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Physical risk modeling
A deep dive into climate risk management

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Introduction

Organizations are increasingly devoting resources to managing risks associated with climate change. While both transition risk and physical risk (see definitions in the next section) are key components of climate risk management, this paper primarily focuses on the landscape of physical risk across industries.

The report discusses the manifestation of physical risks as business risks, the range of practices for measuring and modeling physical risk, and key challenges and solutions for physical risk modeling.

Background on climate risk

Environment, social, and governance (ESG) practices have been top of mind for organizations in recent years as businesses across industries have rapidly accelerated efforts to promote sustainability, transform operations, and manage ESG-related risks.

Climate, one of the key components of the environmental pillar of ESG, has been a particularly large driver of organizational change due to numerous factors including regulatory requirements, evolving stakeholder expectations, increasing frequency and severity of extreme environmental and weather events, internal strategic business decisions such as net-zero commitments, and increased recognition of climate risk factors as drivers of business risks.

Organizations typically focus efforts on climate from two perspectives: inside-out and outside-in. The inside-out perspective considers the impact that an organization has on climate and involves strategic choices on sustainability, such as net-zero commitments in line with Paris Accord emissions reduction goals. The outside-in perspective considers the impact that climate change may have on an organization and focuses on practices for mitigating and measuring climate risk.

Figure 1. ESG pillars and key components[1]

Environmental

- Renewable fuels
- Greenhouse gas emissions
- Energy efficiency
- Climate risk
- Water management
- Recycling processes
- Emergency preparedness

Social

- Health and safety
- Working conditions
- Employee benefits
- Diversity and inclusion
- Human rights
- Impact on local communities

Governance

- Ethical standards
- Board diversity and governance
- Stakeholder engagement
- Shareholder rights
- Pay for performance

Climate risk refers to the adverse consequences of climate change for human or ecological systems. These risks can arise from potential impacts of climate change as well as human responses to climate change.[2] Climate risk is typically |broken down into two key components: transition risk and physical risk. Transition risk refers to stress to certain institutions or sectors arising from the shifts in policy, consumer and business sentiment, or technologies associated with the changes necessary to limit climate change. Physical risk refers to the harm to people and property arising from acute, climate-related disaster events such as hurricanes, wildfires, floods, and heatwaves as well as longer-term chronic phenomena such as higher average temperatures, changes in precipitation patterns, sea-level rise, and ocean acidification.[3]

Figure 2. Sustainability and risk management linage

Why physical risk?

Modeling and measurement of physical risk is an increasing area of focus for organizations across industries. Unlike with transition risk events, acute physical risk events can quickly manifest themselves through extreme, catastrophic weather events in a very short time. For example, a large hurricane can damage infrastructure, disrupt supply chains, harm local and regional economies, and trigger financial losses. Organizations should understand the extent of their exposure to these short-term acute physical risk events.

Compounding the concern around near-term losses due to acute physical risks is the growing frequency and severity of catastrophic weather events in recent years. In the US, damage from billion-dollar disasters increased from $518.5 billion (CPI-adjusted) from 1980–1999 to $1,523.0 billion (CPI-adjusted) from 2000–2019, with the last five years (2018–2022) alone accounting for a total cost of $600.3 billion (CPI-adjusted).[4]

Advances in data and technology have also allowed institutions to develop more sophisticated approaches for physical risk modeling. New data sources available from governments, research institutions, and data vendors are being coupled with sophisticated methodologies in climate science and actuarial analysis to build catastrophe models that provide more accurate estimates of physical risk losses.

By leveraging Representative Concentration Pathways (RCPs)[5] and Shared Socioeconomic Pathways (SSPs)[6] scenarios, while requesting firms measure both common and idiosyncratic hazards, the 2023 Federal Reserve Board Climate Scenario Analysis (FRB CSA) pilot paves the way for financial institutions to develop cutting-edge catastrophe modeling approaches. This represents an advancement from previous regulatory scenario analysis exercises such as the European Central Bank (ECB) guided 2022 Climate Risk Stress Test,[7] which allowed banks to use more simplistic approaches to physical risk—namely, the use of regulatory defined collateral haircuts for a flood scenario and use of macroeconomic shocks for a drought scenario.

The near-term nature of acute physical risks, increasing intensity and severity, advances in data and technology, and evolving regulatory and industry practices have led to an increased focus on modeling and measurement of physical risks. Improved measurement techniques can lead to enhanced strategies for mitigating risks and planning future business activities.

How physical risks manifest as business risks

Physical risk drivers such as extreme weather events (acute physical risks) and longer-term climate shifts (chronic physical risks) can manifest as business risks for organizations across industry sectors. The manifestation of physical risk drivers as business risks, both financial and non-financial risks, occurs through microeconomic and macroeconomic transmission channels, as depicted in figure 3. For example, a flood (acute physical risk) may cause damage to a data storage center owned by the business (microeconomic transmission channel), which, in turn, could lead to operational losses associated with system downtime or lost data.

Figure 3. Climate risks manifest as business risks via transmission channels

Climate risk drivers

Physical risk

- Acute: Event-driven (e.g., floods, cyclones or hurricanes, heat waves)
- Chronic: Longer-term shifts (e.g., precipitation, ocean acidification, rise on sea level)

Transition risk

- Policy and regulation (e.g., carbon tax)
- Technological development (e.g., electric vehicle)
- Sentiment across investors and consumers

Transmission channels

Microeconomic

- Financial impact on business and household
- Business disruption
- Stranded assets and new capital expenditure due to transition
- Loss of income
- Property damage and liability

Macroeconomic

- Reduction in economic output (from increase in mortality, fall in labor supply and productivity)
- Price adjustment (from policy changes, supply shocks, structural reform)
- Socioeconomic changes (from change in consumer preferences, unemployment, migration, etc.)
- Capital depreciation

Business risks

Financial risks

Operational risk

- Supply chain disruptions
- Inadequate internal or external system

Credit risk

- Default by obligors (e.g., business or households)
- Debt deflation
- Collateral value adjustments

Market risk

- Price adjustment of interest rate, foreign exchange, equities, commodities, etc.
- Fall in financial asset value

Liquidity risk

- Potential need for higher liquidity
- Refinancing risk

Underwriting risk

- Higher insurance premiums
- Insurer refusal to underwrite certain exposure
- Insurers refusing renewals

Non-financial risks

Production

- Availability of goods and services

Price/market

- Changes in product demand, purchasing behavior

Casualty

- Loss of property, livelihood

Technology

- Viability, reliability of certain technologies

Relationship

- Strained Interactions, resource conflicts

Legal/regulatory

- Fines, penalties, reduced ability to operate

Human

- Physical, mental health issues, reduced productivity

Physical risks may also manifest themselves as business risks on both a direct and indirect basis. In the example above, damage to property has a direct effect on the operations of the business. However, indirect impacts, sometimes referred to as second-order impacts, may also occur. On a microeconomic level, the operations of a third-party supplier may be disrupted due to damage to physical assets from a flood, leading to operational losses for the business. Physical risks may also result in protracted deterioration of macroeconomic conditions, particularly at local and regional levels, which may further reduce revenue for a particular business.

Manifestation of physical risks as financial and non-financial business risks can occur across industries and sectors as illustrated above. However, several categories of these business risks have elements that are unique to financial institutions. In particular, understanding the impacts of climate risk on credit, market, liquidity, and underwriting risk has been a focus for financial institutions.

Because banks are in the business of lending, credit risk is arguably the most important consideration within the banking sector. While both transition risk and physical risk may manifest as credit risk across a bank's lending book, many banking organizations have taken initial steps to focus efforts of transition risk around commercial and industrial (C&I) and commercial real estate (CRE) portfolios, and physical risk on CRE and mortgage portfolios. This alignment of physical and transition risks to portfolios is in line with the 2023 FRB CSA pilot and is generally aligned to international stress testing exercises such as ECB.

For example, in the mortgage book, a credit loss may arise if a property provided as collateral for a mortgage real estate loan is damaged by the physical impact of a climate-related event. This damage may result in a lower asset value, higher loan-to-value ratios, and increased Loss Given Default (LGD). Further, sustained harm to localized and regional economies may reduce profitability of obligors, increasing Probability of Default (PD).

For financial institutions with investment portfolios and trading books, physical risks can translate to market risks with a reduction in financial asset values. For example, the value of an equity investment could be reduced as the underlying company experiences losses from a physical risk event such as damage to its assets or disruptions to its supply chain. Physical risk may also have a substantial impact on home prices, affecting assets such as Mortgage-Backed Securities (MBS). An analysis by Bernstein & Associates in 2019 showed that US properties exposed to sea-level rise sell for 7% less on average than equivalent unexposed properties matched on key characteristics.[8] The Bank of International Settlements (BIS) has called for additional empirical research using the latest data as the potential grows for the pace of repricing of this risk.[9]

Financial institutions are also particularly affected by the physical risk impacts on liquidity. A severely concentrated and sustained climate-related event can prompt customers to withdraw cash from ATMs or via drawdowns on lines of credit, significantly increasing the financial institution's loan-to-deposit ratios.

Lastly, underwriting risk is particularly relevant in the insurance industry and broader finance industry. Physical risk events can result in higher insurance premiums, and in severe cases, certain properties in vulnerable locations can become uninsurable as insurers withdraw from or refuse coverage for a specific area. This can have an impact on the stability of financial institutions as they rely on insurance coverage for their risk management strategies.

Physical risks, whether acute or chronic, can impact businesses of all types either through direct or indirect mechanisms. By understanding the transmission channels and associated business risks that can materialize, firms can better understand and prioritize risk management and mitigation activities.

Range of practices in modeling methodologies

Physical risk modeling methodologies aim to quantify the impact of acute or chronic climate events by assessing the probability and severity of perils. In this section, we discuss range of practices around multiple aspects of physical risk modeling, including modeling data, methodological complexity, level of granularity, and risk mitigants.

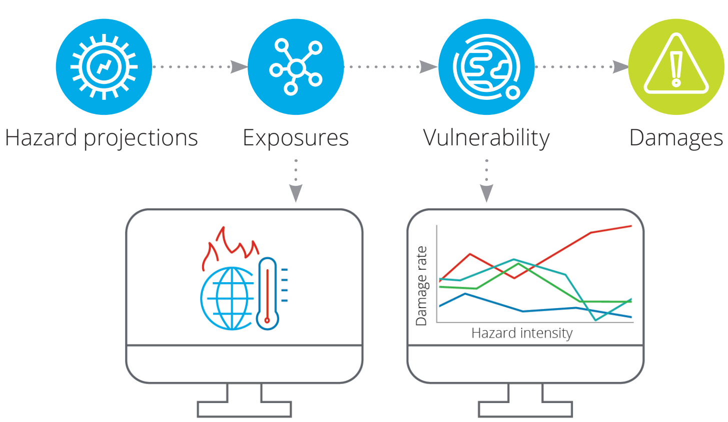
Physical risk assessment requires data on current and future physical hazards, sectoral and spatial data of exposures, and information on vulnerability and adaptive capacity, to estimate damages. Both internal and external data have their own roles in the quantification process. Internal data collection is primarily used to characterize internal assets based on the geolocation and asset type as well as historical loss recorded as a result of hazard events. It is noted that historical data may be less relevant for current or future projections, yet sometimes can be useful for back-testing purposes. External data, on the other hand, is generally used to reflect climate-related attributes, including direct hazard data associated with perils and regions and indirect macroeconomic data considering second-level impact of climate events. Some firms leverage open-source datasets for sourcing physical risk hazard data, such as those from climatological and geological survey agencies. Open-source data and platforms can consist of both past events and forward-looking projections from climate models. Third-party data vendors are also growing rapidly to provide more granular data solutions, such as the assignment of damage scores at the geo-coordinates level for physical risk scenarios. To inform the most suitable approach for the physical risk assessment, it is critical to identify the availability and validity of data based on types and sources.

Institutions may use physical risk models from publicly available research, leverage commercial vendor solutions, or develop in-house modeling approaches. Modeling approaches vary by complexity, assumptions, and input data granularity needs. Common modeling approaches and use cases range from macroeconomic models to catastrophe risk models. The choice of modeling approach can be driven by the focus on direct or indirect damages on a firm's exposure to acute and chronic physical risks.

Macroeconomic models can provide insights on the overall physical risk of company losses from indirect transmission channels. Econometric models often incorporate variables like GDP, unemployment, and inflation, with underlying assumptions based on plausible socioeconomic pathways. Economic factors may also be incorporated into climate science models, capturing the interrelationship between climate factors and macroeconomic variables. Oftentimes, outputs from climate science models are used in scenario analysis to further measure indirect physical risk impact. Publicly available examples include the National Institute Global Econometric Model (NiGEM) developed by National Institute of Economic and Social Research, and the Macroeconomic and Fiscal Model (MFMod), incorporating climate changes and shocks developed by the World Bank.

Catastrophe models are used to estimate losses from natural disasters such as hurricanes and earthquakes and range from simple probabilistic models based on historical losses and exposure analysis to more complex models that incorporate the continuously evolving climate conditions to simulate extreme events. Damage estimation, in this context, can link hazard projections (e.g., frequency and severity) to the exposures (e.g., geolocation and value of firm assets) and associated vulnerability (e.g., adversely impacted propensity by hazard events), through hazard-specific damage functions, as depicted in figure 4.

Figure 4. Framework for catastrophic risk modeling



In scenario analysis, catastrophe risk modeling is used to measure the likelihood, severity, and damage from hazards, mainly on direct impact. These models can be built internally or sourced externally based on data needs and complexity requirements. Some firms are developing in-house capabilities using internal asset data, publicly available catastrophe data, and modeling techniques to project how specific metrics related to hazardous environmental events may change in the future and to estimate the reach of these events in causing collateral damage and potential losses. Various open-source catastrophe risk modeling is available and plays a growing role, including climate adaptation (CLIMADA) used by Climate Impact Explorer and OASIS. Vendor-developed models are being utilized to source more granular asset-level input data or to distill the physical risk impact into numerical scores and ratings.

Regardless of the choice of models, physical risk modeling requires careful consideration of data granularity due the need for location-specific information, such as inputs at the level of a country or a state, and at the level of latitude and longitude coordinates. Granular data is often unavailable and is a key challenge to physical risk modeling. Some organizations leverage remote-sensing data and innovative modeling techniques to improve the data granularity. Moreover, use of additional variables around asset property characteristics (e.g., age of building, building material, number of floors) can lead to better damage forecasting accuracy.

Mitigants can reduce or offset risk associated with physical risk events and should be considered when building physical risk models. For example, physical risks may be offset by factors such as property insurance, disaster funds, and municipal projects like construction of flood walls. However, data availability for risk mitigants remains a challenge for institutions, and methodologies for considering mitigants may vary significantly from firm to firm.

Due to the relatively new, unstandardized, and evolving nature of physical risk models, there are a wide range of practices for data sourcing (from open source to vendor options), modeling approaches (from macroeconomic to catastrophe modeling), level of granularity (from national level to geo-coordinates level), and input variable types (asset characteristics to mitigants) used.

Vendor landscape for physical risk data and modeling

Increased focus on physical risk has led to rise in demand for associated data and modeling solutions. There are numerous vendors in the market providing commercial data and climate technology solutions. Some of these vendors offer proprietary for-profit products, whereas others are publicly available. Each has its own pros and cons for consideration.

Proprietary vendor solutions can provide organizations with access to granular climate data and state-of-the-art modeling methodologies, often allowing enhanced model performance and accuracy. However, vendors may provide limited visibility into their modeling methodologies and assumptions, creating uncertainty in the overall performance and reliability of such products. Further, such products can be costly for organizations, especially those that may not require sophisticated solutions.

For such companies, open-source solutions leveraging publicly available data and models may be an attractive alternative. Such alternatives typically provide greater transparency into the underlying methodology and often provide a reasonable degree of accuracy and granularity. However, organizations should recognize that while the data and methodologies may be free, tailoring and implementing such solutions can be a resource-intensive process.

Challenges and possible solutions in assessing physical risk

Challenge

Organizations are facing constraints on availability and granularity of asset-level data such as building address, construction characteristics, and insurance coverage.

Solution

- Incorporate assumptions and qualitative techniques into modeling frameworks.
- Use third-party vendors and open data sources to augment data gaps.
- Develop comprehensive data controls designed to manage data quality and accuracy.
- Enhance data collection processes for go-forward modeling.

Challenge

To date, industry standards for modeling frameworks have yet to emerge and regulatory guidance provides significant flexibility to organizations for developing approaches.

Solution

- Develop an understanding of the range of practices at peer institutions, research institutions, and vendors before adopting a solution.
- Perform extensive benchmarking and assumptions testing when developing and validating models
- Consider company-specific requirements and idiosyncrasies around hazards, exposure, and vulnerability when choosing a modeling approach.

Challenge

Indirect effects from physical risks such as macroeconomic deterioration, supply chain disruptions, and population migration can be difficult to quantify.

Solution

- Analyze historical indirect impacts from extreme weather events and leverage judgemental assumptions for go-forward dynamics.
- Consider use of simplified macroeconomic estimation approaches to provide initial estimates while industry practices mature.
- Leverage vendor and open-source data related to indirect physical risks, such as impact to labor productivity.

Challenge

Vendor-based solutions often provide limited transparency into underlying methodology and assumptions.

Solution

- Perform initial due diligence on model documentation and testing during vendor selection processes.
- Work with vendors to develop customized model documentation for internal implementation of vendor solutions.
- Understand impact and accuracy of key assumptions and parameters used in the model.
- Leverage outcomes analysis to assess reliability of model results in cases where underlying methodologies are not fully transparent.

Conclusion

Institutions are acknowledging the criticality of physical risk assessment due to the potential for near-term impacts with increasing severity, evolving regulatory and industry practices, and advances in data and technology. Further, physical risk, like other climate risks, has the potential to affect multiple business risks through both micro- and macroeconomic transmission channels. While the availability of reliable physical risk data and a standard quantification approach remain challenges, recent advances in data management practices at both individual institutions and external sources (vendor solutions and open sources) are quickly paving the way for the use of advance modeling techniques for quantifying physical risk.

How Deloitte can help

Deloitte can assist institutions with incorporating physical climate risk understanding into their decision-making processes. With the help of Deloitte's experienced practitioners, institutions can develop bespoke capabilities and create robust quantitative and qualitative models that are tailored to their businesses.

Physical risk modeling services:

- **Risk identification and materiality assessment of physical risks**
- **Identification and sourcing of data for physical risk modeling**
- **Development and customization of climate scenarios for physical risk events**
- **Development and validation of physical risk models**
- **Integration of physical risk considerations into risk stripe processes**
- **Enhancement of downstream reporting and KPIs for physical risk**

Endnotes

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3. Financial Stability Oversight Council (FSOC), *Report on climate-related financial risk, 2021*.
4. National Centers for Environmental Information (NCEI), "Billion-Dollar Weather and Climate Disasters," accessed May 2023.
5. RCPs: These pathways represent different emissions projections under basic, plausible economic and social assumptions while staying within physical constraints.
6. SSPs: These pathways are intended to provide plausible scenarios for how the world evolves in areas such as population, economic growth, education, level of globalization, level of urbanization, and the rate of technological development.
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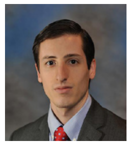

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