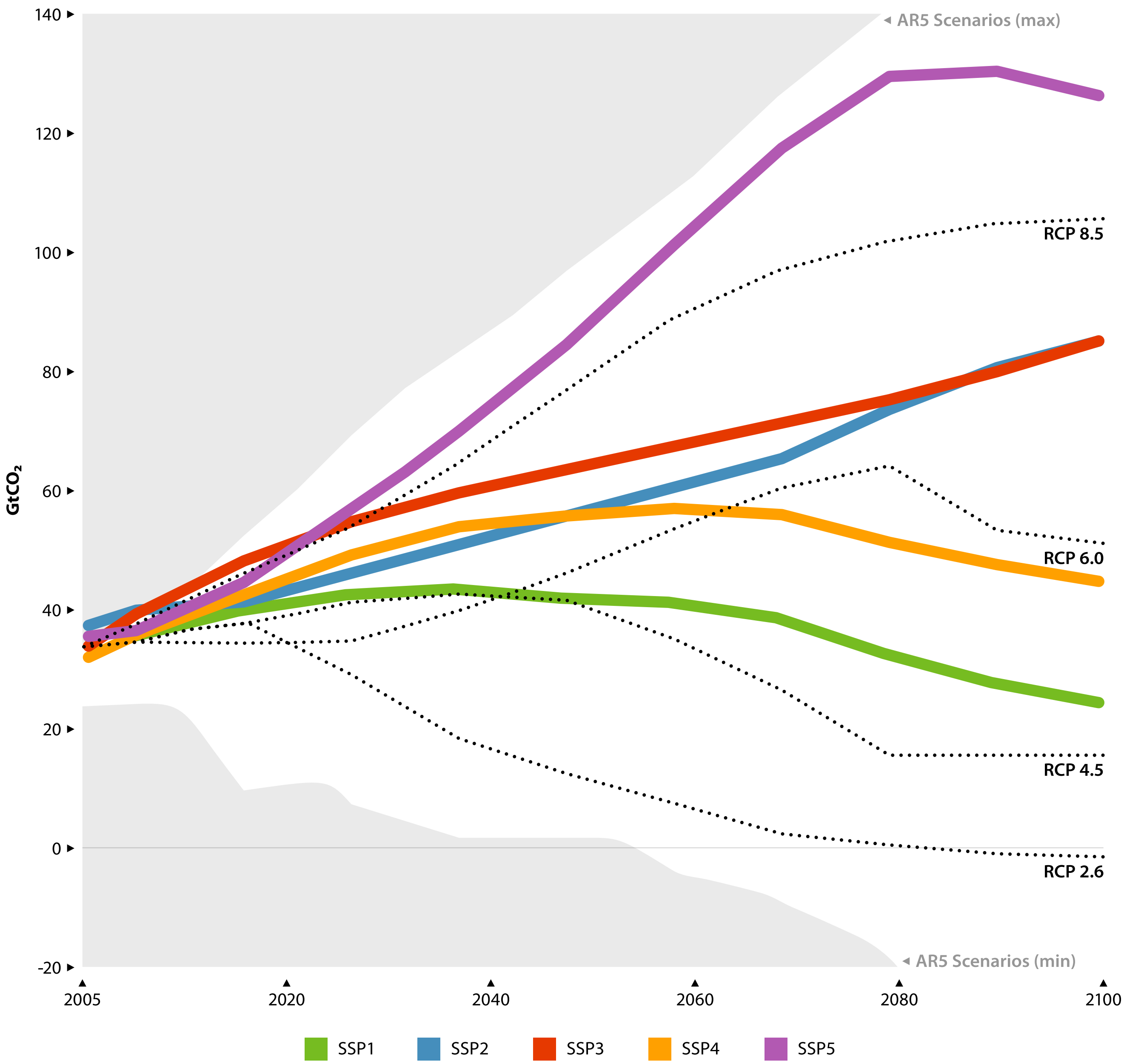


Figure 23: GHG emissions pathways under different RCP and SSP scenarios. Source: IPCC.

The SSPs are:

1. **SSP1 Sustainability – Taking the Green Road** Society shifts toward a more sustainable path, more inclusive development, and a broader emphasis on human well-being. There are increasing commitments to achieving development goals, inequality is reduced both across and within countries, and consumption is oriented toward low material growth and lower resource and energy intensity. SSP1 implies low challenges for mitigation (resource efficiency) and adaptation (rapid development).
2. **SSP2 Middle of the Road** Social, economic, and technological trends follow historical patterns, leading to degraded environmental systems, but the intensity of resource and energy use declines. Global population growth levels off by 2100 but income inequality improves only slowly and challenges to reducing vulnerability to societal and environmental changes remain. SSP2 implies medium challenges to mitigation and adaptation.
3. **SSP3 Regional Rivalry – A Rocky Road** Nationalism and regional conflicts increase, and national policies focus on energy and food security goals within their own regions. Investments in education and technological development decline, consumption is material intensive, and inequalities persist or worsen over time. Addressing environmental concerns is a low priority, leading to strong environmental degradation in some regions. SSP3 implies high challenges for mitigation (regionalized energy / land policies) and adaptation (slow development).
4. **SSP4 Inequality – A Road Divided** Countries are characterised by highly unequal investments in human capital, thus increasing inequalities across and within countries. The gap widens between an internationally connected society and a fragmented collection of lower-income, poorly educated societies. Environmental policies focus on local issues around middle and high-income areas. SSP5 implies low challenges for mitigation (global high tech economy), high for adaptation (regional low tech economies).
5. **SSP5 Taking the Highway** Global markets are increasingly integrated, economies are characterised by the exploitation of abundant fossil fuel resources and by the adoption of resource and energy intensive lifestyles around the world. Local environmental problems like air pollution are successfully managed and there is faith in the ability to manage social and ecological systems, including by geo-engineering if necessary. SSP5 implies high challenges for mitigation (resource / fossil fuel intensive) and low for adaptation (rapid development).

SSPs scenarios are increasingly used as a reference in the literature to inform policy discussion and action. They have been subsequently enriched by follow-up studies, in what are generally called “extended SSPs.” Examples of extended SSPs go in the direction of integration with other existing scenario frameworks or applications to specific sectors or regions.[87,88]

With respect to finance and financial risk, SSPs have shortcomings that prevent them, in their current form, from being applied in the assessment of climate-related financial risks.[89] SSPs do not include climate impacts and do not include a description of the role of the financial system nor of its complexity. This means that SSPs cannot be used alone for climate-financial risk assessment.[90]

APPENDIX C: Banks and Syndicated Loans

The analysis in Section 1 is based on syndicated loan data for the same set of 28 U.S. banks used in Ceres' transition risk report. This dataset now encompasses 60,737 loans totalling $2.2 trillion. The charts in Section 1 focus on the top 10 banks by number of loans. These data are sourced from the Refinitiv DealScan® dataset, encompassing the set of active loans originated from 2010 to present for which the bank is indicated as lender at the time of issue. Descriptive statistics for these loans are shown below:

BANK	NB OF LOANS	VOLUME[1] (Millions USD)	TENOR(MS)	LIB+ (BPS)
BANK OF AMERICA	9418	331,143	54	216
JPMORGAN CHASE	7631	554,274	56	217
CITI	2604	84,475	58	236
WELLS FARGO	6091	318,805	53	190
GOLDMAN SACHS	4606	48,659	62	281
U.S. BANK	3694	97,315	52	171
MORGAN STANLEY	3219	31,773	59	263
PNC	3507	132,073	54	187
TRUIST	2483	144,845	49	215
FIFTH THIRD	3075	49,665	56	235
BNY MELLON	512	1,356	48	130
REGIONS	1985	42,870	54	217
CITIZENS	2778	44,173	57	253
CAPITAL ONE	2170	45,099	56	240
HUNTINGTON	1098	35,373	54	209
COMERICA	1046	32,753	52	210
BBVA	1811	15,544	69	225
STATE STREET	149	3,677	40	147
PEOPLE'S	218	14,982	56	205
CIT GROUP	198	13,873	61	361
SILICON VALLEY	371	35,450	57	303
NORTHERN TRUST	761	10,347	51	143
TIAA	35	1,014	57	263
SYNOVUS	406	19,374	54	208
ZIONS	382	31,726	61	234
NY COMMUNITY	26	1,683	53	226
ALLY	406	24,324	58	452
MUTUAL OF OMAHA	57	0.872	58	307

[1] Total volume of industrial & commercial loans, 2020 balance-sheet information.

Table 7: Summary of syndicated loans used in the analysis in Section 1.

APPENDIX D: Physical Climate Hazards

There are many models, studies, databases, and tools available to banks as they seek to understand the physical climate risks in their portfolios. This appendix describes the analyses used in this report, as well as some other useful data that may be of interest to banks.

Hazard Models informing the CLIMAFIN Methodology (See Section 1 and Appendix A)

River Floods are simulated using the cascade of models of the GLOFRIS framework.[91] GLOFRIS simulates flood risk by combining information on hazard, exposure, and vulnerability.

- Hazard is represented by inundation maps showing inundation extent and depth for floods for return periods between two and 1,000 years. These are simulated using the new version of the hydrological model PCR-GLOBWB.[92]
- Exposure is represented by land-use maps showing the percentage of built-up area per cell from the hyde dataset.[93]
- Vulnerability is represented through depth-damage functions, which show the percentage of the maximum damage that would occur for different inundation depths. For the future simulations, changes in hazard are simulated by forcing the hydrological model PCR-GLOBWB with bias-corrected future climate data from five General Circulation Models (GCMs) taken from ISIMIP.

Coastal Floods are simulated using the DIVA coastal flooding framework.[94] DIVA is also the core coastal risk component of the ISIMIP framework. DIVA uses the global coastal segmentation of Vafeidis et al., which divides the world's coast into about 12,000 coastal floodplains that are homogeneous in their biophysical and socio-economic characteristics.[95] The process is as follows:

1. For each coastline segment, population exposure is assessed by overlaying elevation data from the Shuttle Radar Topography Mission (SRTM) with spatial population data from the Global Rural-Urban Mapping Project (GRUMP).
2. Population exposure is translated into physical capital exposure by applying sub-national GDP per capita rates.
3. Flood damages are computed for flood events with return periods between two to 1,000 years by integrating overall elevation levels affected by the flood event and applying depth-damage functions. Extreme water levels are taken from the GTSR database and are assumed to uniformly increase with sea level rise, following 20th century observations.[96] For each RCP, sea level rise has been computed for four global climate models (HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM, NorESM1- 512 M) using the 50th percentile of ice sheet contributions. Considering the large correlation between coastal flooding and wind-storm impacts, the latter are assessed through a linear interpolation of the relationship between flooding and wind damages inferred from U.S. data.

Wildfires are also simulated by combining information on hazard, exposure, and vulnerability.

- Hazard is modeled using a lognormal model estimated from the MODIS database.[97] The model provides the share of burnt forest area for return periods between two and 1,000 years.
- Exposure is measured through countrywide measures of forest area obtained from the FAO database.
- Vulnerability is measured using the estimate of property losses per acres provided by.[98] For the future simulations, changes in hazard rates are simulated using estimates of the evolution of burnt area provided by Knorr et al. on the basis of eight earth system models.

Extreme temperatures' effects on labor productivity are simulated using the methodology developed by Kjellstrom et al. to estimate impacts of wet-bulb globe temperature on labor productivity for the agriculture, manufacturing, and service sectors using ISO standard work intensity levels.[100] More specifically, the database developed by Roson and Sartori shows expected decrease in labor productivity for a set of 140 countries for a range of increase in mean surface temperature between 1°C and 5°C.[101] Impacts are then derived for each climate scenario by considering return periods between two and 200 years and assuming uniform distribution of mean temperature increase over the scenario uncertainty range.

Agricultural yield data are obtained from the AgCLIM50 study. AgCLIM50 provides a global integrated assessment of the range of potential economic impacts of climate change and stringent mitigation measures in the agricultural sector. The analysis employs five global multi-region multi-commodity models and covers selected combinations of socioeconomic storylines and climate signals by mid-century. Model inputs are harmonised by using the same projections for population and GDP growth, as well as relative biophysical crop yield changes due to climate change. Total production of agricultural products is used as an aggregate indicator of productivity.

Other Hazard-Specific Data Sources

Floods

- Aqueduct, made publicly available by the World Resources Institute, provides projections of future (2030, 2050 and 2080) coastal and river flood risks at the global scale for worst-case and medium-case climate scenarios
- The First Street Flood Factor provides projections of future flood maps for the U.S. under a medium-case climate scenario.
- The sea level rise analysis platform by Climate Central provides future (2050) coastal flood maps for the U.S under a worst-case climate scenario.

Wildfires

Additional information can be obtained from the Global Fire Emission Database and Copernicus Global Wildfire Information System, as well as the World Bank global wildfire hazard database, which predicts fire weather intensity for specific periods.

Agriculture

The NASA Socioeconomic Data and Applications Center provides projections of country and regional changes in grain crop yields due to global climate change. There are many other impact models for specific crops and regions but very few datasets with global geographical and crop coverage.

Disaster Databases - Information on Historical Climate Events

The **EM-DAT Emergency Database** is the most frequently used disaster risk and losses database. It is comprehensive and publicly accessible, and it provides information on disasters from 1900 to 2020 for all UN countries, covering over 20,000 natural and technological disasters. EM-DAT helps identify the most common disaster types in a given country and the associated impacts on human populations. EM-DAT offers a user-friendly interface. Search criteria include time period (year), location (by continent, region, or country), disaster classification as natural (e.g. climatological, such as droughts and wildfires), technological, or complex and information on year, occurrence, total deaths, injured, affected, homeless, total affected, and total damage (000 US$).

DesInventar (also referred to as Disaster Inventory System) is a UNISDR and DEVCO sponsored disaster loss data initiative that assists countries in the collection, documentation, and analysis of data about losses caused by disasters at the community level.

The IFO **Geological and Meteorological Events (GAME) database** is a county-level database covering a rich collection of variables for all counties worldwide from 1979 to 2010. The dataset collects information on geological and meteorological events from primary information and translates them into climate hazards and disaster events on a country-level basis.

National loss databases include frequent but low magnitude events and related economic losses. Notably, the NOAA "storm" event database documents the occurrence of storms and other significant weather phenomena having sufficient intensity to cause loss of life, injuries, significant property damage, and disruption to commerce.

The **CATDAT Natural Hazards Loss Database** maintained by Risk Layers and KIT is the most extensive and quality-assured database for natural perils including over 60,000 events. It removes many inconsistencies throughout databases by going back to original sources and providing socioeconomic checks.

Insurance and re-insurance databases, such as NatCatService and SIGMA, better capture and record the financial losses specific information (e.g. damage to buildings, infrastructure, vehicles etc.). Nevertheless, the values associated with the "losses" are often simply a scaled-up value of uninsured vs. insured exposure, which does not often characterise infrastructure, sectoral losses, or indirect losses (e.g., disruptions to the flow of goods and services).

The **PERILS Industry Exposure & Loss Database** constructs measures of exposure and vulnerability by aggregating insurance data at the level of CRESTA zones.

Other Methodologies for Climate-Financial Risk Assessment

Dietz et al. 2016 provide a top-down assessment of the climate value at risk of global financial assets using Monte-Carlo simulations to explore the parameter space of the DICE integrated assessment model.[102] They find that the expected climate value at risk of global financial assets today is 1.8% along a business-as-usual emissions path.

Ouazad and Kahn provide an assessment of NOAA billion dollar events on mortgage defaults and banks' securitization of loans.[103] Results suggest a substantial increase in securitization activity in years following billion-dollar disasters. Such an increase is larger in neighborhoods for which such a disaster is unexpected. The authors also simulate the impact of increasing climate risk on mortgage origination volumes with and without the government-sponsored enterprises (GSEs) like Fannie Mae and Freddie Mac. Results suggest that the GSEs may act as an implicit insurer, i.e, a substitute for the declining National Flood Insurance Program.

Mandel et al. 2021 provide a bottom-up assessment of the impacts on the banking sector of changes in global flood risks induced by climate change.[104] They find that the level of adaptation is the major determinant of the magnitude of the increase in risk. At the horizon 2080 under RCP 8.5, the risk would increase by 50% with respect to historical levels under a scenario with adaptation, but could increase 10-fold in a scenario without adaptation.

APPENDIX E: U.S. Exposure to Physical Risk through Global Financial Networks

Beyond domestic risks, the U.S. banking system is exposed to global climate risks through cross-border financial exposures. As illustrated by Table 8, the U.S. banking sector has substantial global exposure to foreign sectors.

Outstanding at end-September 2020, in billions of U.S. dollars		
	Claims of U.S. banks on	Liabilities of U.S. banks towards
Banks in all reporting countries	33210.1	29536.6
United Kingdom	5100.2	5280
United States	3289.2	3830.2
France	3330.7	3647.5
Germany	2317.4	2037.7
Japan	4194.1	1548.1
China	1335.4	1415.2
Hong Kong SAR	1658.7	1303.7
Switzerland	870.2	991.7
Netherlands	1247	938.3
Australia	620.9	757.5
Singapore	812.2	703.4
Canada	885.7	689.5
Cayman Islands	598.7	562.9
Italy	615.1	531.1
Luxembourg	665.3	474.9

Table 8: Claims and liabilities of U.S. banks on foreign bank counterparties. Top 15 cross-border positions, by location of reporting banks, outstanding at end of September 2020, in billions of U.S. dollars.

More broadly, the U.S. banking sector is very central to the global interbank network but its external financial leverage (measured as the ratio between claims on foreign financial sectors and domestic GDP) is limited. In relative terms, it is much less exposed than the banking sector of Western European countries. The main U.S. counterparties are developed economies, most importantly the United Kingdom and Japan.

Beyond its direct exposure, the U.S. banking sector is also exposed indirectly to global climate risks through assets held by domestic counterparties. The U.S. collectively is the largest holder of such cross-border assets (approximately $11 trillion) and thus the most exposed to climate risks through this channel.

In order to illustrate the potential magnitude of these cross-border risks, CLIMAFIN conducted an assessment of the indirect exposure of the U.S. banking sector to global flood risk under high-end climate scenarios (RCP 8.5, with adaptation).

Using country-level data on insurance coverage and fiscal position by country, a simple linear model allocates direct damages among the private sector, the public sector, and the insurance sector. The standard approach used in the literature on systemic risk is used to model a shock to banks in each country through their credit exposures.[105] The default probability of the counterparties of the financial sector then increases proportionally to the share of their capital eroded by the initial shock. The expected value of the assets of the financial sector decreases accordingly.

A similar approach is used for the insurance sector in each country and a share of the losses is transmitted to banks as insurance companies' capital buffers erode. All in all, the model factors in:

(i) the direct impact of climate shocks on the public, private, and insurance sectors
(ii) the financial leverage of these sectors
(iii) the exposure of the financial sector, i.e., the sectoral composition of its balance sheet

Overall, the analysis finds that on average, impacts transmitted to the domestic financial sector in a given country amount to 35% to 45% of total domestic impacts.

In order to model the amplification of risk induced through global financial interlinkages, CLIMAFIN uses the debtrank algorithm.[106] When a climate shock hits the financial sector of a country, its capital is eroded. This erosion leads to a devaluation of its liabilities towards the financial sectors of financially connected countries, hence eroding their capital and further propagating the shocks via their liabilities. In order to quantify this effect, the Finflows dataset is used to reconstruct the global network of bilateral financial exposures at the institutional sector level. This allows for an estimate of how damages in each country might affect their international creditors.

Using this methodology, CLIMAFIN assessed the exposure of each country's financial system to global flood risks, the hazard for which the most comprehensive data is available. Western European countries, which have high external leverage, face massive risks through global financial interlinkages, up to an order of magnitude greater than domestic risks. For the U.S. banking sector, though the external risk is substantial, it is commensurate with domestic risks and, at the aggregate level, appears aligned with existing prudential requirements.

ENDNOTES

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