Columbia Law School | COLUMBIA CLIMATE SCHOOL
SABIN CENTER FOR CLIMATE CHANGE LAW

June 17, 2022

The Honorable Gary Gensler
U.S. Securities and Exchange Commission
100 F Street NE
Washington, DC 20549

Re: The Enhancement and Standardization of Climate-Related Disclosures for Investors
Docket ID: SEC-2022-06342; File No. S7-10-22

Dear Chair Gensler and Commissioners,

Columbia Law School's Sabin Center for Climate Change Law ("Sabin Center") and the undersigned climate scientists and other experts studying the effects of climate change submit these comments in response to the Securities and Exchange Commission's ("SEC") request for comments on the proposed rule titled "The Enhancement and Standardization of Climate Related Disclosures for Investors."[1]

These comments reiterate what climate scientists have said for decades: human activities are increasing atmospheric greenhouse gas ("GHG") concentrations which is, in turn, causing global average temperatures to rise. In a 2021 report, the Intergovernmental Panel on Climate Change ("IPCC") concluded that "[i]t is unequivocal that human influence has warmed the atmosphere, ocean and land."[2] The IPCC found that "[e]ach of the last four decades has been successively warmer than any decade that preceded it since 1850. Global surface temperature in the first two decades of the 21st century (2001-2020) was 0.99 [degrees Celsius] higher than 1850-1900."[3] The extent of future temperature increases will depend, in large part, on future GHG emissions. However, "[g]lobal surface temperature will continue to increase until at least mid-century under all emissions scenarios considered" by the IPCC and warming above 2 degrees Celsius is "very likely" unless emissions decline rapidly prior to 2050.[4] Rising temperatures are already increasing the frequency and severity of many types of weather

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[1] The Enhancement and Standardization of Climate-Related Disclosures for Investors, 87 Fed. Reg. 21334 (Apr. 11, 2022) [hereinafter "Proposed Rule"].
[2] IPCC, *Summary for Policymakers, in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS. CONTRIBUTION OF WORKING GROUP I TO THE SIXTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 4 (V. Masson-Delmotte et al., eds, 2021).
[3] *Id*. at 5.
[4] *Id*. at 13-15.

extremes, such as heatwaves and floods, and contributing to sea-level rise and other slow-onset phenomena. As the IPCC has noted, "[w]ith every additional increment of global warming, changes in extremes continue to become larger," and slow-onset changes accelerate.[5]

The SEC has recognized—and numerous studies confirm—that climate change poses significant financial risks to corporate entities and the financial system more generally.[6] For example, a 2019 study by the Carbon Disclosure Project found that 215 of the largest companies globally face almost $1 trillion in potential financial risk from climate change, with approximately half of that risk identified as "likely, very likely, or virtually certain to materialize . . . [within] five years."[7] More recently, in its 2021 report on Climate-Related Financial Risk, the Financial Stability Oversight Council ("FSOC") noted that "[t]he intensity and frequency of extreme weather and climate-related disaster events are increasing and already imposing substantial economic costs."[8] FSOC recognized that, as the magnitude of climate hazards and associated costs increases in coming years, so too will risks to the financial system.[9] Thus, according to FSOC, "climate-related financial risks are an emerging threat to the financial stability of the United States."[10] The Climate-Related Market Risk Subcommittee of the Commodity Futures Trading Commission ("CFTC") has similarly concluded that climate-related risks "are already impacting, or are anticipated to impact, nearly every facet of the U.S. economy" and "may affect the functioning of markets essential for economic activity."[11] In March 2021, the CFTC established a new Climate Risk Unit, dedicated to accelerating action on climate risk and "building a climate-resilient financial system."[12]

The financial risks associated with climate change take a number of forms but are typically divided into two broad categories: (1) physical risks arising from the impacts of climate change on companies' assets, operations, and supply chains; and (2) transition risks arising from government and market responses to climate change. These comments focus on the first category, explaining how climate scientists can model—in the broadest sense of the word—the causes and effects of climate change, and how companies can use climate information to

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[5] *Id*. at 15.
[6] Proposed Rule, *supra* note 1, at 21,335. *See also* FINANCIAL STABILITY OVERSIGHT COUNCIL, REPORT ON CLIMATE-RELATED FINANCIAL RISK (2021), https://perma.cc/6V34-EU4F; COMMODITY FUTURES TRADING COMM'N CLIMATE-RELATED MARKET RISK SUBCOMMITTEE OF THE MARKET RISK ADVISORY COMMITTEE, MANAGING CLIMATE RISK IN THE U.S. FINANCIAL SYSTEM (2020), https://perma.cc/6RHX-XTW7; BOARD OF GOVERNORS OF THE FEDERAL RESERVE SYSTEM, FINANCIAL STABILITY REPORT (2020), https://perma.cc/2VWA-67LV.
[7] CDP, MAJOR RISK OR ROSY OPPORTUNITY: ARE COMPANIES READY FOR CLIMATE CHANGE? (2019), https://perma.cc/XVL3-YF7T.
[8] Financial Stability Oversight Council, *supra* note 6, at 10.
[9] *Id*.
[10] *Id*.
[11] Commodity Futures Trading Comm'n Climate-Related Market Risk Subcommittee of the Market Risk Advisory Committee, *supra* note 6, at 11 & 28.
[12] Commodity Futures Trading Comm'n, *CFTC Acting Chairman Behnam Establishes New Climate Risk Unit*, Press Release Number 8368-21 (Mar. 17, 2021), https://perma.cc/ZD8W-LHPR.

evaluate their exposure to physical risks and hazards associated with climate change.[13]

These comments discuss the science of climate change detection and attribution—the body of research that helps to characterize the role of human activity in climate change—as well as how models are used to develop climate change projections. The goal of these comments is to explain how scientists know that anthropogenic GHG emissions are driving global warming which is, in turn, leading to other climate hazards (e.g., more severe heatwaves, droughts, and floods) that create risks for companies. The comments also highlight climate tools and data that companies can, and already do, use to evaluate climate-related risks to their assets, operations, work force, and supply chains. The sections below further explain these key points:

- There is a robust and perpetually growing body of evidence that establishes a causal connection between rising atmospheric GHG concentrations and physical climate hazards and associated impacts (e.g., water shortages, crop losses, and lost labor hours due to extreme heat).
- Climate models can be used to project future climate change hazards. Modeling climate change under different plausible GHG emissions scenarios provides a better method of estimating climate change impacts than incorrectly assuming that the climate of the recent past will simply continue (unchanged) in the future.
- Downscaled climate models can be used to refine projections from global climate models to finer-scales (e.g., reflecting local climate hazards). Downscaled projections are available to companies and can be used by companies to identify climate hazards that may affect their assets, operations, work force, and supply chains. For example, using downscaled temperature projections, a company could identify potential risks to temperature-sensitive assets, such as natural gas generating plants. By comparing temperature projections to a generating plant's design reference temperature, a company could evaluate the potential for plant de-rates or outages in the future. Temperature projections could similarly be used with crop models to evaluate the potential for future crop losses. Sea level rise projections could also be overlaid on companies' asset maps to identify facilities at risk of nuisance flooding or permanent inundation.
- Some companies are already using downscaled climate projections to evaluate and disclose physical climate-related risks to their assets, operations, work force, and supply chains. Several examples are provided in Part 5 of this letter.

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[13] According to the IPCC, "risk" is "the potential for adverse consequences for human or ecological systems," and a 'hazard' is "the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property infrastructure, livelihoods, service provision, ecosystems, and environmental resources." *See* IPCC, *Summary for Policymakers, in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION AND VULNERABILITY. WORKING GROUP II CONTRIBUTION TO THE IPCC SIXTH ASSESSMENT REPORT SPM-4 & SPM-5 (Hans-Otto Pörtner et al. eds., 2022).

1. Climate Change Detection and Attribution[14]

Attribution science refers to the body of research that explores the link between human activities and climate change.[15] According to the IPCC, distinguishing between the effects of external influences and internal climate variability requires the direct comparison of observed changes in the climate system and those that are expected to result from external forcings, such as anthropogenic GHG emissions.[16] Formal detection and attribution studies use objective statistical tests to determine whether observations contain evidence of the expected responses to external forcing that is distinct from variability generated within the climate system itself.[17]

Attribution research can be broken down into four broad categories:

1. *Climate change attribution* examines how rising concentrations of GHGs and other pollutants in the atmosphere affect many other aspects of the global climate system, including global and regional mean temperatures, sea level, and sea ice extent.[18] Attribution studies have identified human-caused "fingerprint" patterns in literally dozens of different independently monitored variables. In fact, since the mid-1990s, these "pattern-based 'fingerprint' studies have been the primary and most rigorous tool for disentangling the complex causes of recent climate change."[19] Fingerprinting relies on numerical models of the climate system to provide estimates of both the searched-for fingerprint—i.e., the climatic response to a change in one or several forcing mechanisms—and the background "noise" of

[14] Additional information regarding the science of climate change attribution and detection can be found in the Sabin Center's response to Acting Chair Allison Herren Lee's March 2021 request for public input on climate change disclosures. *See* Sabin Ctr for Climate Change Law, Comment Letter in Response to Request for Public Input on Climate Change Disclosures (June 11, 2021), https://www.sec.gov/comments/climate-disclosure/cll12-8911856-244661.pdf. The content of the letter is incorporated here by reference.

[15] Delliang Chen et al., *Framing, Context, and Methods, in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS. CONTRIBUTION OF WORKING GROUP I TO THE SIXTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL OF CLIMATE CHANGE 204 (V. Masson-Delmotte et al., 2021). *See also,* Michael Burger, Jessica Wentz, and Radley Horton, *The Law and Science of Climate Change Attribution*, 45 COLUM. J. ENVTL. L. 57, 64 (2020).

[16] G.C. Hegerl et al., *Understanding and Attributing Climate Change*, *in* CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS. CONTRIBUTION OF WORKING GROUP I TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (S. Solomon et al., eds., 2007). *See also,* NAT'L ACAD. OF SCI., ENGINEERING, AND MEDICINE, ATTRIBUTION OF EXTREME WEATHER EVENTS IN THE CONTEXT OF CLIMATE CHANGE (2016).

[17] Hegerl et al, *supra* note 16, at 667. Detection is the process of demonstrating that the climate has changed in some defined statistical sense, while 'attribution' refers to the process of establishing whether and to what extent human activities are the cause of the detected change. *See id*. at 667-668.

[18] *See, e.g.,* Yang Chen et al., *Future Increases in Arctic Lightning and Fire Risk for Permafrost Carbon*, 11 NAT. CLIMATE CHANGE 404 (2021); Lauren J. Vargo et al., *Anthropogenic Warming Forces Extreme Annual Glacier Mass Loss*, 10 NAT. CLIMATE CHANGE 856 (2020); Qiaohon Sun et al., *A Global, Continental, and Regional Analysis of Changes in Extreme Precipitation*, 34 J. CLIMATE 243 (2020).

[19] Benjamn D. Santer et al., *Human and natural influences on the changing thermal structure of the atmosphere*, 110 PROC. NAT'L ACAD. SCI. 17235 (2013).

natural internal climate variability.[20] The internal and physical consistency of fingerprint results provides compelling scientific evidence of human effects on climate.

2. *Extreme event attribution* examines how human-induced changes in the global climate system have affected the probability, severity, and other characteristics of observed extreme events, such as hurricanes and heat waves. For example, one recent study used the Community Atmospheric Model ("CAM")[21] to analyze how human-induced climate change affected rainfall rates during the 2020 hurricane season, which is estimated to have resulted in more than $40 billion in damages.[22]

3. *Impact attribution* examines how changes in the global climate system affect human and natural systems. Impact attribution studies analyze localized physical climate change impacts, such as floods, droughts, and sea level rise, and the corresponding effects on infrastructure, public health, ecosystems, agriculture, and economies.[23]

4. *Source attribution* is a distinct but related body of research that aims to identify the relative contributions of different sectors, activities, and entities to global climate change.[24]

Climate change attribution, extreme event attribution, and source attribution are mature fields of research, with studies having been performed since the 1990s. Impact attribution is a newer, but rapidly developing, field of research. All four fields of research provide useful insights into how human activities affect the climate system which, in turn, informs modeling of future climate change.

2. Climate Modeling

This section describes the process of using climate models to generate knowledge of climate hazards. Modeling allows researchers to simulate and understand interactions between climate variables using physically-based representations of the climate system in numerical form. Through models, scientists can explore the effect of changes to external factors, like atmospheric GHG concentrations, on specific climate variables (e.g., surface temperatures) and the types of hazards associated with such GHG-induced effects (e.g., changes in rainfall patterns).

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[20] *Id.* at 1

[21] All raw CAM model output is publicly available on the National Center for Atmospheric Research Globally Accessible Data Environment. *See* Nat'l Ctr. Atmospheric Research, *Data Services: Access, Tools & Guidance*, https://perma.cc/Y3ZX-ZX7G (last visited May 20, 2022).

[22] *See* Kevin A. Reed et al., *Attribution of 2020 Hurricane Season Extreme Rainfall to Human-Induced Climate Change*, 13 NATURE COMM. 1905 (2022).

[23] As an example, one recent impact attribution study examined how increases in the number of wet days and in extreme daily rainfall affect economic growth rates. *See* Maximillian Kotz et al, *The effect of rainfall changes on economic production*, 601 NATURE 223 (2022).

[24] Source attribution studies have, for example, assessed the cumulative GHG emissions attributable to specific oil, natural gas, coal, and cement producers (among others). *See, e.g.,* RICHARD HEEDE, CARBON MAJORS: ACCOUNTING FOR CARBON AND METHANE EMISSIONS 1854–2010: METHODS & RESEARCH REPORT (2014), https://perma.cc/448G-SYUA.

Developing an understanding of the type of climate hazards present (e.g., in a given region, affecting a specific company, etc.) is a critical first step in assessing potential impacts of climate change. Using climate hazard data, companies can evaluate potential climate-related risks to their assets, operations, work force, and supply chains.

While some other commenters have expressed concern about the reliability of climate models,[25] research shows that past model predictions (e.g., of global average temperatures) have been highly accurate. One way to assess model accuracy is to compare previous model projections made years or decades ago to actual climate observations—a process referred to as "hindcasting."[26] One recent study used hindcasting to assess the performance of climate model projections published between 1970 and 2007. The authors found that the climate models were "skillful in predicting subsequent GMST [global mean surface temperature] changes, with most models examined showing warming consistent with observations" and that there was "no evidence that the climate models . . . systematically overestimated or underestimated warming over their projection period."[27] Another study analyzed global temperature and sea-level data over the past several decades and compared those records with projections published in the IPCC's Third and Fourth Assessment Reports. The analysis showed that "global temperature continues to increase in good agreement with the best estimates of the IPCC, especially if we account for the effects of short-term variability due to the El Niño/Southern Oscillation, volcanic activity, and solar variability".[28]

2.1. Types of Climate Models

Each component of the climate system – or a combination of components – can be represented by models of varying degrees of complexity.[29] There are three classes of climate models:

1. Energy balance models, which are the oldest and simplest type of climate model, estimate changes in the climate system from an analysis of the Earth's energy budget (i.e., the balance of energy entering and leaving the Earth).[30]

2. Intermediate complexity models, which are similar to energy balance models but incorporate

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[25] *See, e.g.,* Lawrence Cunningham et al., Comment Letter on Proposed Rule on The Enhancement and Standardization of Climate-Related Disclosures for Investors (Apr. 25, 2022), https://www.sec.gov/comments/s7-10-22/s71022-20126528-287180.pdf. As the material presented in this letter demonstrates, the concerns expressed by Professor Cunningham and others are misplaced.
[26] Hausfather, *supra* note 47.
[27] Zeke Hausfather et al., *Evaluating the Performance of Past Climate Model Projections*, 47 GEOPHYSICAL RES. LETTERS 1 (2020).
[28] Stefan Rahmstorf et al., *Comparing climate projections to observations up to 2011*, 7 ENVTL. RES. LETTERS 4 (2012).
[29] *Id*.
[30] Lauren Harper, *What are climate models and how accurate are they?* STATE OF THE PLANET BLOG (May 18, 2018), https://perma.cc/3QJ6-Q2UR.

the effect of changes in the Earth's land, oceans, and ice features on the climate.[31] Intermediate complexity models are used to project changes in climate over long time scales and large spatial scales.[32]

3. Comprehensive climate models (General Circulation Models and full Earth System Models), which are more sophisticated than energy balance and intermediate complexity models.[33] General Circulation Models are based on physical laws that describe the fully-coupled dynamics of the atmosphere and ocean, expressed through mathematical equations.[34] Earth System Models, also referred to as coupled carbon-cycle climate models, are similar to General Circulation Models but also incorporate the dynamics of the land surface, vegetation, the carbon cycle, and other elements of the climate system.[35] Both General Circulation Models and Earth System Models are built upon the fundamental laws of physics or the empirical relationships established from observations and, when possible, are constrained by fundamental conservation laws.[36]

There are more than forty scientific institutions worldwide that develop climate models.[37] In order to facilitate comparison of model results across these institutions, the Coupled Model Intercomparison Project ("CMIP") serves as a framework for climate model experiments, allowing scientists to compare and assess climate models in a systematic way.[38] The most recent, sixth phase of CMIP model runs ("CMIP6") provided many different types of simulations that were evaluated by the IPCC's Sixth Assessment Report. As part of CMIP6, there are twenty-two specialized experiments—called Model Intercomparison Projects ("MIPs")—which prescribe standardized experiment designs, time periods, output variables or observational reference dates to better facilitate the direct comparison of climate models.[39]

2.2. Climate Model Projections

The first step in simulating and quantifying the climate response to past, present, and future human activities is to simulate historical and/or present climate for extended simulation periods, typically across multiple decades or several centuries. Models can be used to simulate a previous climate before anthropogenic GHG emissions became prominent, as well as to simulate the effect of natural factors (e.g., volcanic activity and changes in the Sun's energy activity) and

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[31] *Id*.
[32] *Id*.
[33] *Id*.
[34] Chen et al., *supra* note 15, at 215.
[35] *Id*.
[36] *Id.*
[37] Zeke Hausfather, *CMIP6: The next generation of climate models explained*, CARBON BRIEF (Dec. 2, 2019, 8:00 AM), https://perma.cc/F69B-R3U6.
[38] Zeke Hausfather, *Q&A: How do climate models work?* CARBON BRIEF, https://perma.cc/8LVD-HZ4Y (Jan. 15, 2018, 8:30 AM).
[39] Chen et al., *supra* note 15, at 182.

human activities on the climate.[40] Two general types of simulation are typically performed to make projections of future changes in the climate system:

1. Equilibrium simulations involve changing the CO_2 concentrations – e.g., doubling the CO_2 level – and running the model again until it reaches a new equilibrium. Modelers can then estimate the corresponding changes to the climate based on the doubling of CO_2 emissions by calculating the differences between the climate statistics in the "doubled CO_2" and "pre-industrial CO_2" simulations.[41]

2. Transient simulations involve forcing the model with a specific scenario of future changes in GHG emissions, particulate pollution, and land surface properties. For example, the IPCC has developed a set of scenarios that represent different time-dependent "storylines" of GHG and aerosol concentrations based on differing assumptions regarding population growth, energy intensity and efficiency, and economic growth.[42] (Climate modeling using emissions scenarios is discussed further in Part 2.3 below.)

2.3. Climate Modeling Using Emission Scenarios

Representative Concentration Pathways ("RCPs") were used in simulations of future climate change that were assessed in the IPCC's Fifth Assessment Report. RCPs provide four different scenarios for GHG emissions in the 21st century, as well as for air pollutant emissions and changes in land use. Each RCP is defined by its emissions pathway and total radiative forcing[43] by 2100.[44] Broadly speaking, the RCP scenarios consist of a stringent GHG emissions mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0), and one high emissions scenario (RCP8.5).

The RCP scenarios were developed by the IPCC using Integrated Assessment Models ("IAMs"). IAMs typically incorporate simple climate models (such as the Energy-Balance Models described above), carbon cycle models, and social science models that consider demographic, political, and economic variables that influence GHG emission scenarios.[45] Each RCP was generated using IAMs to estimate the changes in radiative forcing through 2100 associated with each of the four "storylines."

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[40] E. Ahlonsou et al., *The Climate System: An Overview, in* CLIMATE CHANGE 2001: THE SCIENTIFIC BASIS, CONTRIBUTION OF WORKING GROUP I TO THE THIRD ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 95 (J.T. Houghton et al., eds., 2001).
[41] *Id.*
[42] *Id.*
[43] Radiative forcing is a cumulative measure of human-caused perturbations to Earth's energy balance, expressed in Watts per square meter.
[44] Intergovernmental Panel on Climate Change, *Representative Concentration Pathways (RCPs)*, DATA DISTRIBUTION CENTRE, https://perma.cc/3475-P4JY (last visited May 20, 2022).
[45] IAMs differ from General Circulation Models, which focus solely on modeling the physical climate system. *See* CENTER FOR INTERNATIONAL EARTH SCIENCE INFORMATION NETWORK, THEMATIC GUIDE TO INTEGRATED ASSESSMENT MODELING OF CLIMATE CHANGE (1995), https://perma.cc/R57L-7KGP.

RCP data are publicly available for download and use to make 21st century climate change projections under different emission scenarios.[46] Many different entities, including management consulting firms such as McKinsey & Company, already use climate models driven by RCPs to assess the physical risks of climate change. For example, in a recent report by the McKinsey Global Institute, the authors used RCP8.5 in their analysis of future physical climate risks. They found that by 2050:

- global average temperatures are expected to warm by 2.3 degrees Celsius relative to the preindustrial baseline;
- the time spent in drought is projected to increase such that, in some areas (e.g., parts of the Mediterranean, Africa, and the Americas), drought conditions could occur up to eighty percent of each decade; and
- the likelihood of extreme precipitation events is expected to increase more than fourfold along the east coast of North America (compared to the period from 1950-1981).[47]

This information can then be used to estimate the socioeconomic impacts of climate change associated with different emissions trajectories. For example, the McKinsey report identified "the socioeconomic risk from acute hazards, which are on-off events like floods or hurricanes, as well as from chronic hazards, which are long-term shifts in climate parameters like temperature" from 2020 to 2030 and from 2030 to 2050.[48] Among other things, the report found that temperature increases associated with RCP8.5 will mean that:

> "By 2030 . . . between 250 million and 360 million people could live in regions where there is a non-zero probability of a heat wave exceeding the threshold for survivability for a healthy human being in the shade (a measure of livability, without factoring in air conditioner penetration). The average probability of a person living in an at-risk region experiencing such a lethal heat wave at least once over the decade centered on 2030 is estimated to be approximately 60 percent . . . . By 2050, the number of people living in regions exposed to such heat waves could rise further, to between 700 million and 1.2 billion . . . The global average number of working hours that could be lost due to increasing heat and humidity in exposed regions (a measure of workability impacts) could almost double by 2050, from 10 percent to 15 to 20 percent." (Internal citations omitted).[49]

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[46] *See* RCP Database, Version 2.0.5, https://tntcat.iiasa.ac.at/RcpDb/dsd?Action=htmlpage&page=download.
[47] JONATHAN WOETZEL ET AL., MCKINSEY GLOBAL INSTITUTE, CLIMATE RISK AND RESPONSE: PHYSICAL HAZARDS AND SOCIOECONOMIC IMPACTS 10 (2020), https://perma.cc/55NE-TVTU.
[48] *Id*. at 2.
[49] *Id*. at 23.

The IPCC's Sixth Assessment Report highlights a newer set of illustrative scenarios, derived from five Shared Socio-economic Pathways ("SSPs"), that encompass a range of possible future developments with respect to anthropogenic drivers of climate change.[50] Each pathway is built upon an internally consistent, plausible, and integrated description of a socio-economic future.[51] They include quantitative projections of socio-economic drivers, including population, gross domestic product, and urbanization. The five SSPs represent: 'sustainability' (SSP1), a 'middle-of-the-road' path (SSP2), 'regional rivalry' (SSP3), 'inequality' (SSP4), and 'fossil fuel-intensive' development (SSP5). The narratives and drivers underlying each SSP were used to develop scenarios of energy use, air pollution control, land use, and GHG emissions using IAMs.[52]

Like RCPs, SSPs yield information about the approximate radiative forcing level in 2100. This information is encoded in the name of the SSP (SSPX-Y, where 'X' represents the Shared Socio-economic Pathway family (1-5), and 'Y' represents the approximate radiative forcing level in 2100). These combinations are widely used in the climate impact studies assessed in the IPCC Sixth Assessment Report.[53] For example, the IPCC describes SSP5-8.5 as a "high reference scenario with no additional climate policy. CO_2 emissions roughly double from current levels by 2050" in SPP5-8.5.[54] According to the IPCC, the SSP and RCP scenarios "are designed to span a plausible range of future pathways," and can be used to develop projections of future climate conditions in various possible futures.[55]

2.3. Downscaling Climate Models

General circulation models generally divide the world up into grids in order to perform calculations. A typical model might have a grid cell size of sixty miles or more for one side of the cell, resulting in coarse-resolution projections that cover large geographic areas. These projections may not be sufficiently granular to enable companies to fully assess the impacts of climate change on specific assets and operations. Downscaling the output from global climate models to finer spatial scales can partially bridge this information gap. There are two main approaches to downscaling:

1. Dynamical downscaling uses higher spatial resolution regional climate models to directly simulate regional climate processes and regional responses to global change.[56] The regional models usually cover a selected domain (such as the continental United States) and receive information from more coarsely resolved general circulation models at the boundaries of the

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[50] Chen et al, *supra* note 15, at 230.
[51] *Id.*
[52] *Id.*
[53] *Id.* at 231.
[54] *Id.*
[55] *Id*. at 196.
[56] Aristita Busuioc, *Empirical-statistical downscaling: Nonlinear statistical downscaling*, OXFORD RESEARCH ENCYCLOPEDIA OF CLIMATE SCIENCE (2021).

regional domain.

2. Statistical downscaling uses historically-based statistical relationships between the large-scale and local-scale climate to estimate future changes in local climate from large-scale general circulation model projections.[57]

Downscaled climate projections have been published by various governmental and academic institutions:

- The Department of Energy, National Aeronautics and Space Administration, and National Oceanic and Atmospheric Administration have jointly published zip-code-level temperature projections and county-level precipitation and sea level projections.[58]

- The U.S. Geological Survey has partnered with the College of Earth, Ocean, and Atmospheric Sciences at Oregon State University to develop a "Regional Climate Change Viewer" that includes downscaled projections for over 60 climate variables, including air temperature and precipitation.[59]

- The Bureau of Reclamation has partnered with multiple universities and non-governmental organizations to develop downscaled projections for temperature and precipitation at the watershed level. The projections are designed to enable assessment of climate change impacts on watershed hydrology, ecosystems, and water and energy demand across the U.S.[60]

- The Geospatial Innovation Facility at the University of California at Berkeley has developed Cal Adapt, a web-based tool that provides projections for several climate variables, including temperature and precipitation, under two climate change scenarios on a 3.5 × 3.5-mile spatial grid.[61]

- The Climate Impact Lab has developed the Global Downscaled Projections for Climate Impacts Research, a globally downscaled version of temperature and precipitation from the most recent CMIP6 projections, with a resolution of approximately 15 miles.[62]

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[57] *Id*. at 1.

[58] *See Energy Data Gallery*, U.S. CLIMATE RESILIENCE TOOLKIT, https://toolkit.climate.gov/topics/energy/energy-data-gallery (last updated Sept. 24, 2019).

[59] U.S. Geological Survey, *Regional Climate Change Viewer*, http://regclim.coas.oregonstate.edu/visualization/rccv/index.html (last visited May 20, 2022).

[60] U.S. Bureau of Reclamation et al., *Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections*, https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/#Welcome (last visited May 20, 2022).

[61] *About Cal-Adapt*, CAL-ADAPT, https://cal-adapt.org/about/ (last visited May 20, 2022).

[62] Climate Impact Lab, Introducing Our New Global Downscaled Projections for Climate Impact Research, https://impactlab.org/news-insights/introducing-our-new-global-downscaled-projections-for-climate-impacts-research/ (last visited June 14, 2022).

3. Overcoming Challenges and Uncertainties

Climate science is sufficiently robust to assess the likelihood of certain climate change hazards and evaluate their impacts on companies' assets and operations. There are, however, remaining uncertainties and limitations in how climate science can be used. As explained in this section, researchers have techniques and language to address these challenges, with the goal of ensuring that climate science remains a source of useful information about the climatic "shape of things to come." A particular focus of previous research has been to identify climate change responses that are robust across a wide range of different climate models, that are interpretable in terms of basic, well-understood physics (such as the decrease in snowpack associated with human-caused warming), and that have reliable multidecadal observational records.

As noted above, scientists can assess how well a climate model functions by comparing its outputs to observational data. However, observational data may sometimes be incomplete, or entirely unavailable. Modeling climate impacts at fine geographic scales (e.g., regionally or locally) can result in additional sources of uncertainty due to downscaling or bias correction.[63] For example, statistical downscaling relies on the assumption that the statistical relationships used to transform global climate model output remains true under novel environmental conditions that have yet to be observed directly.[64] One strength of using dynamical downscaling methodologies is that such models rely on explicit representations of physical principles in the atmosphere that are expected to hold true under climate change, but this method can be sensitive to large-scale biases in the downscaling models (and in the global climate models used to generate the data being downscaled).[65]

Researchers can address these uncertainties by articulating the nature and extent to which local climate predictions may differ from regional predictions modeled at a larger scale. Assume, for example, that researchers want to study the future climate impacts on a particular city in North America. While regional modeling may suggest that North America will experience an increase in average surface temperatures, an individual city may experience more or less warming than the average for the continent. This variation can be investigated by analyzing regional-scale climate processes and factors such as land use, aerosol concentrations, and small-scale natural variability in the area of interest. Uncertainties in the observational data can also be studied and may influence attribution of observed climate changes and/or impacts to specific causal factors. For example, the IPCC states that the scarcity of temperature recording stations

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[63] Bias correction refers to the correction of projected raw, daily global circulation model output using the differences in the mean and variability between general circulation models and observations over a set reference period. *See* Ed Hawkins et al., *Calibration and bias correction of climate projections for crop modelling: An idealised case study over Europe. Agricultural and Forest Meteorology*, 170 AGRICULTURAL & FOREST METEOROLOGY 19 (2013).
[64] Geophysics Fluid Dynamics Laboratory, *Climate Model Downscaling*, https://perma.cc/K25U-3UYS (last visited May 21, 2022).
[65] *Id*.

can explain the overall low confidence in changes in surface air temperatures in the Antarctic region.[66]

The results of individual studies are typically expressed in terms of calibrated uncertainty and likelihood language. For example, the IPCC's Sixth Assessment Report uses a framework for applying expert judgment in the evaluation and characterization of assessment findings. This calibrated language is designed to consistently evaluate and communicate uncertainties associated with incomplete knowledge due to a lack of available information, or from disagreement regarding what is known or even knowable.[67] This methodology assigns qualitative expressions of confidence—such as *very low, low, medium, high,* and *very high*—based on the robustness of evidence for a finding and uses quantitative expressions—such as *virtually certain* (99-100% probability)—to describe the likelihood of a finding.[68] For example, the IPCC report states that "observed increases in areas burned by wildfires have been attributed to human-induced climate change in some regions (*medium* to *high confidence*)."[69] Language of this kind is used to manage uncertainties in a rigorous, systematic way.[70] Of course, the language scientists have developed to address unavoidable uncertainty in this enterprise must not be confused with the reliability of the results and conclusions.

In sum: as in any scientific endeavor, some uncertainties are unavoidable, but researchers can frame results at an appropriate scale and use language that clearly communicates the extent to which modeling and observations produce results with a high level of confidence. Such techniques allow companies to effectively use model outputs to assess climate-related risks to their assets and operations. The case studies included below further emphasize and demonstrate this point.

4. Information Available to Reporting Entities

As described in the above sections, climate science can reveal useful information about a company's exposure to acute and slow-onset climate changes. Two types of this information are discussed below, but these examples are not exhaustive. Additionally, available and relevant climate information will vary across different sectors and industries.

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[66] Nathaniel L. Bindoff et al., *Detection and Attribution of Climate Change: from Global to Regional, in* CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS. CONTRIBUTION OF WORKING GROUP 1 TO THE FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (T.F. Stocker et al. eds., 2013).
[67] Hans Pörtner et al., *Technical Summary, in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION AND VULNERABILITY. WORKING GORUP II CONTRIBUTION TO THE IPCC SIXTH ASSESSMENT REPORT (Hans-Otto Pörtner et al. eds., 2022).
[68] *Id.* at 4
[69] IPCC, *supra* note 13, at SPM-8.
[70] *See* Elisabeth A. Lloyd et al., *Climate Scientists Set the Bar of Proof Too High*, 165 CLIMATIC CHANGE 55 (2021) ("[C]limate scientists have set themselves a higher level of proof in order to make a scientific claim than law courts ask for in civil litigation in the USA, the UK, and virtually all common law countries.").

First, information regarding where climate hazards are likely to be felt. This information may allow a company to assess which of its physical assets, operations, and supply chains are located in areas known to be vulnerable to climate hazards. Such an assessment may enable the company to better understand the nature and extent of any climate-related vulnerabilities. Companies can use climate models that produce a probabilistic assessment[71] of hazards within a given area to identify risks to assets in the affected region.[72] This would enable the company to disclose, for example, that its principal place of business is situated within a geographic area that scientists have concluded is *very likely* [90-100% outcome probability] to experience flooding exacerbated by climate change.

Second, information on how specific climate hazards are predicted to change in frequency or severity. These hazards include both extreme events and longer-term, slow onset changes to the environment. Using information about climate hazards, companies can evaluate current and future risks to their assets and operations.

5. Case Studies

The case studies below highlight how companies can and do make use of the data and analytical techniques highlighted in these comments to assess climate hazards, evaluate potential impacts on their assets, operations, and supply chains, and communicate useful information about their exposure to physical climate related risks.

5.1. Con Ed's Climate Vulnerability Study

Following Hurricane Sandy in 2012, Consolidated Edison Company of New York ("Con Ed") conducted a comprehensive climate change vulnerability study to evaluate the likelihood and consequences of a range of climate change scenarios.[73] The study provides an example of how companies can conduct – and ultimately disclose – an assessment of physical climate-related risks and hazards.

Con Ed's vulnerability study evaluated climate change trends and potential extreme weather events across the company's service territory over three-time horizons: near (2030), intermediate (2050), and long-term (2080).[74] The study focused on climate variables that could impact Con Ed's operations, planning, and infrastructure, namely temperature, humidity,

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[71] Probabilistic assessments indicate areas where, for example, models show a higher chance of above or below average temperatures or precipitation. *See* NOAA, *Climate Models*, CLIMATE DATA PRIMER, https://perma.cc/HL6K-33Y4 (last visited May 20, 2022).

[72] *See, e.g.,* ISIMIP, *The Inter-Sectoral Impact Model Intercomparison Project*, https://perma.cc/UV5D-PBXQ (last visited May 20, 2022). Utilizing climate model output at a more granular level than the model itself operates—i.e., downscaled data—requires an acknowledgment that the local risk of exposure to an extreme event may differ from what the model predicts at a larger scale.

[73] CONSOLIDATED EDISON, CLIMATE CHANGE VULNERABILITY STUDY (2019), https://perma.cc/39E4-B77T. [Included as Attachment 1 to this letter]

[74] *Id*. at 17.

precipitation, sea level rise and coastal flooding, extreme events, and multiple or compounding events.[75]

For each climate variable mentioned above, the study team used a broad model ensemble—consisting of 32 global climate models—to address differences across models and to provide a more comprehensive view of future climate in the region.[76] Each global climate model was simulated using RCP4.5 and RCP8.5 to evaluate climate change hazards and account for model uncertainty under each RCP scenario.[77] In order to achieve a more accurate representation of the local climate across the New York Metropolitan Region (i.e., Con Ed's service territory), the study team bias corrected and downscaled the global climate model projections using weather station data over a 1976-2005 historical baseline from three weather stations across the service territory.[78]

The Con Ed study revealed specific, actionable information about the impacts of climate change on the company's assets and operations. For example, the climate projections developed for the study showed a significant increase in the number of days with average temperatures above 86ºF (up 1200 percent) and days with maximum temperatures above 95ºF (up 575 percent) by 2050, which "create potential risks for Con Ed[] as they drive demand for air conditioning and stress electrical and infrastructure systems."[79] The study further showed that Con Ed's system could be impacted by sea level rise and associated coastal flooding. According to climate projections, by 2100, 500-year flood events are expected to occur every ten years and the water-depth of present-day 100-year floods is expected to increase by up to fifty percent.[80] The vulnerability study determined that, with this increase in flood height, at least seventy-five of Con Ed's electric substations would be vulnerable to flooding during a 100-year storm.[81] Con Ed would need to spend $636 million to harden those seventy-five substations.[82]

Where quantitative results were not available for specific climate-related risks, the study described those risks in qualitative terms. For example, the study notes that "the percentage of very strong and destructive (i.e., Categories 4 and 5) hurricanes is projected to increase in the North Atlantic basin. It can therefore be argued that climate change could make it more likely for some of these storms to impact the New York Metropolitan Region, although the most dominant factor will remain unpredictable climate and weather variability."[83]

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[75] *Id*.
[76] *Id*.
[77] *Id*.
[78] *Id*.
[79] *Id*. at 19-20.
[80] *Id*. at 23-24.
[81] *Id*. at 44.
[82] *Id*.
[83] *Id.* at 24-25.

Based on the findings of the vulnerability study, Con Ed was able to identify specific assets that face physical climate risks and develop a plan to manage those risks (e.g., by replacing or hardening assets). After completing the vulnerability study, Con Ed developed a Climate Change Implementation Plan that explains how it "will incorporate climate change projections for heat, precipitation, and sea level rise from the . . . study into its operations to mitigate climate change risks to its assets and operations and establishes an ongoing process to reflect the latest science in the Company's planning."[84] The Implementation Plan identifies 5-, 10-, and 20-year actions that Con Edison will take with respect to load forecasting, load relief planning, reliability planning, asset management, system planning, emergency response activities, and worker safety protocols.[85] The actions include elevating new critical electrical infrastructure in floodplains by three-feet to account for sea level rise and reduce the risk of inundation during coastal storms.[86]

In summary, the Con Ed vulnerability study serves as a representative example of how companies can use the techniques highlighted in this letter to identify, evaluate, and ultimately disclose physical climate-related risks to their assets and operations.

5.2. UNEP FI's Climate Risk Landscape Assessment

In a 2021 report—*The Climate Risk Landscape*—the United Nations Environment Programme Finance Initiative ("UNEP FI") surveyed various climate risk assessment tools that can be and, in some cases, are already being used by financial institutions to evaluate and disclose physical and transition risks associated with climate change.[87] The report reviews nineteen commercially-available tools for assessing physical climate risk and eighteen commercially available transition risk assessment tools.[88] With respect to the former, the report finds that existing tools can be used to evaluate acute risks associated with extreme weather events, flooding, wildfires, and landslides, as well as chronic risks associated slow onset climate change impacts, such as sea level rise.[89] The report further notes existing tools are "being constantly updated to allow for more granular analysis that takes into account a broader, more plausible set of scenarios," and enables financial institutions to "provide consistent and market-ready disclosures."[90] According to report, physical risk data is becoming easier to access in formats that are "easily usable by financial institutions."[91]

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[84] CONSOLIDATED EDISON, CLIMATE CHANGE IMPLEMENTATION PLAN 1 (2020), https://perma.cc/A32Z-JPGS.
[85] *Id.* at 2.
[86] *Id*. at 8.
[87] PAUL SMITH, UNEP FI, THE CLIMATE RISK LANDSCAPE: A COMPREHENSIVE OVERVIEW OF CLIMATE RISK ASSESSMENT METHODOLOGIES (2021), https://www.unepfi.org/publications/banking-publications/the-climate-risk-landscape/. [Included as Attachment 2 to this letter]
[88] *Id*. at 15 & 29.
[89] *Id*. at 32.
[90] *Id*. at 35 & 37.
[91] *Id*. at 37.

Following release of the 2021 report, UNEP FI ran a pilot program in which forty-eight global banks and investors were given an opportunity to learn about, and trial, twelve commercially available climate risk assessment tools.[92] The program participants included TD Asset Management Inc. ("TDAM"), which manages $434 billion in assets on behalf of 3 million investors.[93] TDAM trialed emissions analysis, climate scenario alignment analysis, transition risk analysis, and physical risk analysis tools made available by Institutional Shareholder Services ("ISS") ESG.[94] We focus here on the physical risk analysis tool, which TDAM used to "measure[] the potential financial impact of the six most costly natural climate hazards such as floods, droughts or wildfires on the value of" a global equity portfolio that held 195 securities from over thirty countries.[95] TDAM's analysis showed that physical climate risks are projected to result in a 1.6 percent and 2.8 percent change in portfolio value by 2050 under the most likely and worst-case RCP scenarios, respectively, and that "80% of the climate value-at-risk of the portfolio can be attributed to just 30 securities."[96] TDAM also used the ISS ESG tool to evaluate the financial risks posed by specific climate impacts and found that wildfires and heat stress presented the greatest risk to its portfolio.[97]

Another participant in the pilot program was Intesa Sanpaolo, an Italian bank that serves 13.5 million customers and has €341 billion in assets under management.[98] Intesa Sanpaolo worked with Risk Management Solutions, Inc. ("RMS"), which has developed over 300 catastrophe risk models that can be used to assess "how frequently a given location can be expected to be impacted" by a particular hazard (e.g., flooding in excess of six feet), as well as "the frequency and severity of the economic impact caused by" the hazard.[99] RMS used the models to quantify the flood risk of a sample of Intesa Sanpaolo's mortgage portfolio in regions throughout Italy under RCP6.0 and RCP8.5.[100] Using RMS data, Intesa Sanpaolo calculated the impact on Loss Given Default and the Probability of Default to range from five to thirty-nine percent of the initial values.[101] Intesa Sanpaolo further estimated, under RCP8.5, the average annual loss would increase fifty percent over the baseline in the provinces of Rome and Naples by 2040.[102]

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[92] DAVID CARLIN & ALEXANDER STOPP, UNEP FI, THE CLIMATE RISK TOOL LANDSCAPE: 2022 SUPPLEMENT (2022), https://www.unepfi.org/publications/the-climate-risk-tool-landscape-2022-supplement/. [Included as Attachment 3 to this letter]
[93] TD Asset Management, *About Us*, https://perma.cc/8AR9-AXPN (last visited May 19, 2022).
[94] Carlin & Stopp, *supra* note 92, at 38-39.
[95] *Id*. at 39.
[96] *Id*. at 42.
[97] *Id*. at 43.
[98] Intesa Sanpaolo, *Business*, ABOUT US, https://perma.cc/QU5L-VXT2 (last updated May 11, 2022).
[99] Carlin & Stopp, *supra* note 92, at 26 & 62.
[100] *Id*. at 64.
[101] *Id*. at 66.
[102] *Id*. at 65.

A third pilot program participant was Desjardins Group, a financial cooperative with 7.5 members and customers, and over $397 billion in assets.[103] Desjardins partnered with The Climate Service ("TCS"), which used its Climanomics platform to evaluate physical and transition risks across fifty of Dejardins' real assets.[104] The Climanomics platform models absolute climate risk, measured in millions of USD and relative climate risk, reported as percent of asset value.[105] The analysis of Dejardins' assets revealed that fluvial flooding is the greatest physical risk to the assets under both RCP4.5 and RCP8.5 scenarios.[106] Drought was identified as the second greatest physical risk to the assets.[107] Desjardins was able to conduct asset-level risk analyses. For example, the analysis showed that a dairy farm located northeast of Montreal, Canada, would "face a modeled average annual loss (MAAL) of 6.7% to 8.5% for RCP4.5 and RCP8.5, respectively."[108] The analysis further showed that "[t]he highest risks faced are from temperature extremes, followed to a lesser degree by fluvial flooding and drought at both RCP4.5 and RCP8.5 scenarios. The largest difference among the two is temperature extremes representing a 5.7% MAAL in RCP8.5 and 3.9% MAAL in RCP4.5."[109]

The above examples demonstrate how companies can use existing tools to evaluate, and ultimately disclose, the physical risks they face from flooding, drought, and other climate change impacts. As UNEP FI has noted, climate risk assessment methodologies are advancing rapidly, and new tools are becoming available.[110] UNEP FI predicts that physical risk models will continue to improve and provide increasingly "granular" data that will "allow[] more accurate risk analysis." [111]

5.3. Rio Grande Project EIS

The Bureau of Reclamation's Final Environmental Impact Statement ("EIS") for the Rio Grande Project provides another example of how private companies can use climate science to understand and communicate the physical risks of climate change.[112]

The Rio Grande Project supplies irrigation to about 178,000 acres of land and provides electrical power for communities and industries in the area. Physical features of the project include the Elephant Butte and Caballo dams, as well as hundreds of miles of canals and

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[103] Desjardins Group, *Quick facts about Desjardins*, https://perma.cc/7HHX-XPXQ (last visited May 19, 2022).
[104] Carlin & Stopp, *supra* note 92, at 80.
[105] *Id*.
[106] *Id*. at 84.
[107] *Id*.
[108] *Id*. at 85.
[109] *Id*. at 85.
[110] *Id*. at 8; Smith, *supra* note 87, at 35.
[111] Smith, *supra* note 87, at 37.
[112] BUREAU OF RECLAMATION, FINAL ENVIRONMENTAL IMPACT STATEMENT: CONTINUED IMPLEMENTATION OF THE 2008 OPERATING AGREEMENT FOR THE RIO GRANDE PROJECT, NEW MEXICO AND TEXAS (2016), https://perma.cc/K3YN-8C5T.

associated infrastructure, and a hydroelectric plant. The project's climate impact analysis was designed to understand how the management of this system would operate under future climate conditions through 2050. Therefore, the EIS used climate model output generated from an ensemble of 112 statistically downscaled projections and developed three possible scenarios – a drier scenario, a median or "central tendency" scenario, and a wetter scenario. Hydrology models were then used to simulate changes in runoff and streamflow across the river basin of the Rio Grande using these three precipitation scenarios.

In the EIS, the study authors were able to isolate 'worst case' scenarios for various regions across the river basin. For example, the wetter scenario represented a worst case for species that inhabit the Elephant Butte reservoir, while the drier scenario is the worst case for species located downstream of the Caballo dam. This study further demonstrates the techniques outlined in this letter, such as employing qualitative narratives as appropriate and using ensemble data from multiple climate models, can produce critical information that characterizes the climate risk to a company's physical assets.

6. Conclusion

As the IPCC has recognized, it is "unequivocal" that human activities are warming the planet, leading to "widespread and rapid changes" that pose significant economic and other risks.[113] Using the methods described above, companies can assess, and ultimately disclose, their exposure to physical risks of climate change. As the case studies demonstrate, private companies and others are already successfully employing available climate tools and data to generate critical information that can and is informing their own decision-making and that of investors.

Sincerely,

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[113] IPCC, *supra* note 2, at 4.

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Attachments (3):

(1) Consolidated Edison, Climate Change Vulnerability Study (2019)

(2) Paul Smith, UNEP FI, The Climate Risk Landscape: A Comprehensive Overview of Climate Risk Assessment Methodologies (2021)

(3) David Carlin & Alexander Stopp, UNEP FI, The Climate Risk Landscape: 2022 Supplement (2022)

ATTACHMENT 1

Consolidated Edison, Climate Change
Vulnerability Study (2019)

Climate Change Vulnerability Study

December 2019

Climate Change Vulnerability Study

December 2019

In partnership with:

With contributions from O'Neill Management Consulting, LLC, The Risk Research Group, Inc., and Jupiter Intelligence Inc.

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Executive Summary

In its 2013 rate case filing after Superstorm Sandy, Con Edison proposed $1 billion in storm hardening investments to build additional resiliency into its energy systems. Con Edison worked with a Storm Hardening and Resiliency Collaborative to recommend optimal investments for the proposed storm hardening funds, including the recommendation that Con Edison conduct a Climate Change Vulnerability Study (Study). As described by the New York State Public Service Commission, the purpose of this Study is to aid in the ongoing review of the Company's design standards and development of a risk mitigation plan.[1] Over the course of the Study, Con Edison regularly convened a stakeholder group to provide feedback, consisting of many of the same participants from the Storm Hardening and Resiliency Collaborative. The findings from the Study equip Con Edison with a better understanding of future climate change risks and strengthen the company's ability to more proactively address those risks.

This Study describes historical and projected climate changes across Con Edison's service territory, drawing on the best available science, including downscaled climate models, recent literature, and expert elicitation. Con Edison recognizes the global scientific consensus that climate change is occurring at an accelerating rate. The exact timing and magnitude of future climate change is uncertain. To account for climate uncertainty, the Study considered a range of potential climate futures reflecting both unabated and reduced greenhouse gas concentrations through time and evaluated extreme event "stress test" scenarios.

This Study evaluates present-day infrastructure, design specifications, and procedures against expected climate changes to better understand Con Edison's vulnerability to climate-driven risks. This analysis identified sea level rise, coastal storm surge, inland flooding from intense rainfall, hurricane-strength winds, and extreme heat as the most significant climate-driven risks to Con Edison's systems. Con Edison has unique energy systems, and vulnerabilities vary across those systems. The utility's electric, gas, and steam systems are all vulnerable to increased flooding and coastal storms; workers across all commodities are vulnerable to increasing temperatures; and the electric system is also vulnerable to heat events.

While Con Edison already uses a range of measures to build resilience to weather events, the vulnerabilities identified in this Study guide the company to pursue additional strategies to mitigate climate risks. The Study establishes an overarching framework that can work to strengthen Con Edison's resilience over time. While many adaptation strategies focus on avoiding impacts altogether, a comprehensive resilience plan also requires a system that can reduce and recover from impacts, particularly following outages.

Over the course of 2020, Con Edison will develop and file a Climate Change Implementation Plan, which will specify a governance structure and a strategy for implementing adaptation options over the next 5, 10, and 20 years. While this Study assesses vulnerabilities within Con Edison's present-day systems to a future climate, the implementation plan must also consider the evolving market for energy services, and potential changes to services and infrastructure driven by customers, government policy and external actions over time.

[1] Cases 13-E-0030, 13-G-0031, 13-S-0032, Order Adopting Storm Hardening and Resiliency Collaborative Phase Three Report Subject to Modifications (January 25, 2016).

The Need for a Study

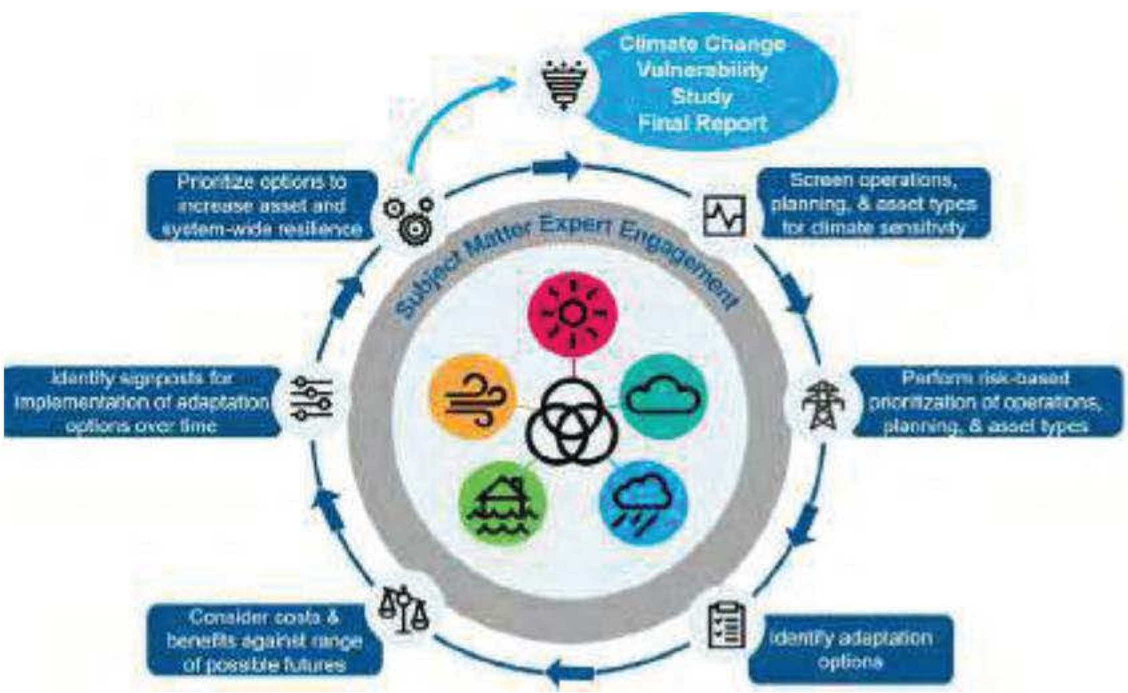
The New York State Public Service Commission approved an Order and funding for Con Edison to conduct a Climate Change Vulnerability Study, with a requirement for delivery by the end of 2019. The Con Edison Department of Strategic Planning undertook this Study with support from more than 100 subject matter experts throughout the company and in collaboration with ICF's climate adaptation and resilience experts and Columbia University's Lamont-Doherty Earth Observatory. The Study was designed to meet three primary goals:

> Con Edison's resilience to climate change has important implications for increasingly interconnected societal, technological, and financial systems that the company serves.

1. Research and develop a shared understanding of new climate science and projected extreme weather for the service territory.
2. Assess the risks of potential impacts of climate change on operations, planning, and physical assets.
3. Review a portfolio of operational, planning, and design measures, considering costs and benefits, to improve resilience to climate change.

The Study used an integrated approach to achieve these goals, as shown in Figure 1.

Figure 1 ■ General approach overview: The process cycles through the steps for each climate hazard, beginning with 'Screen operations, planning, and asset types for climate sensitivity'. The process results in the Climate Change Vulnerability Study Final Report.



A New Understanding of Climate Science and Extreme Weather

Con Edison will face new challenges from a rapidly changing climate through the 21st century. To better understand these challenges, the Study characterized historical and projected changes to climate hazards within the service territory to estimate the magnitude and timing of potential climate vulnerabilities. Climate variables that present outsized impacts to Con Edison include temperature, humidity, precipitation, sea level rise, and extreme events, such as rare hurricanes and long-duration heat waves.

Temperature

Average and maximum air temperatures are projected to increase throughout the century relative to historical conditions. Assuming unabated greenhouse gas concentrations, Con Edison could experience up to 23 days per year in which maximum temperatures exceed 95°F by 2050 relative to 4 days historically. Heat waves with 3 or more days when *average* temperatures exceed 86°F in Central Park are projected to occur up to 5 and 14 times per year by 2050 and 2080, respectively, relative to 1 heat wave every 5 years historically.

Humidity

The frequency of very high heat index thresholds, which combines both temperature and humidity, is projected to increase dramatically through the century. The number of days per year where the heat index equals or exceeds 103°F could increase by 7 to 26 days by 2050, compared with only 2 days historically. In addition, Con Edison evaluates the relationship of system load to an index called temperature variable (TV), which is similar to a heat index, but considers the persistence of heat and humidity over several days. Looking forward, TV thresholds that historically occur only once per year (e.g., 86°F) are projected to become common occurrences within a generation, occurring between 4 and 19 times per year by 2050 and between 5 and 52 times per year by 2080 based on reduced and unabated greenhouse gas concentrations, respectively.

Precipitation

Con Edison’s service territory experiences rainfall, downpours, snowfall, and ice. Climate change is projected to drive heavier precipitation across these event types. For example, the heaviest 5-day precipitation total could be 11.8 inches at Central Park by 2050, which represents a 17% increase over the historical reference period. Ultimately, projections point to a future defined by more frequent heavy precipitation, likely accompanied by smaller increases in the frequency of dry or light precipitation days.

Sea Level Rise

Sea levels are very likely to rise between 0.62 and 1.94 feet by 2050. In turn, rising sea levels will have profound effects on coastal flooding, as sea level rise increases both the frequency and height of future floods. For example, the flood height associated with the 1% annual chance flood (i.e., the so-called 100-year flood) in New York City is projected to increase from 8.3 feet to as much as 13.3 feet by 2100 relative to mean sea level at the Battery tide gauge. By the end of the century, today’s annual chance flood could occur at every high tide.

Extreme Events

Extreme events are low-probability and high-impact phenomena, such as hurricanes and long-duration heat waves. While difficult to simulate in climate models, a growing body of evidence suggests that many extreme events will increase in frequency and intensity as a result of climate warming. This Study considers high impact "worst-case"[2] extreme event scenarios, including a prolonged heat wave, a Category 4 hurricane, and an unprecedented nor'easter, to understand these changes and their impacts on Con Edison.

Characterization of Con Edison's Vulnerabilities to Climate Risks

Heat and Temperature Variable

The core electric vulnerabilities to increasing temperature and TV include increased asset deterioration, decreased system capacity, increased load, and decreased system reliability. Since the internal temperature of electric power equipment is determined by the ambient temperature as well as the power being delivered, higher ambient temperatures increase the internal operating temperature of equipment.

Higher internal operating temperatures increase the rate of aging of the insulation of electric equipment such as transformers, resulting in decreased total life of the assets. Higher internal temperatures, resulting from higher average and maximum ambient temperatures, also reduce the delivery capacity of electric equipment such as transformers. In addition, higher ambient temperatures increase the operating temperature of overhead transmission lines, causing increased sagging. One remedy is to decrease the operational rating of the assets to reflect the new operating environment. However, derating the system due to increasing temperatures would effectively decrease the capacity of the system, and Con Edison will need to make investments to replace that capacity if it is needed.

Similarly, higher TV can cause higher peak loads due to increases in demand for cooling. Increases in load may also require investments in system capacity to meet the higher demand. The combination of decreased capacity and increased load is best addressed through Con Edison's existing 10- and 20-year load relief program. Addressing this combined risk is estimated to cost between $1.3 billion and $4.6 billion by 2050 (based on future projections using Representative Concentration Pathway (RCP) 4.5 10^{th} and RCP 8.5 90^{th} percentiles, respectively).

Increases in heat waves are expected to affect the electric network and non-network systems by decreasing reliability. Con Edison uses a Network Reliability Index (NRI) model to determine the reliability of the underground distribution networks. The Study's forward-looking NRI analysis found that with an increase in the frequency and duration of heat waves by mid-century, between 11 and 28 of the 65 underground networks may not be able to maintain Con Edison's standard of reliability by 2050, absent adaptation.

Outdoor worker safety may be a concern across all Con Edison commodities if heat index values rise as projected. When needed, Con Edison can implement safety protocols (e.g., shift modifications and hydration breaks) already practiced in mutual aid work that the company provided in hotter locations such as Florida and Puerto Rico. Similarly, to supply sufficient cooling in 2080, Con Edison's heating, ventilation, and air conditioning (HVAC) capacity will have to increase by 11% due to projected increases in dry bulb temperature. These systems have a roughly

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[2] "Worst-case" scenarios are meant to explore Con Edison system vulnerabilities related to rare extreme weather events and formulate commensurate adaptation and resilience strategies. Scenarios represent one plausible permutation of extreme weather and the severity of actual events may exceed those considered.

15-year life span and therefore can be upgraded during routine replacements with minimal cost increases.

Flooding from Precipitation, Sea Level Rise, and Coastal Storms

All underground assets are vulnerable to flooding damage (i.e., water pooling, intrusion, or inundation) from precipitation events, sea level rise, and coastal storms. Following Superstorm Sandy in 2012, Con Edison protected all infrastructure in the floodplain against future 100-year storms and 1 foot of sea level rise (e.g., submersible infrastructure, flood walls, pumps, elevation). Sea level rise projections suggest that Con Edison's 1 foot of sea level rise risk tolerance threshold may be exceeded as early as 2030 and as late as 2080.

Electric substations, overhead distribution, underground distribution, and the transmission system are sensitive to precipitation-based hazards, although the design of Con Edison's assets already mitigates some of these risks. For example, flooding from increased intense precipitation can damage non-submersible electrical equipment, although Con Edison designs all underground cables and splices to operate while submerged in water. In addition, all underground distribution equipment installed in flood zones and all new installations are submersible.

To assess future asset vulnerability to sea level rise and storm surge, the Study team analyzed the exposure of Con Edison's assets to 3 feet of sea level rise, while keeping the other elements of Con Edison's existing risk tolerance constant (i.e., a 100-year storm with 2 feet of freeboard). Of the 324 substations (encompassing generating stations, area substations, transmission stations, unit substations, and Public Utility Regulating Stations), 75 would be vulnerable to flooding during a 100-year storm if sea level rose 3 feet. In addition, 32 gas regulators and five steam generation stations would be exposed. Hardening all of these assets would cost approximately $680 million.

Both the gas and steam distribution systems are vulnerable to water entry, which can reduce system pressure and limit distribution capacity. In the gas system, low-pressure segments[3] are particularly vulnerable to this risk. In addition, the steam system is susceptible to "water hammer" events when a high volume of water collects around a manhole, causing steam in the pipes underneath to cool and condense. Interaction between steam and the built-up condensate may cause an explosion, both damaging the steam system and putting public safety at risk.

Across all commodities, increased winter precipitation can wash salt from city roads, causing an influx of salt-saturated runoff into manholes and percolation into the ground. Salt can cause equipment degradation, arcing, manhole fires or explosions, and failure of underground assets.

Extreme and Multi-Hazard Events

The Study team reviewed the vulnerabilities of Con Edison's electric, gas and steam systems to future extreme events based on specific, worst case extreme event narratives (Category 4 hurricane, a strong nor'easter, and a prolonged heat wave) designed to stress-test these systems.

Storm surge driven by an extreme hurricane event (i.e., a Category 4 hurricane) has the potential to flood both aboveground and belowground assets. In addition, wind stress and windblown debris can lead to tower and/or line failure of the overhead transmission system and damage overhead distribution infrastructure, which could cause widespread customer outages.

[3] The Con Edison gas system contains piping operating at three pressures: low, medium, and high.

An extreme nor'easter may cause significant damage to assets across all commodities. During nor'easters, accumulation of radial ice can cause tower or line failure of the overhead transmission system. Similarly, snow, ice, and wind can damage the overhead distribution system.

Con Edison's systems are vulnerable to exceeding system capacity during extreme temperatures; gas systems may experience overloading during extreme cold, and electric systems during extreme heat.

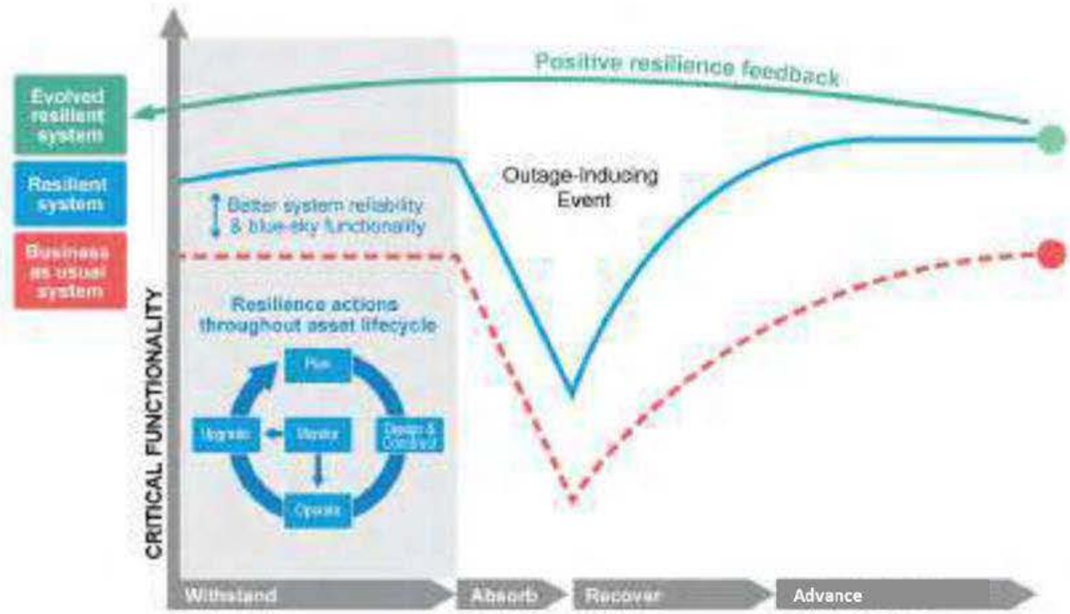
On an operational level, the increasing frequency and intensity of extreme weather events may exceed Con Edison's currently robust emergency preparedness efforts. Con Edison's current "full-scale" response, which calls for all Con Edison resources and extensive mutual assistance, is initiated when the number of customers out of service reaches approximately 100,000. However, low-probability extreme events can increase customer outages and outage durations by orders of magnitude, outpacing current levels of emergency planning and preparedness.

Resilience Management Framework

A resilience management framework will help Con Edison build resilience over time.

To conceptualize how to systematically address vulnerabilities, the Study team developed a resilience management framework (Figure 2). The framework encompasses investments to better withstand changes in climate, absorb impacts from outage-inducing events, recover quickly, and advance to a better state. The "withstand" component of this framework prepares for both gradual and extreme climate risks through resilience actions throughout the life cycle of the assets. As such, many adaptation strategies fall under this category. Investments to increase the capacity to withstand also provide critical co-benefits such as enhanced blue-sky functionality and reliability of Con Edison's systems. The resilience management framework facilitates long-term adaptation and creates positive resilience feedback so that Con Edison's systems achieve better functionality through time. To succeed, each component of a resilient system requires proactive planning and investments.

Figure 2 ■ Conceptual figure representing a resilience management framework designed to withstand changes in climate, absorb and recover from outage-inducing events, and advance to a better state. Most resilience actions should occur systematically throughout the asset life cycle to enhance the ability to withstand changes in climate, while also enhancing system reliability and blue-sky functionality. Resilient systems also adapt so that the functionality of the system improves through time (green line). Each component of a resilient system requires proactive planning and investments.



Adaptation Measures to Address Vulnerabilities

> Con Edison already has undertaken a range of measures to build resilience; this Study identified additional adaptation options to address vulnerabilities under a changing climate.

Con Edison has already undertaken a range of measures to increase the resilience of its systems. For example, lessons learned and vulnerabilities exposed during past events, including Superstorm Sandy (2012) and the back-to-back nor'easters (winter storms Riley and Quinn, 2018), resulted in significant capital investments to harden the system. Looking forward, as Con Edison is investing in the system of the future—one with greater monitoring capabilities, flexibility, and reliability—it is simultaneously building a system that is more resilient to extreme weather events and climate change. In addition to new investments, Con Edison also conducts targeted annual updates to its system to ensure capacity and reliability, which help the company keep pace with recent changes in temperature and humidity.

Withstand Gradual Changes in Climate and Extreme Events

Resilience actions should occur systematically throughout an asset's life cycle to enhance the ability to withstand changes in climate while also enhancing system reliability and blue-sky functionality. This can be accomplished through planning, designing, and upgrading assets in a resilient manner, with ongoing monitoring throughout.

Plan

Incorporating climate change projections into Con Edison's routine planning processes will help identify capital needs and help the systems gradually adjust to changes in climate. Some of the types of planning processes and tools that may benefit from consideration of climate change include the following:

- Load and volume forecasting for all commodities
- Load relief planning for the electric system, which should include reduced system capacity and higher load due to warmer temperatures
- Working with utilities in other environments to understand how they plan and design their system for the climate Con Edison will experience in the future
- Long-range planning for all commodities
- Network reliability modeling and planning

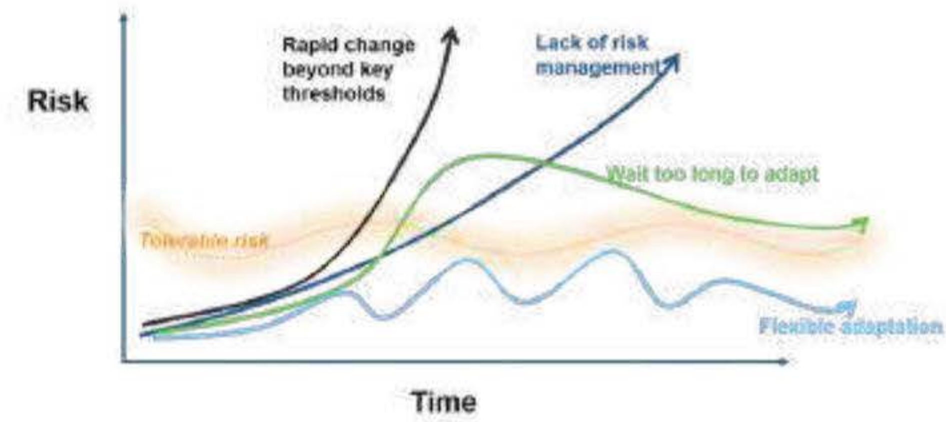
Design

The key to designing resilient infrastructure is to update design standards, specifications, and ratings to account for likely changes in climate over the life cycle of the infrastructure. While there is uncertainty as to the exact changes in climate an asset will experience, selecting an initial climate projection design pathway allows engineers to design infrastructure in line with Con Edison's risk tolerance. The Study team suggests an initial climate projection design pathway that follows the 50th percentile merged RCP 4.5 and 8.5 projections for sea level rise and high-end 90th percentile merged RCP 4.5 and 8.5 projections for heat and precipitation.

Upgrade

Changing design standards will influence the construction of new assets but does not address the vulnerability of existing assets. A flexible and adaptive approach to managing and upgrading assets will allow Con Edison to manage risks from climate change at acceptable levels, despite uncertainties about future conditions. The flexible adaptation pathways approach allows Con Edison to adjust adaptation strategies as more information about climate change and external conditions that may affect Con Edison's operations is learned over time. Figure 3 depicts how flexible adaptation pathways are based on flexible management to maintain tolerable levels of risk.

Figure 3 ■ Flexible adaptation pathways in the context of tolerable risk and risk management challenges to non-flexible adaptation. Adapted from Rosenzweig & Solecki, 2014.



As conditions change over time, Con Edison will need to consistently track these changes to identify when decision making for additional or alternative adaptation strategies is required. This approach relies on monitoring indicators, or "signposts," that provide information which is critical for adaptive management decisions. Broad categories of signposts that Con Edison should consider monitoring include climate variable observations and best available climate projections; climate impacts; and policy, societal, and economic conditions. Predetermined thresholds for these conditions signal the need for a change in action, which support decisions on when, where, and how Con Edison can take action to continue to manage its climate risks at an acceptable level. The body of this report provides many specific examples of proactive investments in resilience and their signposts; a few selected examples are provided in Table 1.

Table 1 ■ Examples of adaptation strategies to upgrade existing infrastructure and signposts to trigger action

Strategy	Signpost
Implement electric reliability strategies, such as: • Split the network into two smaller networks. • Create primary feeder loops within and between networks. • Install a distribution substation. • Incorporate distr buted energy resources and non-wires solutions. • Design complex networks that consider combinations of adaptation measures.	Forward-looking network reliability index exceeds 1 per unit
Upgrade HVAC systems.	End of the existing asset's useful life
Retrofit ventilated equipment with submersible equipment to eliminate the risk of damage from water intrusion.	Expanded area of precipitation-based flooding; better maps of areas at risk of current and future precipitation-based flooding
Replace limiting wire sections with higher rated wire to reduce overhead transmission line sag during extreme heat wave events. Alternatively, remove obstacles or raise towers to reduce line sag issues.	Increased incidence of line sag; higher operating temperatures
Strategically expand program to elevate gas regulator vent line termini to include additional regulators exposed to floodplains associated with stronger storms and inland flooding.	When sea level rise exceeds 1 foot; reported or observed flooding in vicinity of asset without vent line protectors

Absorb and Recover from the Impacts of Extreme Events

It is neither efficient nor cost-effective for Con Edison to harden its systems to withstand every type of extreme event. Instead, Con Edison must use a broader suite of adaptation strategies to absorb and recover from the inevitable disruptions caused by extreme events exceeding their design standards. Con Edison currently incorporates "absorb" into its design and operations with, for example, a limited ability to control customer demand and shed load in extreme cases. A broader suite of strategies focuses on emergency preparedness, limiting customer impact and improving customer coping, including the following:

- Supporting the creation of resilience hubs (spaces that support residents and coordinate resources before, during, and after extreme weather events (Baja, 2018) and have continued access to energy services)
- Using smart meters to implement targeted load shedding to limit the impact to fewer customers during extreme events
- Strengthening staff skills for streamlined emergency response
- Planning for resilient and efficient supply chains
- Coordinating extreme event preparedness plans with external stakeholders
- Incorporating low-probability events into long-term plans
- Expanding extreme heat worker safety protocols
- Examining and reporting on the levels of workers necessary to prepare for and recover from extreme climate events
- Investing in energy storage, on-site generation, and energy efficiency programs

Advance

Advancing to a better adapted, more resilient state after an outage-inducing event (i.e., building back better/stronger) begins with effective pre-planning for post-event reconstruction. Even with proactive resilience investments, events can reveal system or asset vulnerabilities. Where assets need to be replaced during recovery, having a plan already in place for selection and procurement of assets designed to be more resilient in the future can help to ensure that Con Edison is adapting to a continuously changing risk environment. Outage-inducing events also provide important opportunities to measure the performance of adaptation investments, helping to inform additional actions that further resilience.

Next Steps

> In 2020, Con Edison will develop an implementation plan that details priority actions needed in the next 5, 10, and 20 years.

As a next step from this Study, Con Edison will develop a detailed Climate Change Implementation Plan to integrate the recommendations from this Climate Change Vulnerability Study. The implementation plan will be developed in close coordination with Con Edison SMEs and will utilize quarterly meetings with external stakeholders. The implementation plan will consider updates in climate science, finalize an initial climate design pathway, integrate that pathway into company specifications and processes based on input from subject matter experts, develop a timeline for action with associated costs and signposts, and recommend a governance structure. Some key items for consideration in the implementation plan include determining the appropriate amount of proactive investment, changes in the policy/regulatory and operating environment and the establishment of a reporting structure.

Introduction

Study Background and Objectives

Con Edison's resilience to climate change has important implications for increasingly interconnected societal, technological, and financial systems that the company serves. Developing a shared understanding of Con Edison's vulnerability to climate change is critical to ensuring the continued strength of the company over the coming century. The Con Edison Climate Change Vulnerability Study (Study) has three primary goals:

1. Develop a shared understanding of new climate science and projected climate and extreme weather for the territory.
2. Assess the risks of potential climate change impacts on Con Edison's operations, planning, and physical assets.
3. Review a portfolio of operational, planning, and design measures, considering costs and benefits, to improve resilience to climate change.

The Study was conducted as an outcome of the 2013 rate case. In 2013, Con Edison worked with a Storm Hardening and Resiliency Collaborative in parallel with the rate case to provide parties with an opportunity to fully examine proposals for plans to protect against storms. In 2014, the New York State Public Service Commission approved an Order and funding for Con Edison to implement measures to plan for and protect its systems from the effects of climate change, including conducting a climate change vulnerability study. The Study was developed by the Con Edison Department of Strategic Planning, in collaboration with ICF's climate adaptation and resilience experts and Columbia University's Lamont-Doherty Earth Observatory. The members of this partnership are collectively referred to as the Study team. The Study team relied on inputs and expertise from Con Edison subject matter experts (SMEs), including engaging more than 100 SMEs through a series of in-person meetings, teleconferences, and workshops.

Guiding Principles

The Study used six key principles to efficiently meet its objectives and benefit Con Edison. The Study employed a decision-first and risk-based approach, applying the best available climate science to produce flexible and adaptive solutions and mitigate risks associated with climate change and extreme weather events. The Study process was transparent and interactive to ensure that it can be replicated and institutionalized.

Decision-first approach. The Study team used a decision-first approach, which focuses on understanding the broader vulnerabilities and constraints of the system, the objectives and needs of stakeholders, and the adaptation options available, before considering the projected changes in future climate. The Study team first identified the needs of decision makers (i.e., Con Edison leadership and SMEs) and worked from there to determine information requirements based on decision goals, instead of starting by amassing as much data as possible. This approach places a higher priority on understanding the decision-making context and providing enough information to inform those decisions, which helps to prioritize near- and long-term risks and develop effective solutions despite the existence of deep uncertainties related to future climate change.

Risk-based approach. The Study team employed a risk-based approach that considers both the likelihood and the consequence of potential changes in the climate. This involves identifying a comprehensive set of plausible future climate outcomes and assessing their probability and associated impact on Con Edison's service territory. Doing so allows Con Edison to assess its vulnerability to—and to prepare for—*high-probability and low-impact*, as well as *low-probability and high-impact*, outcomes.

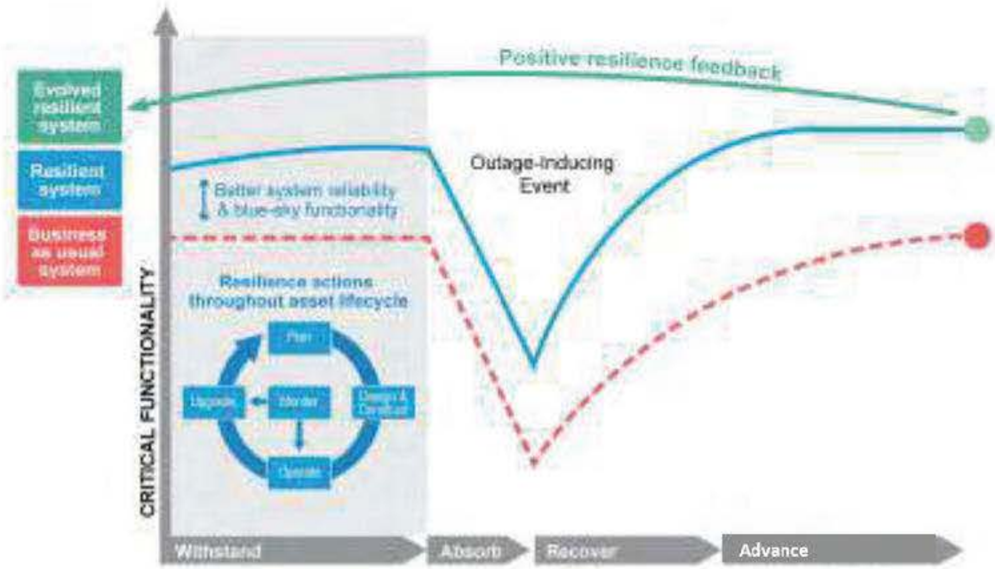
Best available climate science. The Study team prioritized continuous dialogues among climate scientists, climate adaptation specialists, and Con Edison SMEs to identify which climate scenarios, time periods, hazards, variables, and thresholds are important for Con Edison's operations, infrastructure, and planning. The Study team assessed multiple lines of evidence to capture historical climate conditions in the territory and employed a comprehensive set of Global Climate Models to identify the extent to which current climate conditions may change throughout the 21st century. Ultimately, the Study team synthesized climate information into metrics relating plausible effects of climatic changes on operations, infrastructure, and planning.

Transparent and replicable. A transparent and replicable approach allows Con Edison to institutionalize its adaptation strategy and increase its adaptive capacity over time. This will help SMEs establish their adaptation efforts into emerging policies and procedures, as well as train the next generation of SMEs in resilience building. Transparency also engenders trust with internal and external stakeholders.

Flexible solutions and adaptive implementation. A flexible and adaptive approach will allow Con Edison to manage risks from a changing climate at acceptable levels, despite uncertainties about future conditions. Adaptive implementation pathways, or flexible adaptation pathways, are a recognized approach to adaptation planning and project implementation that ensures adaptability over time in the face of uncertainty: changes in energy demand, technologies, population, and other driving factors, and refinements in the scientific understanding of future climate. Under the adaptive approach, resilience measures can be sequenced over time, allowing Con Edison to protect against near-term changes while leaving options open to protect against the wide range of plausible changes emerging later in the century.

Resilience management framework. The Study introduces a resilience management framework that allows Con Edison to mitigate risks associated with climate changes and extreme weather events most relevant to Con Edison's service territory (Figure 4). Resilient systems are composed of more than hardening measures alone, and instead consider measures that increase resilience throughout the life cycle of outage-inducing climate events. These measures include the system's capacity to "withstand," "absorb," and "recover" from climate risks and "advance" resilience. In this way, the resilient management framework is particularly important for addressing complex extreme events with significant uncertainties and extreme thresholds to build into hardening measures alone. In turn, resilient systems offer critical co-benefits, such as improved system reliability and blue-sky functionality, reduced consequences from non-climatic risks, and more resilient customers. A resilience management framework also facilitates long-term adaptation, which enhances the critical functionality of the system through time and creates positive resilience feedback. To succeed, each measure of a resilient system requires proactive planning and investments.

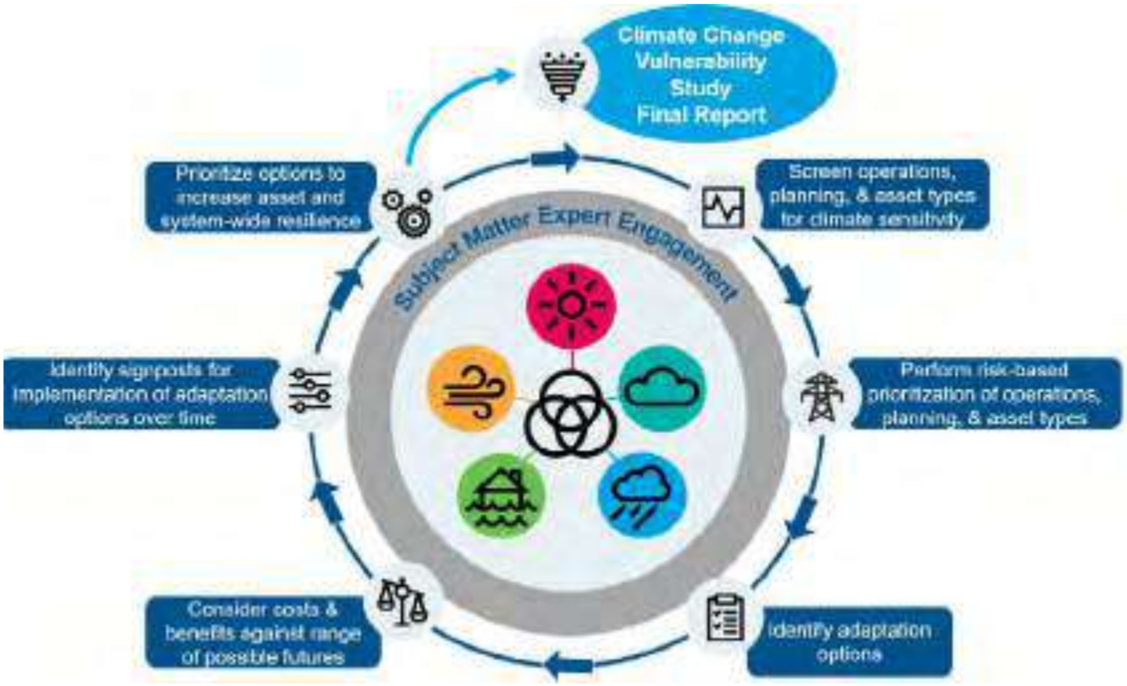
Figure 4 ■ **Conceptual figure representing a resilience management framework designed to withstand changes in climate, absorb and recover from outage-inducing events, and advance to a better state. Most resilience actions should occur systematically throughout the asset life cycle to enhance the ability to withstand changes in climate, while also enhancing system reliability and blue-sky functionality. Resilient systems also adapt so that the functionality of the system improves through time (green line). Each component of a resilient system requires proactive planning and investments.**



Study Methodology

The Study uses an integrated approach, with Con Edison SMEs providing support throughout the process. A rapid screen of the sensitivity of operations, planning, and assets (referred to for simplicity as "assets" throughout the rest of this document unless otherwise stated) for each climate change hazard provided the basis for a risk-based prioritization of assets. The Study team performed detailed analyses for the sensitive assets, including identifying a portfolio of adaptation options and qualitatively considering the financial costs, co-benefits, and resilience of each option. These detailed analyses will inform the development of flexible solutions and the further prioritization of assets and options to increase systemwide resilience during the creation of Con Edison's Climate Change Implementation Plan in 2020. Figure 5 depicts the Study's general approach.

Figure 5 ■ General approach overview: The process cycles through steps for each climate hazard, beginning with 'Screen operations, planning, and asset types for climate sensitivity'. The process results in the Climate Change Vulnerability Study Final Report.



Screen operations, planning, and asset types for climate sensitivity. The Study began by establishing and confirming a clear set of climate change hazards and relevant thresholds for operations, planning, and asset types. The study team engaged SMEs to identify the extent to which each climate change hazard is a factor in asset design or operation and rate sensitivities by considering impacts from previous weather events and key climate information used in design or operation. Only assets with high sensitivity were considered in the subsequent risk-based prioritization process.

Perform risk-based prioritization of operations, planning, and asset types. Following the high-level screen for sensitivity, the Study team sought to prioritize operations, planning processes, and asset types for further analysis.

- Heat and humidity: Heat and humidity design standards vary across Con Edison assets, so the Study team used a risk workbook to guide SMEs through a structured process to identify the *probability of impact* (based on the probability of exceeding thresholds and the impact of threshold exceedance) and the *consequence of impact*. Together, these components create an *overall risk score* for each relevant asset and climate change hazard combination. *Consequence* is defined as the likely impact to the overall system given the possibility for damage or failure of the particular asset, and includes reliability, safety, environmental damage, and financial costs to the company or customers. The Study team identified several asset types and variable combinations with high sensitivity and high overall climate risk to carry forward as priorities in the analysis.
- Sea level rise and storm surge: Sea level rise and storm surge is a geographically defined hazard with a common design standard across all Con Edison assets. As such, there was a need to

identify potentially exposed assets rather than prioritize among them. The Study team used Geographic Information System (GIS) modeling to evaluate the specific type and number of assets that would be exposed under various future scenarios.

- Precipitation: Very few of Con Edison's assets have design standards tied to precipitation. For the few that were identified, the Study team evaluated whether the assets would withstand future increases in the intensity of precipitation events. In addition, the Study team worked with Con Edison SMEs to identify and prioritize the operational impacts of precipitation on the various commodities.
- Extreme events: By definition, the extreme events analyzed in the study exceed all existing Con Edison design standards. As such, the Study team conducted a workshop with SMEs to prioritize extreme event risks based on the following:
  - The potential for impacts on operations, planning, and assets
  - How prior major weather events affected assets and operations
  - The preparations that Con Edison has in place for future extreme events
  - How longer or more intense events might overwhelm current preparedness efforts

Identify adaptation options. For the identified vulnerabilities, the Study team developed adaptation response options through SME engagement, review of relevant literature, and lessons learned from adaptation options implemented in regions with similar challenges. Adaptation options include strategies to withstand a changing climate, such as engineering design, operations, and planning strategies, as well as strategies to absorb and recover from extreme events. The Study team considered adaptation options that are often already in use to manage the hazard, but which may require revision or updating to deal with changing risk. The Study team also considered both short-term and long-term solutions and took steps to understand and assess the limitations of adaptation options.

Consider costs and benefits of adaptation options against a range of possible futures. The Study team worked with SMEs to develop order of magnitude costs of the various adaptation strategies, where feasible. Where possible, the Study team conducted a multi-criteria analysis of the adaptation options to compare criteria that may be difficult to quantify or monetize, or that may not be effectively highlighted in the financial analysis.

Identify signposts for implementation of adaptation options over time. Evaluation of adaptation measures in the context of a continuously changing risk environment poses a challenge to typical project planning, design, and execution. It is important to ensure that decision-making processes support flexible solutions that allow for effective risk management in the face of irreducible uncertainties in projections of future climate conditions. The Study uses an adaptive implementation pathway approach to achieve this goal. The Study team designed a framework for "signposts," which represent information that will be tracked over time to help Con Edison understand how climate, policy, and process conditions change and, in turn, trigger additional action.

Prioritize options to increase asset and systemwide resilience. Once the prior steps were completed, the Study team circulated the findings to SMEs to allow them to strike, add, or refine strategies. This process resulted in the prioritized set of strategies included in this report.

Historical and Future Climate

Con Edison in a Changing Climate

Earth's climate is not static; it changes in response to both natural and human-caused drivers. The past decade was the warmest on record, and global atmospheric warming has increased at a faster rate since the 1970s (GCRP, 2017), which the global climate science community attributes to increasing human-caused greenhouse gas emissions (IPCC, 2013).

A growing body of research reveals that a range of climate hazards will likely increase in frequency and intensity as a result of atmospheric warming (GCRP, 2017; IPCC, 2013). For example, a warmer atmosphere increases the frequency, intensity, and duration of heat waves; holds more water vapor for heavy precipitation events; and accelerates ice loss from Earth's large ice sheets, contributing to sea level rise and coastal storm surge. These climate changes highlight how changes in the global climate system affect local climatology and weather in Con Edison's service territory. Local changes include both long-term mean changes, such as gradual increases in temperature and sea level, and changes in extreme events, such as heat waves, hurricanes, and storm surge. In most cases, long-term climate change amplifies and increases the likelihood of extreme events. In turn, climate changes and baseline climate hazards cause both direct (e.g., physical damage to infrastructure) and indirect (e.g., changing customer behavior) impacts across the electric, gas, and steam systems of Con Edison's business.

Rapid climate change will bring new challenges to Con Edison through the 21st century. This Study develops climate projections to characterize these challenges. Still, conceptualizing climate change in tangible terms is notoriously difficult. Another way to describe potential climate change is through climate analogs, which match expected future climate change at a location to current climate conditions in another. Under this perspective, New York City's temperature and precipitation by 2080 could more closely resemble current conditions in southern cities such as Memphis, TN, and Little Rock, AR, if greenhouse gas emissions continue unabated (Fitzpatrick & Dunn, 2019).[4]

[4] Climate analogs are illustrative and vary depending on the choice of evaluation metrics, decade, and climate scenario. In this case, analogs are determined using metrics for seasonal minimum and maximum temperature and total precipitation.

Con Edison's Understanding and Assessment of Climate Change

The Study team developed improved, downscaled climate projections and used best available science to understand and evaluate climate change trends and potential extreme weather events across Con Edison's service territory over near- (2030), intermediate- (2050), and long-term (2080) time horizons.[5] This approach builds on methods used by the New York City Panel on Climate Change (NPCC) and introduces a range of benefits (see Table 2). The Study team focused on climate variables that could present outsized impacts to operations, planning, and infrastructure across the electric, gas, and steam segments of Con Edison's business. These include temperature, humidity, precipitation, sea level rise and coastal flooding, extreme events, and multiple—or compounding—events.

The primary tools for understanding future climate change are Global Climate Models (GCMs), which mathematically simulate important aspects of Earth's climate, such as changes in temperature and precipitation, natural modes of climate variability (e.g., El Niño and La Niña events), and the influence of human greenhouse gas emissions (GCRP, 2017). Over short timescales (i.e., years to decades), individual GCM projections can differ from one another due to unpredictable natural climate variability, differences in how models characterize small-scale climate processes, and their response to greenhouse gas emissions/concentration assumptions. For these reasons, future climate analyses often consider a large ensemble of GCMs to better discern long-term trends, account for uncertainty, and consider a fuller range of potential future climate outcomes. To this end, the Study team used a broad model ensemble (i.e., 32 GCMs) for each climate variable of interest to address the spread across models and provide a comprehensive view of future climate.

While GCMs use a finer spatial resolution than ever before, they still provide coarse-resolution estimates of future climate, with model grid cells typically extending approximately 100 kilometers on one side. To achieve a more accurate representation of local climate in the New York Metropolitan Region, the Study team bias-corrected and downscaled GCM projections (i.e., statistically adjusted simulations to bring them closer to observed data) using weather station data over a 1976–2005 historical reference period from three weather station locations spanning Con Edison's service territory, including Central Park, LaGuardia Airport, and White Plains Airport.[6]

GCM simulations are driven by a standard set of time-dependent greenhouse gas concentration trajectories called Representative Concentration Pathways (RCPs), developed by the Intergovernmental Panel on Climate Change (IPCC). RCPs consider different evolutions of fossil fuels, technologies, population growth, and other controlling factors on greenhouse gas emissions through the 21st century. To acknowledge uncertainty in future greenhouse gas concentrations, the Study team selected the commonly used RCPs 4.5 and 8.5 to drive each GCM, following precedent set by IPCC and NPCC. RCP 4.5 represents a moderately warmer future based on a peak in global greenhouse gas emissions around 2040. In contrast, RCP 8.5 represents a hotter future

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[5] Columbia University's Lamont-Doherty Earth Observatory led the analysis of temperature, humidity, and precipitation projections and extreme event information. ICF provided insights into future climate conditions using localized constructed analog (LOCA) projections, analyzed sea level rise projections, and synthesized extreme event narratives. Jupiter Intelligence provided projections of extreme temperatures and the urban heat island effect.
[6] Technical information regarding bias-correction and downscaling methods used in this Study are provided in the appendices for the relevant climate variables.

corresponding to "business as usual" increases in greenhouse gas concentrations through the century.

The Study team used a model-based probabilistic framework to evaluate climate change hazards and account for model uncertainty under different RCP scenarios. Specifically, the Study team analyzed high-end estimates (e.g., the 90th percentile of projections across climate models), and mid-point (50th percentile) and low-end (10th percentile) projections for both RCPs. In doing so, the Study Team considered the range of potential climate outcomes across models and RCPs to form a comprehensive risk-based approach. Under this framework, the RCP 8.5 90th percentile approximates a stress test to characterize low probability, high-impact climate change, and its impact on Con Edison.

This Study builds on the approach used by NPCC. Table 2 provides a high-level overview of climate information advances developed as part of this Study.

Table 2 ▪ Overview of climate projection methods in this Study relative to the NPCC2 (2015) climate projections of record for New York City

NPCC2 (Reference Projections)	Con Edison Study
Combined projections from two scenarios (RCPs 4.5 and 8.5)	Separate scenario projections
Four time periods (2020–2080)	Seven time periods (2020–2080) to align with planning processes
Single reference point (Central Park)	Multiple reference points tailored to the service territory (Central Park, White Plains, and LaGuardia)
Downscaling using the "delta method"	Downscaling using "quantile mapping"
Limited set of climate variables	Numerous Con Edison-specific variables and multi-variable projections (e.g., heat plus humidity)

The Study also evaluates Con Edison's vulnerability to rare and complex extreme events, such as major hurricanes and long-duration heat waves, that may increase in intensity and frequency as a result of climate change. Such events play an outsized role in shaping the public's perception of climate change vulnerability and how institutions should address its unique challenges. While the Study team uses model-based probabilistic projections to inform many climate variables, such as long-term mean temperatures and sea level, it is more challenging to project the rarest events, such as a 1-in-100-year heat wave, and multi-faceted and difficult to model events such as hurricanes. Obstacles to modeling rare and complex extreme events include the brevity of the historical record relative to the rarity of the event, and challenges associated with modeling extremes that have important features at very small space and time scales.

To address these challenges, the Study team constructed a series of extreme event narratives based on historical analogs and the best available climate science. In contrast with model-based probabilistic projections, narratives represent plausible future worst-case scenarios[7] meant to stress-test Con Edison's system. The narratives merge a decision-first and risk-based approach, blending best available science with decision maker-defined high impacts to develop a better understanding of Con Edison's vulnerability to rare, complex extreme events.

Overview of Climate Science Findings Relevant to Con Edison

The Study team's analysis characterized historical and future changes in temperature, humidity, precipitation, sea level rise, and extreme events within Con Edison's service territory. This information supports a risk-based understanding of potential climate-related vulnerabilities within the company's operations, planning, and physical assets. The sections below provide an overview of projected climate changes relevant to Con Edison. While projections were prepared for Central Park, LaGuardia, and White Plains as described above, this section commonly uses Central Park as a reference point due to its central location and because it currently serves as a reference point for many Con Edison operations. The report appendices contain detailed information on other locations and the full scope of climate projections and corresponding vulnerabilities developed for this Study.

Temperature

Both average and maximum air temperatures are projected to increase throughout the century relative to historical conditions (Figure 6). Climate model projections reveal significant increases in the number of days per year in which average temperatures exceed 86°F (up to 26 days per year, relative to a baseline of 2 days) and maximum temperatures exceed 95°F (up to 23 days per year from a baseline of 4 days; Figure 7) by 2050. At the same time, winter minimum temperatures are expected to fall below 50°F as many as 40 fewer times per year than in the past by mid-century, representing a 20% decrease.

The timing and magnitude of climate change over the coming century remains uncertain, particularly with respect to rare and multi-faceted extreme events. This uncertainty presents challenges for institutions such as Con Edison in understanding the potential effects of climate change and the associated risks to their business, operations, and financial performance.

Scenario analysis is a proven way to address these challenges. For example, Task Force on Climate-Related Financial Disclosures (TCFD) scenarios use forward-looking projections to provide a framework to help companies prepare for risks and opportunities brought about by climate change. The scenarios used in this Study are similarly hypothetical constructs, but differ from TCFD scenarios in that they provide quantitative details regarding future extreme event conditions (e.g., regarding specific storm characteristics) so that Con Edison can better plan for specific impacts to assets and infrastructure. Ultimately, this Study uses both climate science and stakeholder-driven perspectives to develop plausible, high impact worst-case scenarios designed to stress-test Con Edison's system.

[7] Worst-case scenarios are meant to explore Con Edison system vulnerabilities related to rare extreme weather events and formulate commensurate adaptation and resilience strategies. Scenarios represent one plausible permutation of extreme weather and the severity of actual events may exceed those considered.

Figure 6 ■ Historic (black line) and projected (colored bands) average air temperature in Central Park during the summer under two greenhouse gas concentration scenarios (RCPs 4.5 and 8.5)

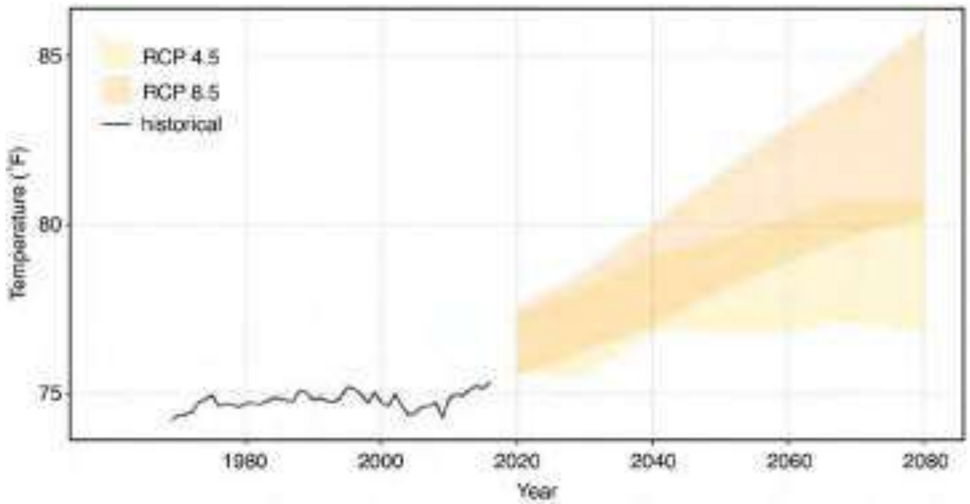
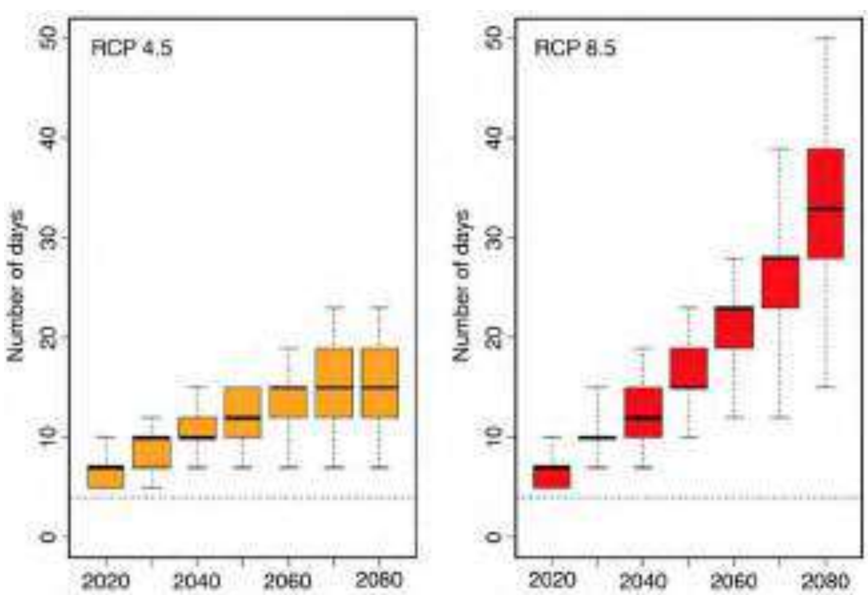


Figure 7 ■ The average number of days per year with maximum summer air temperatures exceeding 95°F in Central Park under two greenhouse gas concentration scenarios (RCPs 4.5 and 8.5). The dashed horizontal lines show the historical average number of days. Box plots correspond to the 10th, 25th, 50th, 75th, and 90th percentile projections.

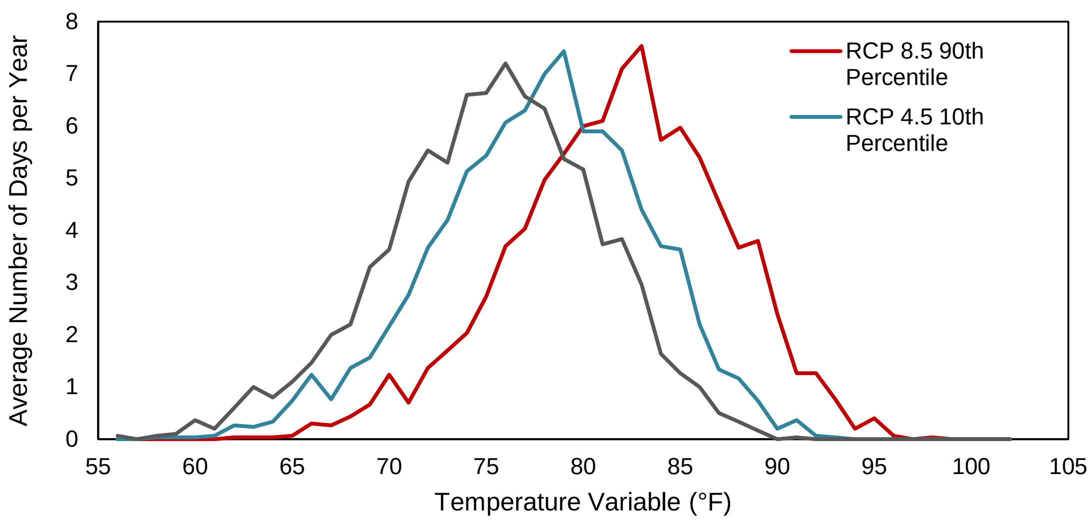


Multi-day heat events, known as heat waves, create potential risks for Con Edison as they drive demand for air conditioning and stress electrical and infrastructure systems. The number of heat waves, defined here as 3 or more consecutive days when *average* temperatures exceed 86°F in Central Park, is projected to increase up to 5 and 14 events per year by 2050 and 2080, respectively, relative to 0.2 events per year historically. The magnitudes of temperature increases are projected to be greatest at LaGuardia and Central Park and smaller at White Plains.

Humidity

The New York Metropolitan Region is susceptible to significant combinations of heat and humidity, which cannot be captured by temperature alone. The combination of temperature and humidity drives electric demand within Con Edison's service territory. To address this, the company currently evaluates the potential for high loads using an index referred to by Con Edison as temperature variable (TV),[8] which incorporates considerations of both temperature and humidity. Looking forward, TV thresholds that have historically occurred only once per year (e.g., 86°F), are projected to become common occurrences within a generation, occurring between 4 and 19 times per year by 2050 and 5 and 52 times per year by 2080, under the RCP 4.5 10th percentile and RCP 8.5 90th percentile, respectively, at LaGuardia (Figure 8). Smaller increases are expected at White Plains.

Figure 8 ■ Distributions showing historical (black line) and 2050 projected (blue and red lines) summer (June–August) daily electric TV at LaGuardia Airport. The 2050 projections show both the RCP 8.5 90th percentile and the RCP 4.5 10th percentile distributions.



The heat index is a typical indicator of "how hot it feels," which considers the combined effect of air temperature and relative humidity. The index assesses health risks associated with overheating, including for Con Edison employees working under hot conditions. Looking forward, the frequency of occurrence for very high heat index thresholds is projected to increase dramatically through the century. Projections reveal that the number of days per year when the heat index equals or exceeds 103°F at LaGuardia could increase to between 7 and 26 days by 2050 under the RCP 4.5 10th percentile and the RCP 8.5 90th percentile, respectively, compared to only 2 days historically.

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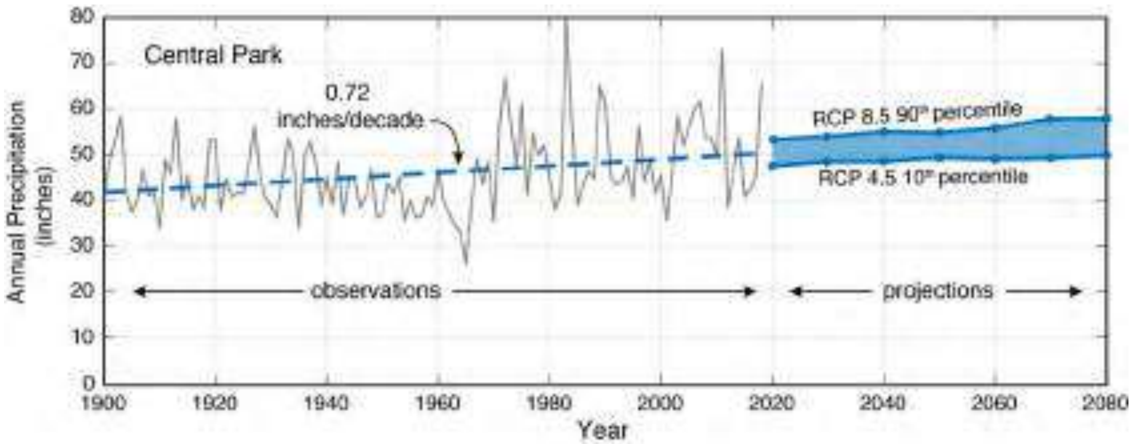
[8] Temperature variable is calculated using the weighted time integration of the highest daily recorded 3-hour temperature and humidity over a 3-day period. The reference TV for Con Edison is 86°F, which approximates a heat index of 105°F.

Precipitation

Con Edison's service territory experiences a range of precipitation events over a range of timescales, including rainfall, downpours, snowfall, and ice. Climate change is projected to drive heavier precipitation across these event types because a warmer atmosphere holds more water vapor and provides more energy for strong storms. Looking forward, average annual precipitation is projected to increase by 0% to 15% relative to the historical baseline in Central Park through 2050 (Figure 9).

Figure 9 ■ Observed and projected annual precipitation at Central Park. Projections show potential annual precipitation under both the RCP 8.5 90th percentile and the RCP 4.5 10th percentile. Projections represent 30-year time averages (shown as blue circles), which reveal the long-term trend, but underrepresent year-to-year variability. The dashed line represents the linear trend though the observational record, with observed increases given in inches per decade.



Projections of heavy rainfall reveal similar increases. For example, the heaviest 5-day precipitation amount could be 11.8 inches at Central Park by 2050, which represents a 17% increase over the historical reference period. Data from the Northeast Regional Climate Center[9] show that 25-year, 24-hour precipitation amounts at Central Park, LaGuardia, and White Plains could increase by 7% to 14% and 10% to 21% by mid- and late-century, respectively. Ultimately, projections point to a future defined by more frequent heavy precipitation and downpours, likely accompanied by smaller increases in the frequency of dry or light precipitation days (GCRP, 2017).

Projections for changes in snow and ice are more uncertain than those for rainfall. Overall, models project a decrease in snowstorm frequency corresponding to a warming climate (Zarzycki, 2018). However, while the likelihood of a given storm producing snow instead of rain will decrease in the future, if atmospheric conditions are cold enough to support frozen precipitation, then storms are expected to produce more snow (or ice) than during the present day (Zarzycki, 2018).

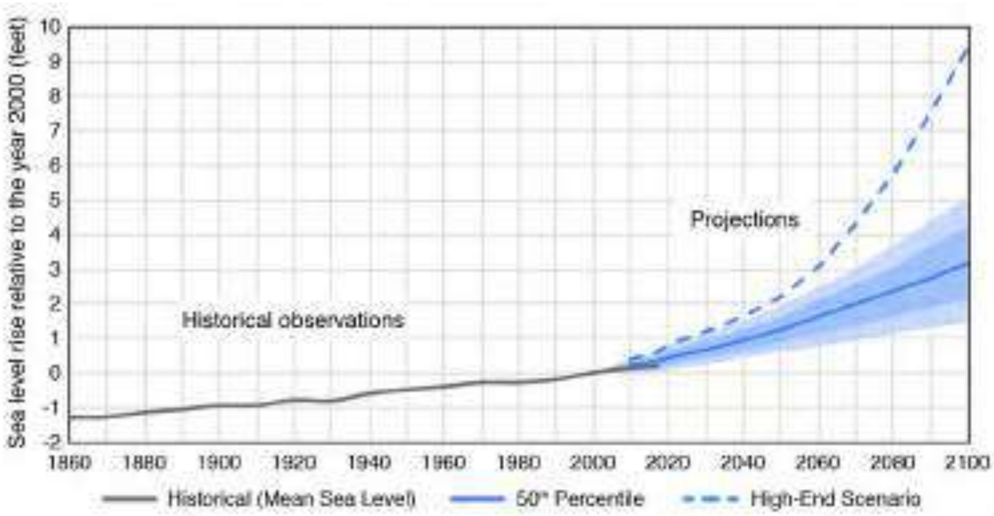
Sea Level Rise

A range of underlying factors, including thermal expansion of the ocean, the rate of ice loss from glaciers and ice sheets, atmosphere and ocean dynamics, and vertical coastline adjustments determine local sea level rise within Con Edison's service territory. State-of-the-art probabilistic

[9] http://ny-idf-projections.nrcc.cornell.edu/

projections (Kopp et al., 2014; 2017) determined these contributions and characterized the rate of future sea level rise in the region under both RCPs 4.5 and 8.5 (e.g., Figure 10). These sea level rise projections include a unique high-end scenario driven by rapid West Antarctic ice sheet mass loss in the later 21st century (DeConto & Pollard, 2016; Kopp et al., 2017). Con Edison has always implemented anti-flooding measures. Following Superstorm Sandy in 2012, the company implemented a minimum protection design standard of "FEMA plus three feet,"[10] allowing for 1 foot of sea level rise. In turn, forward-looking projections determine when sea level rise may exceed Con Edison's established risk tolerance of 1 foot of sea level rise.

Figure 10 ■ Historical and projected sea level rise in New York City under RCP 8.5 relative to the year 2000. The grey line shows historical mean sea level at the Battery tide gage. Projections are relative to the 2000 baseline year. The solid blue line shows the 50th percentile of projected sea level rise. The darker shaded area shows the likely range (17th–83rd percentiles), while the lighter shaded area shows the very likely range (5th–95th percentiles). The blue dashed line depicts a high-end projection scenario driven by rapid West Antarctic ice sheet mass loss in the later 21st century (DeConto & Pollard, 2016; Kopp et al., 2017).



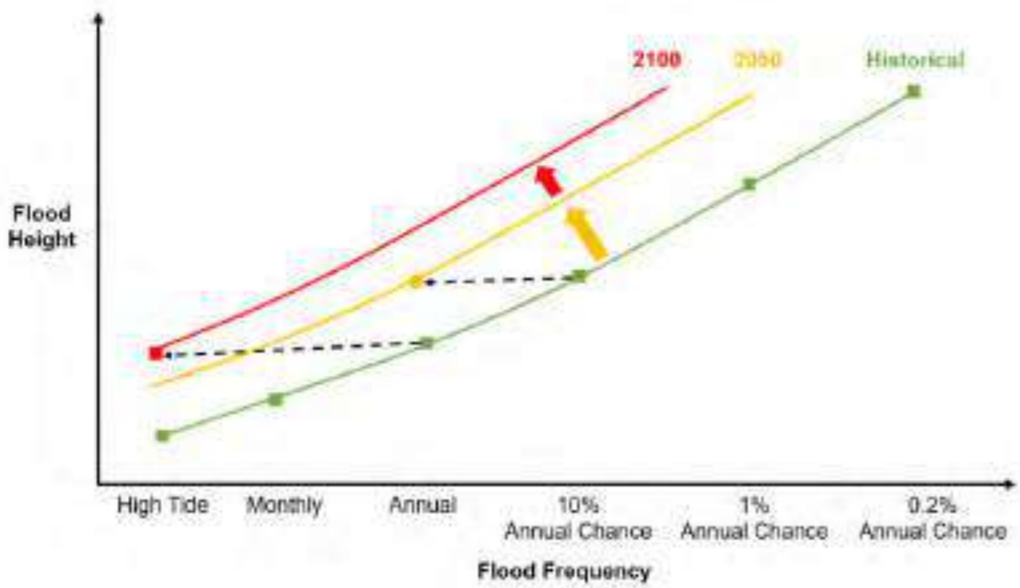
Sea level rise will very likely be between 0.62 and 1.74 feet and 0.62 and 1.94 feet at the Battery tide gauge in lower Manhattan by 2050 under RCPs 4.5 and 8.5, respectively. Projections suggest that Con Edison's 1-foot sea level rise risk tolerance threshold may be exceeded as early as 2030 and as late as 2080.

In turn, rising sea levels will have profound effects on coastal flooding, as sea level rise is expected to increase both the frequency and height of future floods (Figure 11). For example, the flood height associated with the 1% annual chance (100-year) flood in New York City is projected to increase from 10.9 feet to as much as 15.9 feet under RCP 8.5 by 2100, representing an increase of close to 50%.[11] Similarly, today's 0.2% annual chance (500-year) flood could look like a 10% annual

[10] This includes the FEMA 1% annual flood hazard elevation, 1 foot of sea level rise and 2 feet of freeboard (to align with 2019 Climate Resiliency Design Guidelines published by the New York City Mayor's Office of Recovery and Resiliency).
[11] Flood values are above the mean lower low water (MLLW) datum at the Battery tide gauge. MLLW is measured as 2.57 feet below mean sea level at the Battery.

chance (10-year) flood in 2100, making it 50 times more likely. At the end of the century, today's annual chance flood could occur at every high tide.

Figure 11 ■ Projected changes in the frequencies of historical flood heights as a result of sea level rise. Dashed lines represent projected changes in frequency; solid lines represent illustrative changes in flood frequency coinciding with flood heights



Extreme Events

Rare extreme events, such as strong hurricanes and long-duration heat waves, are low-probability and high-impact phenomena that pose outsized risks to infrastructure and services across Con Edison's service territory. While modeling rare extreme events remains challenging and at the forefront of scientific research, a growing body of evidence suggests that many types of extreme events will likely increase in frequency and intensity as a result of long-term climate warming.

To address these challenges, the Study team used feedback from Con Edison SMEs to prioritize a suite of extreme event narratives that combine plausible worst-case events from both climatological and impact perspectives. In turn, the narratives represent future worst-case scenarios designed to stress-test Con Edison and the local and regional systems with which it connects. The chosen narratives considered a prolonged heat wave, a Category 4 hurricane, and an unprecedented nor'easter striking the region.

Best available climate science reveals that climate change will likely amplify these extremes over the coming century. For example, the mean heat wave duration in New York City is expected to increase to 13 and 27 days by 2050 and 2080, respectively, based on RCP 8.5 90th percentile projections (NPCC, 2019). At the same time, broadscale atmospheric and ocean surface temperature changes may drive stronger hurricanes and extratropical cyclones. Looking forward, while the total number of hurricanes occurring in the North Atlantic may not change significantly over the next century, the percentage of very strong and destructive (i.e., Categories 4 and 5) hurricanes is projected to increase in the North Atlantic basin (IPCC, 2013). It can therefore be argued that climate change could make it more likely for one of these storms to impact the New York Metropolitan Region, although the most dominant factor will remain unpredictable climate and weather variability (Horton & Liu, 2014). Finally, some recent studies project a 20% to 40% increase in nor'easter strengthening (i.e., producing the types of storms with destructive winds) immediately inland of the Atlantic coast by late-century, suggesting stronger storms may more frequently impact the New York Metropolitan Region with heavy precipitation, wind, and storm surge (Colle et al., 2013)

Signposts: Monitoring and Climate Science Updates

Understanding Con Edison's vulnerabilities to climate change and adapting to those changes over time require a robust monitoring strategy. Climate change evolves through time, meaning that the current spread of potential future climate outcomes produced by models will eventually converge on a smaller set of climate realizations. To keep up with this evolution, a range of signposts are required to sufficiently gauge relevant rates of change and best prepare Con Edison for the most likely climate future.

An awareness of past and present climate conditions in Con Edison's service territory is critical for understanding the trajectory of climate change. Con Edison currently operates a number of stations that monitor climate variables and is finalizing plans to expand the number of monitoring locations. Increasing observations from monitoring stations will help measure both local climate variations and climate change through time, informing Con Edison's climate resilience planning. Citywide observations of variables, such as hourly temperatures, precipitation, humidity, wind speed, and sea level, are paramount to building a broad and usable set of guiding measurements. With accurate and up-to-date data on these variables, Con Edison can better monitor both changing conditions and potential points of vulnerability.

Con Edison can supplement monitoring through a regularly updated understanding of the best available projections as models and expert knowledge evolve over time. Climate projections continually improve as the scientific community better understands the physical, chemical, and biological processes governing Earth's climate and incorporates them into predictive models. Ultimately, Con Edison wants to draw on the best available data and projections that are driven by scientific consensus, but also are accessible and applicable to company needs. Signposts for updating climate science used to inform potential Con Edison vulnerabilities include major science advancements, such as the release of the new Coupled Model Intercomparison Project (CMIP) projections and their integration and validation in new IPCC, NPCC, and National Climate Assessment (NCA) reports. These assessments include updated probabilistic climate projections representing model advancements, the best available science regarding difficult-to-model extreme events, and literature reviews reflecting the current state of science as guided by leading experts. Such signposts could justify Con Edison updating their climate projections of record to reflect the best available science or projections that represent a significant departure from previous understanding. Historically, major scientific reports, such as the IPCC, have been released about every 6 to 7 years, which provide a potential constraint on how frequently Con Edison's understanding of climate change within the service territory might be revisited.

Existing Efforts and Practices to Manage Risks Under a Changing Climate

Although this Study is Con Edison's first comprehensive assessment of climate change vulnerabilities, Con Edison has already undertaken a range of measures to increase the resiliency of its system. Lessons learned and vulnerabilities exposed during past events, most recently Superstorm Sandy (2012) and the back-to-back nor'easters (winter storms Riley and Quinn, 2018), resulted in significant capital investments to harden the system.

In addition, as Con Edison invests in the system of the future—one with greater monitoring capabilities, flexibility, and reliability—it is simultaneously building a system that is more resilient to extreme weather events and climate change. For example, grid modernization will both increase efficiency and enhance monitoring capabilities by employing new technology and modes of data acquisition. Con Edison is planning to support numerous grid modernization initiatives that target energy storage technologies, communications systems, distributed energy resources infrastructure and management, complex data processing, and advanced grid-edge sensors (Con Edison, 2019). Con Edison additionally plans to modernize its Control Center to assume more proactive and centralized management of its complex distribution grid. Throughout these modernization initiatives, the company remains in close collaboration with the City of New York.

Con Edison also conducts targeted annual updates to its system to ensure capacity and reliability. These annual updates help the company keep pace in real time with changes in some key hazards. For example, when conducting electric load relief planning, Con Edison incorporates load forecasts that use an annually updated set of TV data. Although these forecasts are not grounded in future projections that consider climate change, they do account for the most recent climate trends and, as such, allow the company to stay in stride with the most current data.

Con Edison's previous adaptation measures have made targeted improvements in (1) physical infrastructure, (2) data collection and monitoring, and (3) emergency preparedness. The following measures are illustrative of these targeted improvements, but are not meant to be exhaustive of the efforts that Con Edison has undertaken:

Physical Infrastructure

- Adopting the Dutch approach of "defense in depth" after Superstorm Sandy to protect all critical and vulnerable system components from coastal flooding risks, including the following:

- Upgrading and increasing the number of flood barriers and other protective structures
- Reinforcing tunnels
- Replacing equipment with submersible equivalents in flood zones (e.g., targeted main replacement program, gas system)
- Installing pumps and elevating infrastructure behind flood walls

- Protecting or elevating critical electrical infrastructure to the Federal Emergency Management Agency (FEMA) 100-year flood elevation plus 3 feet to account for sea level rise and freeboard during coastal storms
- Undertaking a targeted main replacement program that addresses low-pressure gas mains in low-lying areas, as well as other potentially vulnerable gas mains
- Installing isolation devices to limit the impact of damaged infrastructure on customers by de-energizing more granular sections of the system, when necessary
- Engaging innovative technologies to reduce the impact of extreme weather on electric distribution systems and quicken the recovery, including the following:
  - Demand response technologies that more efficiently regulate load
  - Automated splicing systems that reduce feeder processing times

Data Collection and Monitoring

- Developing programs that employ machine learning and remote monitoring to identify areas of heightened vulnerability in Con Edison's systems, including the following:
  - Leak-prone areas of the gas distribution system
  - Gas system drip pots that require draining
- Initiating a more diligent inspection system that effectively assesses the functionality of assets, as well as their exposure to potential hazards (e.g., nearby vegetation), including the following:
  - Underground network transformers and protectors
  - Underground structures
  - Flushing of flood zone vaults
  - Rapid assessments of overhead feeders
  - Overhead system pole-by-pole inspection for specification compliance
- Future deployment of advanced metering infrastructure (AMI) throughout the service territory has the potential to both improve information flow to customers and help absorb the impacts of extreme events. Specifically, AMI might be able to rapidly shed load on a targeted network to help ensure demand does not exceed supply, which reduces potential damages and likelihood of network-wide outages in the event of an extreme event.

Emergency Preparedness

- Improving contractor and material bases for post-storm repair crews and equipment, including the following:
  - Expanding and diversifying spare material inventories
  - Ensuring that all spare materials are housed in safe locations
- Conducting post-event debriefings to understand the impact of weather conditions on system performance
- Engaging with major telecommunications providers and enhancing communications systems among customer networks
- Facilitating equipment-sharing programs across New York State to ensure access to supplies during emergency response

Con Edison recognizes that the drivers behind future planning operations are inherently uncertain and is committed to both closely monitoring key signposts and continuously updating company investment plans and priorities.

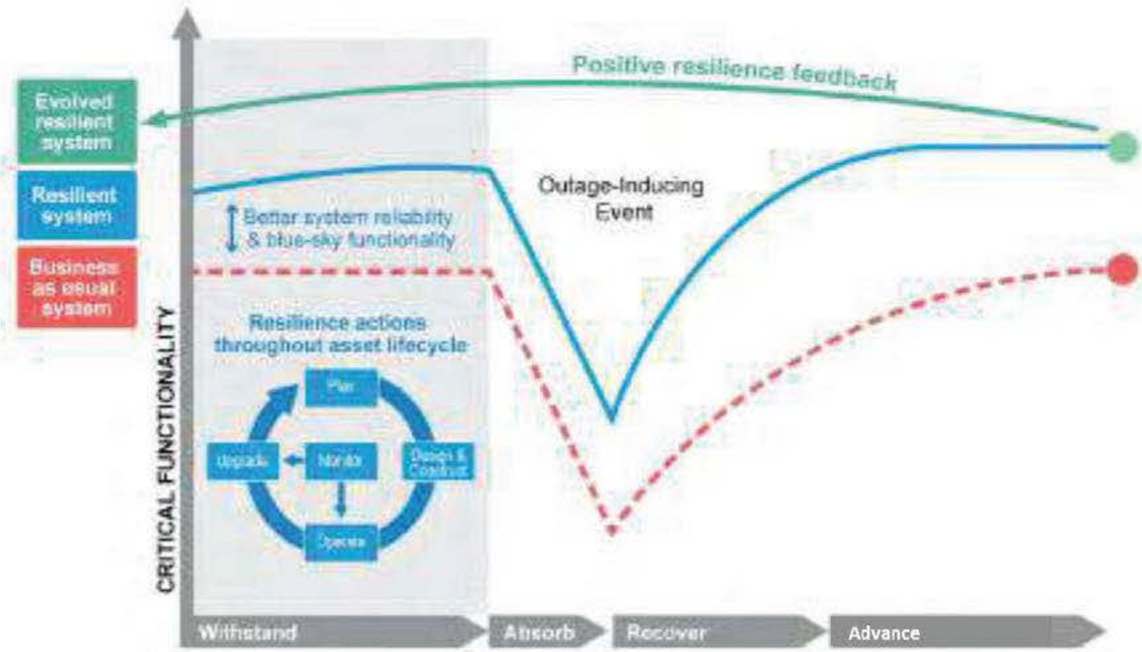
Vulnerabilities, a Resilience Management Framework, and Adaptation Options

Con Edison may face greater vulnerabilities due to future changes in temperature, humidity, precipitation, sea level rise, and extreme weather events. To understand this, the Study team evaluated key vulnerabilities of Con Edison's present-day electric, gas, and steam systems under a changing climate. The physical assets, operations, and planning of each system are uniquely vulnerable. In turn, building a detailed understanding of key vulnerabilities is an important step toward identifying priority adaptation measures.

Resilience Management Framework

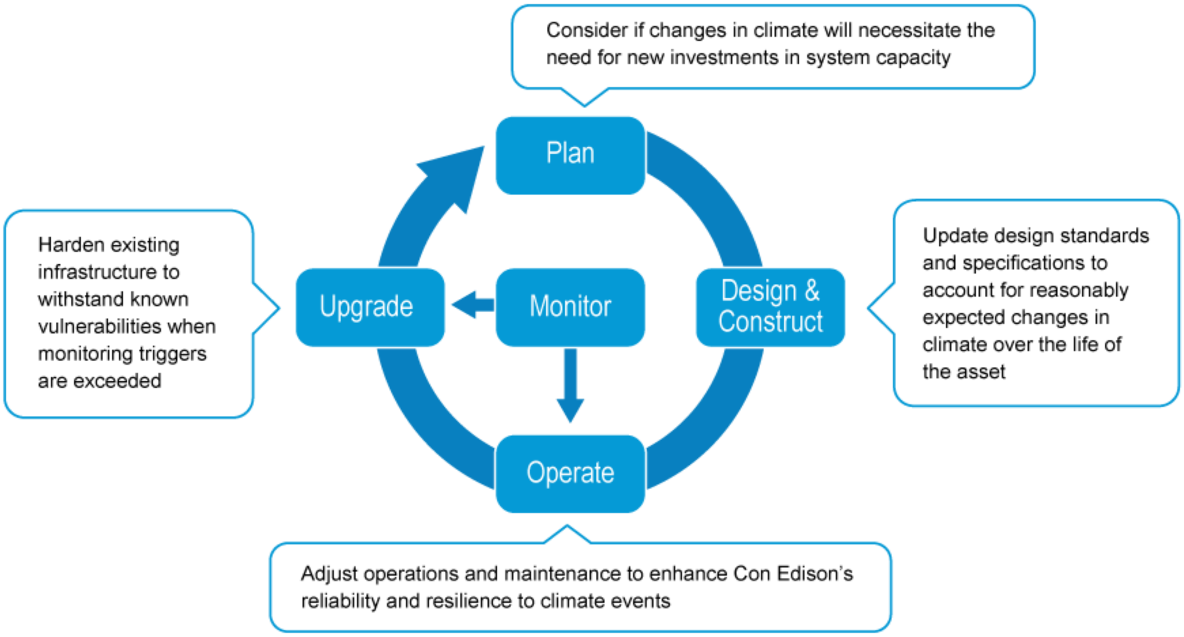
Under a changing climate, Con Edison will likely experience the increasing frequency and intensity of both gradual climate changes and extreme events. In response, the Study team developed a resilience management framework (Figure 12) to outline how a comprehensive set of adaptation strategies would mitigate future climate risks. The framework encompasses investments to better withstand changes in climate, absorb impacts from outage-inducing events, recover quickly, and advance to a better state. The "withstand" component of this framework prepares for both gradual (chronic) and extreme climate risks through resilience actions throughout the life cycle of assets. As such, many of the adaptation strategies identified in the following sections fall under the category of systematically bolstering Con Edison's ability to withstand future climate risks. Investments to increase the capacity to withstand also provide critical co-benefits, such as enhanced blue-sky functionality and the reliability of Con Edison's system. The resilience management framework facilitates long-term adaptation and creates positive resilience feedback so that Con Edison's system achieves better functionality through time. To succeed, each component of a resilient system requires proactive planning and investments.

Figure 12 ▪ Conceptual figure representing a resilience management framework designed to withstand changes in climate, absorb and recover from outage-inducing events, and advance to a better state. Investing in a more resilient system (blue line) provides benefits relative to a less resilient, or business-as-usual, system (red dashed line) before, during, and after an outage-inducing event. Most resilience actions should occur systematically throughout the asset life cycle to enhance the ability to withstand changes in climate, while also enhancing system reliability and blue-sky functionality. Resilient systems also adapt so that the functionality of the system improves through time (green line). Each component of a resilient system requires proactive planning and investments.



"Withstand" entails proactively strengthening the system to mitigate and avoid climate change risks and increase the reliability of Con Edison's system. "Withstand" investments are not necessarily a one-time event. Rather, the ability to withstand climate change must be integrated and revisited throughout the life cycle of Con Edison's assets. Doing so requires changes in the planning, design, and construction of new infrastructure; ongoing data collection and monitoring; and eventually investing in the upgrade of existing infrastructure, using forward-looking climate information. This life cycle approach to considering climate change is captured in Figure 13. Across Con Edison's electric, gas, and steam systems, planning for new investments in system capacity serves as a critical and strategic opportunity to integrate climate considerations. In addition, an important aspect of increasing the capacity of new investments to withstand changes in climate is maintaining strong design standards that account for gradual changes in chronic stressors and more frequent extreme events. However, since design standards do not apply to existing infrastructure, a strong monitoring program and signposts for additional adaptation investments could help ensure that Con Edison's existing infrastructure remains resilient to climate change by informing adjustments to operations and potential needs for upgrades.

Figure 13 ■ "Withstand" actions and investments must be revisited throughout the life cycle of Con Edison's assets.



"Absorb" includes strategies to reduce the consequences of outage-inducing events, since Con Edison cannot and should not harden its energy systems to try to withstand every possible future low-probability, high-impact extreme weather event. These actions, many of which Con Edison is already implementing, include operational changes to reduce damage during outage-inducing events and to protect exposed systems from further damage.

"Recover" aims to increase the rate of recovery and increase customers' ability to cope with impacts after an outage-inducing event. Such strategies build on Con Edison's Emergency Response Plans and Coastal Storm Plans. In addition, there is a role that Con Edison can play to increase customer coping and prioritize the continued functioning of critical services. Resilient customers are those who are prepared for outages and are better able to cope with reduced energy service—through measures such as having on-site energy storage, access to locations in their community with power, the ability to shelter in place without power, and/or prioritized service restoration for vulnerable customers.

"Advance" refers to building back stronger after climate-related outages and updating standards and procedures based on lessons learned. Even with proactive resilience investments, outage-inducing climate events can reveal system or asset vulnerabilities. Adjusting Con Edison's planning, infrastructure, and operations to new and future risks after an outage-inducing event, while incorporating learning, will allow for a more effective and efficient transition to greater resiliency. Con Edison has taken this approach in the past, including investing a billion dollars in storm hardening measures after Superstorm Sandy. Moving forward, restoring service following an outage-inducing climate event to a better adapted, more resilient state begins with effective pre-planning for post-event reconstruction. Where assets need to be replaced during recovery, having a plan already in place for selection and procurement of assets designed to be more resilient in the future can help to ensure that Con Edison is adapting to future extremes in a continuously changing risk environment.

Implementation of adaptation strategies throughout all of these phases will need to be adjusted over time to manage for acceptable levels of risk despite uncertainties about future conditions. The flexible adaptation pathways approach, described in further detail in the subsequent section, ensures the adaptability of adaptation strategies over time as more information about climate change and external conditions becomes available.

All Commodities (Electricity, Gas, and Steam)

Vulnerabilities

The Study team identified priority hazards for each of Con Edison's commodity systems (electric, gas, and steam) and found that several hazards were priorities across all three systems, although these hazards present unique vulnerabilities to the various assets within each system. The hazards common to all three systems are heat index, precipitation, sea level rise and storm surge, and extreme and multi-hazard events. These are discussed below. System-specific vulnerabilities are subsequently discussed in separate sections.

Heat Index

Worker safety may be a point of vulnerability if heat index values rise as projected. The Occupational Safety and Health Administration has set a threshold of 103°F for high heat index risk for people working under hot conditions. During the base period (1998–2017), there were 2 days per year with maximum heat greater than or equal to 103°F (but below 115°F). Under a lower emissions climate scenario (RCP 4.5 10^{th} percentile), the 103°F threshold may be met 5 to 7 days per year by 2050; under a higher emissions scenario (RCP 8.5 90^{th} percentile), this may occur 14 to 20 days per year by 2050. This poses a potential health threat to all Con Edison workers whose duties require outdoor labor.

Projected increases in heat index may also affect cooling equipment across Con Edison's systems, including the HVAC units for Con Edison buildings, air cooling towers for the electric system, and a water cooling tower for Con Edison's East River Steam Generating Plant. In order to supply sufficient cooling to its systems in 2080, Con Edison's HVAC systems will have to increase their capacity by 11% due to projected increases in dry bulb temperature. These systems have a roughly 15-year life span and therefore can be upgraded during routine replacements at an incremental cost of $1.3 million for 157 units. Similarly, Con Edison's cooling towers will have to increase their capacity by 30% by 2050. Cooling towers have a 20- to 35-year life span, allowing them to be upgraded during routine replacements at an incremental cost of $1.1 million for 19 cooling towers at 13 sites.

Precipitation

The Study team conducted an analysis of the physical and operational vulnerabilities of Con Edison's steam system, gas system, and transmission and substation components of the electric system. Findings indicated that all underground assets are vulnerable to flooding damage (i.e., water pooling, intrusion, or inundation) from heavy precipitation occurring over a short period of time. Specific vulnerabilities and their relevant thresholds vary significantly by commodity and, as such, are outlined in their respective sections.

Sea Level Rise and Storm Surge

The Study team broke down evaluation of priority vulnerabilities related to sea level rise into two components.

The first component focuses on design standards for new infrastructure. The Study team assessed Con Edison's coastal flood protection standards for robustness to projected sea level rise. Con Edison's current design standard for coastal flood protections includes the FEMA 1% annual flood hazard elevation, 1 foot for sea level rise, and 2 feet of freeboard, which aligns with New York City's Climate Resilience Design Guidelines for critical infrastructure and water elevations that Con Edison experienced during Superstorm Sandy. Under high-end sea level rise (e.g., due to either rapid ice loss from the West Antarctic Ice Sheet corresponding to Kopp et al., 2017, or RCP 8.5 95th percentile projections corresponding to Kopp et al., 2014), the existing 1 foot sea level rise risk tolerance threshold could be exceeded by 2030; however, under more likely scenarios, the current threshold could be exceeded between 2040 and 2080.[12] The probability that sea level rise will exceed the 1-foot sea level rise risk tolerance by 2020 is under 10%; that increases to 65% to 70% by 2050, and to 100% by the 2080s.

The second evaluation component identified specific physical vulnerabilities of Con Edison's existing assets to impacts related to sea level rise, which are described by commodity below.

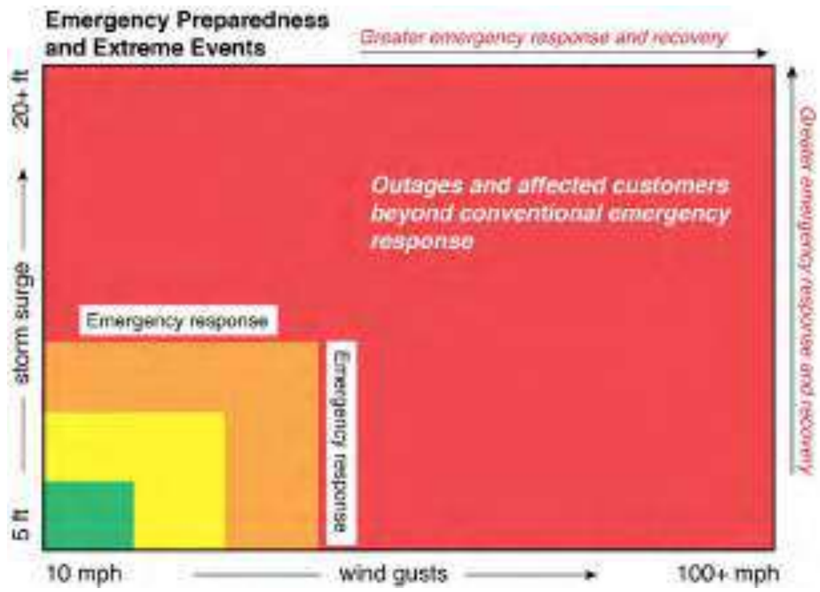
Extreme and Multi-Hazard Events

Assets across all systems are vulnerable to possible damage from extreme event flooding. Storm surge driven by an extreme hurricane event (i.e., a Category 4 hurricane) has the potential to flood both aboveground and belowground assets. Specific asset damage varies by commodity and is outlined in the commodity-specific sections. In addition, flooding from ice-melt and snowmelt may cause significant damage to assets across all commodities, especially if the melt contains corrosive road salts.

On an operational level, increasing frequency and intensity of extreme weather events may exceed Con Edison's currently robust emergency preparedness efforts. Con Edison's extreme weather response protocols are specified in the company's hazard-specific Emergency Response Plans and Coastal Storm Plans for electric, steam, and gas systems. Con Edison's current "full-scale" response, which calls for all Con Edison resources and extensive mutual assistance, is initiated when the number of customers out of service reaches approximately 100,000. However, low-probability extreme events can increase customer outages and outage durations by an order of magnitude, outpacing current levels of emergency planning and preparedness, as shown in Figure 14.

[12] The sea level rise projections use a baseline year of 2000. For more details on these projections and how they relate to Con Edison's design standards, see Appendix 4.

Figure 14 ■ Schematic diagram illustrating the increasing impacts during an extreme event (e.g., hurricane with extreme wind gusts and storm surge) that demands correspondingly large emergency response efforts that may exceed those experienced historically.



Adaptation Measures to Address Vulnerabilities

Several adaptation measures help address vulnerabilities across Con Edison's electric, gas, and steam systems: improved monitoring systems and capabilities to support planning and decision making, emergency preparedness and full system recovery, and improved customer coping.

Improved Monitoring Systems and Capabilities to Support Planning and Decision Making

Con Edison can collect updated and comprehensive data to further strengthen the resilience of its long-term plans and decision-making processes to climate change. Signposts guide planning and decision making, especially through informing the timing of implementation and the adjustment of adaptation measures, described in greater detail in the section below on Moving Towards Implementation.

As previously mentioned, it is important to have the latest information on climate variables and projections as the climate changes and the science improves. Monitoring local climate rates of change across the service territory can help Con Edison better track both changing conditions and potential points of vulnerability across its systems. Specific adaptation measures per commodity that are dependent on the monitoring of climate variable information are detailed in the respective commodity sections. In addition to information on climate variables, Con Edison will need to stay abreast of the latest climate science projections generated by expert organizations such as IPCC, NCA, and NPCC. The Study team suggests that Con Edison could revise its planning and decision-making processes at least every 5 years to incorporate updated climate science information.

Emergency Preparedness and Full System Recovery

Con Edison should consider a range of adaptation strategies to increase capacity for an efficient preparedness and recovery process, as defined in Table 3.

Table 3 ■ **Emergency preparedness and system recovery adaptation strategies**

Adaptation Strategy	Measures
Strengthen staff skills for streamlined emergency response.	• Use technology to increase the efficiency of emergency response work crews. • Review the Learning Center courses to ensure that crews are developing the skills required for emergency response. • Incorporate supply shortages into emergency planning exercises.
Plan for resilient and efficient supply chains.	• Develop a resilience checklist for resilient sourcing. • Have a plan already in place for selection and procurement of assets designed to be more resilient in the future. • Ensure that parts inventories are housed out of harm's way and in structures that can survive extreme weather events. • Standardize equipment parts, where possible.
Coordinate extreme event preparedness plans with external stakeholders.	• Continue coordination with telecommunication providers, including through joint emergency response drills. • Continue and strengthen collaboration with the city to improve citywide design, maintenance, and hardening of the stormwater system. For example, improved drainage could alleviate the potential impacts of flooding and increase the effectiveness of adaptation measures in which Con Edison invests (e.g., drain hardening at manholes).
Incorporate low probability events into long-term plans.	• Continue expanding the Enterprise Risk Management framework to include lower probability extreme weather events and long-term issues (e.g., 20+ years). • Conduct additional extreme weather tabletop exercises informed by the future narratives outlined in this report, and consecutive extreme weather events. • Consider expanding the definition of critical facilities and sensitive customers.
Track weather-related expenditures.	• Con Edison's Work Expenditures Group could track expenditures, such as the cost of outages and repairs or customer service calls. Concurrently tracking climate and cost data will enable Con Edison to perform correlation analysis over time.
Update extreme event planning tools.	• Con Edison currently uses an internal Storm Surge Calculator (an Excel workbook that determines the flood measures to be employed for coastal assets based on a given storm tide level) to help plan for coastal flooding impacts. Con Edison could adjust inputs to this program to reflect the following: – Updated storm surge projection information, using high-end forecasted surge – Information from coastal monitoring, such as sea level rise and coastal flooding • In addition, Con Edison could regularly revisit the definition of critical equipment so that the Storm Surge Calculator can best inform prioritization of equipment upgrades.
Expand extreme heat worker safety protocols.	• Implement safety protocols (e.g., shift modifications and hydration breaks) practiced in mutual aid work in hotter locations such as Florida and Puerto Rico. • Examine and report on the levels of workers necessary to prepare for and recover from extreme climate events.
Improve recovery times through system and technology upgrades.	• Consider the use of drones and other technology (satellite subscription) or social media apps for damage assessment. • Use GIS system to facilitate locating and documenting damage. • Expand the use of breakaway hardware and detachable service cable and equipment.

Improved Customer Coping

Extreme events can present outsized risks compared to chronic events—risks that, in some cases, also extend to larger geographic areas. For example, impacts from hurricanes can overwhelm multiple facets of Con Edison's system and surrounding communities. Con Edison is positioned at the center of increasingly interconnected societal, technological, and financial systems, making it difficult and inefficient to evaluate risks solely on a component-by-component basis (Linkov, Anklam, Collier, DiMase, & Renn, 2014). Together, these factors necessitate different approaches to considering adaptation compared with climate changes for which probabilities are more easily assigned.

While the City of New York has primary responsibility for coordinating resident emergency response efforts, Con Edison can play a role in increased customer coping and resilience. This includes helping customers cope with reduced energy service if an extreme event leads to prolonged outages (e.g., supporting on-site energy storage, access to locations in the community with power, prioritized service restoration for vulnerable areas). Table 4 provides more specific adaptation strategies. Overall, Con Edison could consider expanding the definition of critical facilities and sensitive customers.

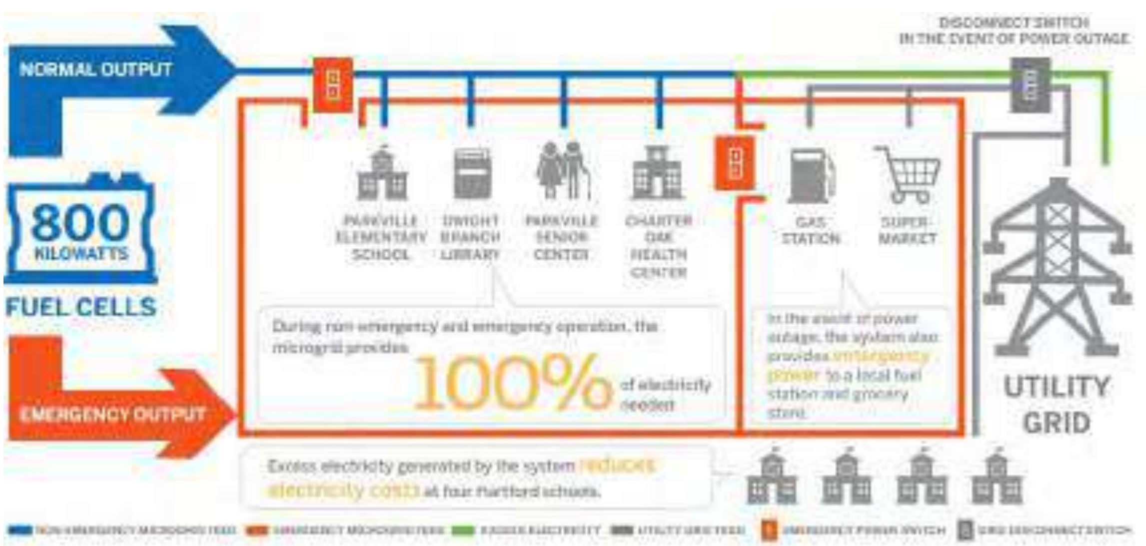
Table 4 ■ Improved customer coping adaptation strategies

Adaptation Strategy	Measures
Create resilience hubs (see below for more information).	• Use solutions such as distr buted generation, hardened and dedicated distribution infrastructure, and energy storage so that resilience hubs can function akin to microgrids to provide a range of basic support services for citizens during extreme events. • Continue to promote the pilot resilience hub at the Marcus Garvey Apartments in Brooklyn, using a lithium ion battery system, fuel cell, and rooftop solar to provide back-up power to a building with a community room that has refrigerators and phone charging. • Support additional deployment of hybrid energy generation and storage systems at critical community locations and resilience hubs. • Use AMI capabilities to preserve service for vulnerable populations, if poss ble.
Invest in energy storage.	• Continue to enhance customer resilience through continued installation of energy storage strategies, including on-site generation at substations or mobile storage on demand/transportable energy storage system (TESS) units, and compressed natural gas tank stations. • Continue to explore ways to help customers install, maintain, and make use of distributed energy resource assets for power back-up, self-sufficiency, and resilience purposes.
On-site generation	• Con Edison currently supports on-site generation for customers through programs such as rebate and performance incentives for on-site residential and commercial photovoltaic solar generation, incentives for behind-the-meter wind turbines, and incentives for combined heat and power projects that Con Edison currently facilitates in collaboration with the New York State Energy Research and Development Authority. • On-site generation is a recommended approach for locations where resilience hubs may not be affordable or necessary. • Con Edison could continue to encourage on-site generation for individual businesses and residential buildings.
Energy efficiency	• Support improved passive survivability, or the ability to shelter in place for longer periods of time, through enhanced energy efficiency programs. • Continue to support energy efficiency programs and further expand its energy efficiency program portfolio to include additional incentives for energy-efficient building envelope upgrades.

Resilience hubs are an emerging idea in resilience planning, which focus on building community resilience by creating a space (or spaces) to support residents and coordinate resources before, during, and after extreme weather events (Baja, 2018). A key requirement for a resilience hub is continued access to energy services. The objective of a resilience hub is to be able to provide a range of basic support services for citizens during extreme events. To accomplish this, resilience hubs may require a hybrid energy solution that includes multiple generation sources (e.g., solar and natural gas generation) and energy storage (i.e., batteries), plus dispatching controls, similar to the functionality of a microgrid. Figure 15 and Figure 16 demonstrate how a fuel cell-based microgrid can be used to power key community locations during normal operating conditions and during emergency events.

Figure 15 ■ Fuel cell-based microgrid supplying energy to key community locations (Constellation Energy)

Figure 16 ■ Diagram of microgrid operations during normal and emergency operations (Constellation Energy)



Electric System

Electric System Overview

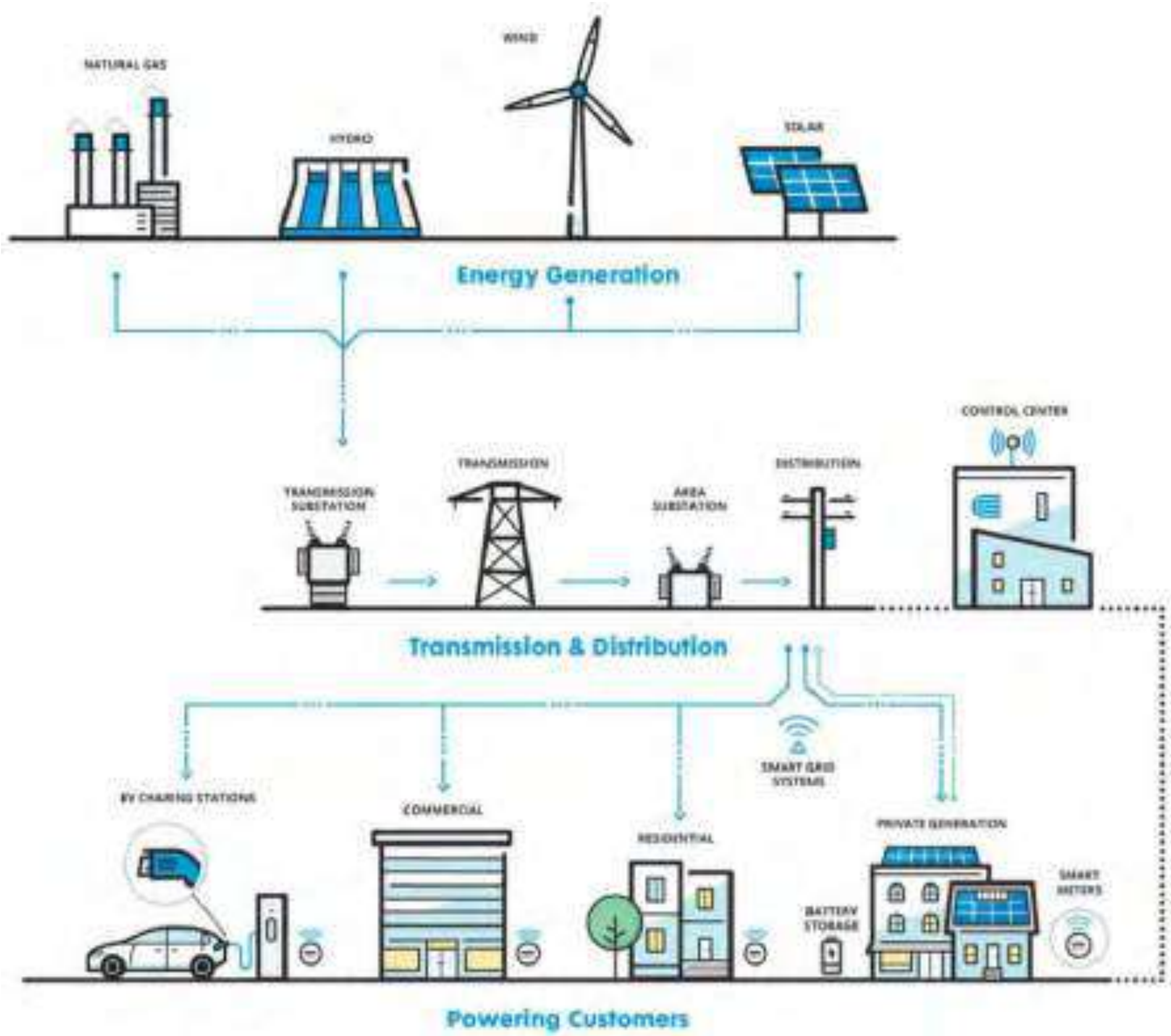
Con Edison's electric service territory includes both New York City and Westchester County, covering an area of 660 square miles and serving 3.3 million customers. Figure 17 depicts a schematic of the Con Edison electric system.

Con Edison's grid is a delivery system that connects energy sources to customers. While most electricity delivered is produced by large third-party generating stations, distributed energy resources also supply energy to the grid.

Energy produced by generating sources is delivered via the Con Edison transmission system, which includes 430 circuit-miles of overhead transmission lines and the largest underground transmission system in the United States, with 749 circuit-miles of underground cable. The system also includes 39 transmission substations. The high-voltage transmission lines bring power from generating facilities to transmission substations, which supply area substations, where the voltage is stepped down to distribution levels.

Con Edison has two different electric distribution systems—the non-network (primarily overhead) system and the network (primarily underground) system. The network system is segmented into independent geographical and electrical grids supplied by primary feeders at 13 kilovolts (kV) or 27 kV. The non-network system is designed using either overhead autoloops with redundant sources of supply, or 4-kV overhead grids arranged in a network configuration or as underground residential distribution systems designed in loop configurations.

Figure 17 ■ Diagram of the Con Edison Electric System



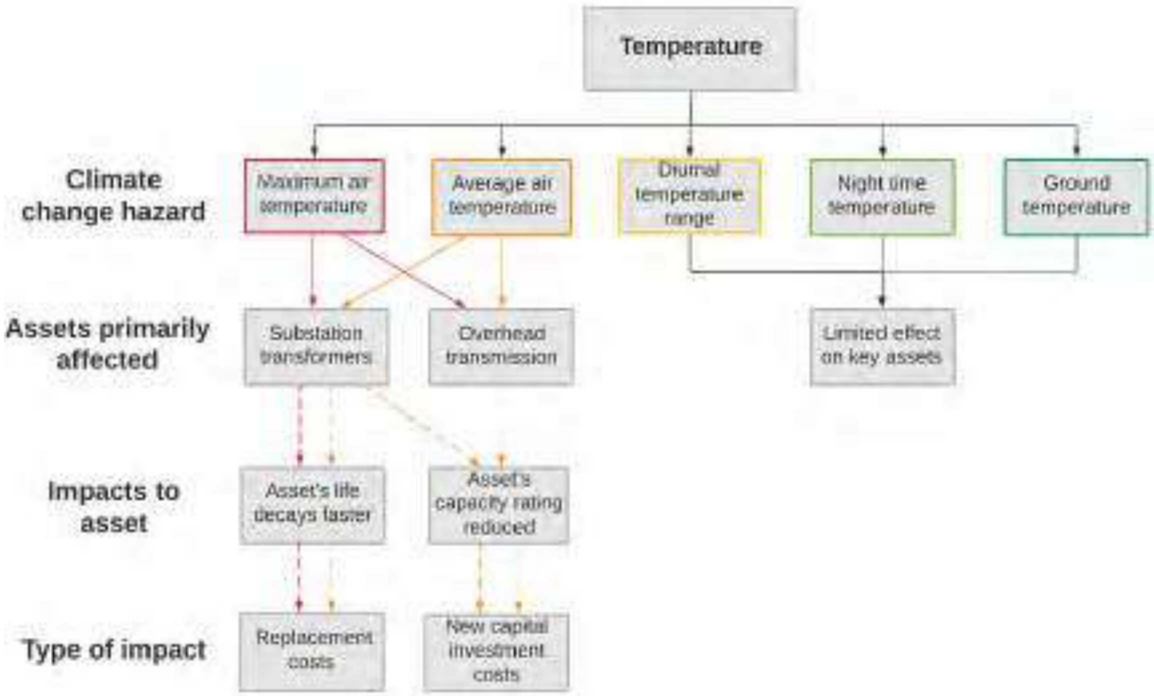
Electric Vulnerabilities

Assets in the electric segment of Con Edison's business are most vulnerable to climate-induced changes in temperature/humidity and sea level rise. Both climate hazards have already shown their ability to bring about outages or damage assets and interrupt operations and carry the potential for future impacts. More information on specific vulnerabilities for these and other climate stressors is discussed below.

Heat and Temperature Variable (TV)

The core electric vulnerabilities for increasing temperature and TV include increased asset deterioration, decreased asset capacity, decreased system reliability, and increased load. Figure 18 illustrates how temperature-related stressors, such as maximum and average air temperature, lead to impacts on the electric system.

Figure 18 ■ Temperature-related impacts on Con Edison's electric system



Increased Asset Deterioration

Increased average temperatures pose a threat to substation transformers. Within a substation, transformers are the asset most likely to be affected by projected higher temperatures since their ambient temperature design reference temperature is lower (i.e., 86°F) than that of most other assets.[13] Higher average and maximum ambient temperatures increase the aging rate of the insulation in transformers, resulting in decreased asset life.[14]

Decreased Asset Capacity

Because an asset's internal temperature is the result of the ambient temperature in which it operates, as well as the amount of power it delivers, operating in an ambient temperature above the design reference temperature decreases the operational rating of the asset. However, derating the system due to increasing temperatures would effectively decrease the capacity of the system. When the capacity of the system is decreased, Con Edison must make investments to replace that capacity. The Con Edison system is currently designed with the capacity to meet a peak summer demand of more than 13,300 megawatts (MW). Based on projected temperature increases, capacity reductions in 2050 could range from 285 MW

[13] Buses, disconnect switches, circuit breakers, and cables all have a design reference temperature of 104°F or higher.

[14] Not every excursion above the designed-for temperature will result in decreased service life. Two conditions must be met for the useful life of the transformer insulation to experience an increased rate of decay: (1) the ambient reference temperature rating must be exceeded, and (2) the transformer must be operating at the rated load, typically as a result of the network experiencing a single or double contingency.

to 693 MW for overhead transmission, switching stations, area station and sub-transmission, and network transformers.[15] This could potentially result in a capital cost of $237 million to $510 million by 2050.

The primary impact of increases in ambient temperatures on overhead transmission lines (assuming peak load) is increased line sag. Insufficient line clearance presents a safety risk should standard measures such as vegetation management not alleviate the risk. If standard measures cannot be applied, the lines would have to be derated and investments would be needed to replace the diminished capabilities of the line.

Decreased System Reliability

Increases in TV-related events are expected to affect the electric network and non-network systems by decreasing reliability. Con Edison uses a Network Reliability Index (NRI) model to determine the reliability of the underground distribution networks.[16] Con Edison has set an NRI value of 1 per unit (p.u.) as the threshold over which reliability is considered unacceptable. Currently, there are no networks that exceed this standard.

The Study team modeled how the NRI value of each network would change without continued investments in the system. The forward-looking NRI analysis found that with an increase in the frequency and duration of heat waves by mid-century, between 11 and 28 of the networks may not be able to maintain Con Edison's 1 p.u. standard of reliability by 2050, absent adaptation. Under the higher emissions scenario (RCP 8.5 90th percentile), projected impacts are relatively severe, even by 2030, with up to 21 total networks projected to exceed the NRI threshold by that year, absent adaptation (Figure 19). These deficiencies can be reduced by continuing to make investments to better withstand climate events, which Con Edison has done in the past through measures such as infrastructure hardening and added redundancy, diversity, and flexibility in power delivery. Such measures carry the co-benefit of improving blue-sky functionality and reliability.

Currently, Con Edison replaces paper-insulated, lead-covered (PILC) cables as an effective first line of defense against NRI increases. Con Edison is committed to continued investment in this measure, which will help reduce this heat-related vulnerability in the near term. The Study team also quantified the value of other measures to maintain network reliability, including innovative distribution designs and the use of distributed resources, which can be part of microgrids.

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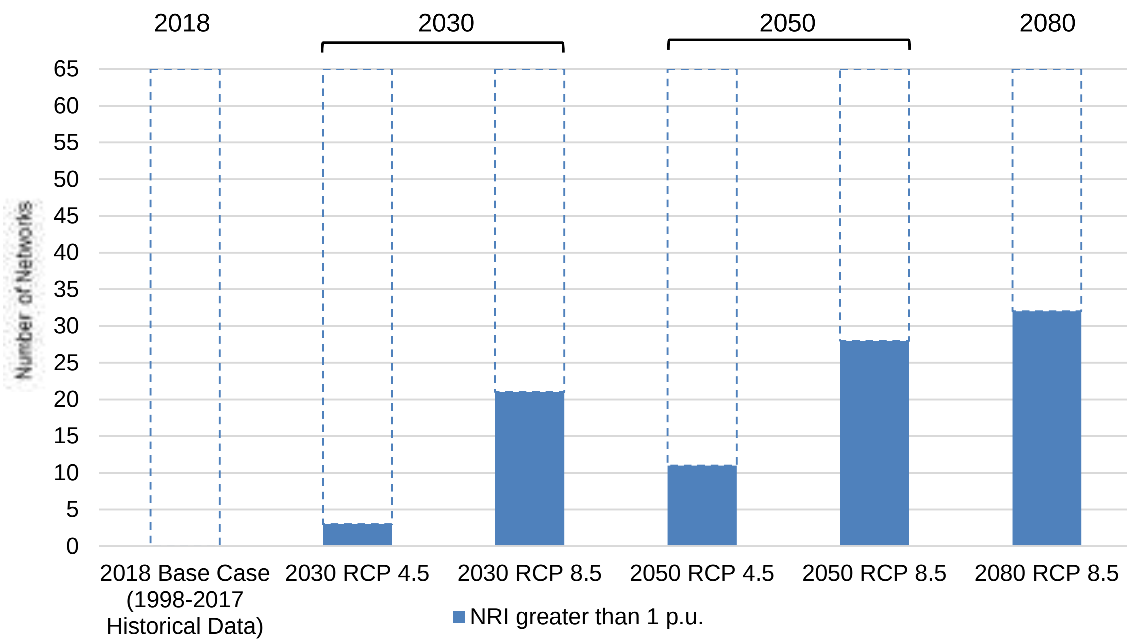
[15] The assumed decrease in capacity is 0.7% per °C (0.38% per °F) for substation power transformers, and 1.5% per °C (0.8% per °F) for overhead transmission conductors (Sathaye, 2013).

[16] NRI is a Monte Carlo simulation used to predict the performance of a network during a heat wave. The program uses the historical failure rates of the various components/equipment that are in the network, and through probability analysis determines which networks are more likely to experience a shutdown.

Figure 19 ■ The number of networks above the NRI threshold of 1 p.u. under both climate scenarios for 2030, 2050, and 2080



The Study team also analyzed the impact of climate change on non-network reliability, which is measured in terms of the System Average Interruption Frequency Index (SAIFI).[17] The results indicate that the reliability of the non-network system is somewhat vulnerable to heat events; however, climate impacts would be negligible out to 2080. The average contribution to reliability from non-network autoloop feeder failures and 4-kV grid supply feeder failures due to increased temperatures would only contribute up to 8% of the maximum threshold SAIFI of 0.45 (i.e., a 0.035 increase in SAIFI in 2080) (New York Department of Public Service, 2018).

Increased System Load

When temperature and humidity increase, demand for electricity for cooling also increases. Therefore, higher TV in the summer can cause higher peak loads. The Study team found an increase in peak load in 2050 of 6.9% to 19.2%, as compared to historical conditions. These projected changes in load are due only to the impact of changing TV, and do not take into consideration changes in other factors (e.g., population, increased air conditioning penetration). The Study team found a decrease in winter peak electric load.

Increases in load may require investments in system capacity to meet the higher demand. This cost could be between $1.1 billion and $3.1 billion by 2050. The 10- and 20-year load relief investment plans use asset ratings and load forecasts as key inputs, both of which include temperature as a factor. This combination of a greater demand and a decreased capacity to fill that need will likely warrant a revision to the load relief planning process in the future (Table 5).

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[17] SAIFI is a measure of customer reliability. It is the average number of times that a customer is interrupted for 5 minutes or more over the course of 1 year.

Table 5 ■ The combined impacts of increased load and asset capacity reduction in 2050

Scenario	Total capacity under base and future temperature conditions (MW)	Incremental capacity reduction due to temperature	Peak load during current and future 1-in-3 events (MW)	Incremental load increase due to changes in TV	Total additional capacity needed under climate scenarios (MW)
Base Case 2050	13,300	0	13,525	–	0
RCP 4.5 10th percentile 2050	13,015	285	14,949	1,424	1,709
RCP 8.5 90th percentile 2050	12,607	693	16,491	2,966	3,659

Secondary Vulnerabilities

The Study team identified additional heat and humidity-related vulnerabilities in Con Edison's system that were not flagged as priority vulnerabilities but nonetheless present risks.

- **Transmission system:** Con Edison's current transmission system is designed for the highest anticipated loads based on historical values. The Study team found that while load exceeded 90% of the peak load (presenting the possibility for thermal overload) on 1.5% of summer days historically, by 2050, this may increase to 5.2% of days under the RCP 8.5 90th percentile scenario. This shift in TV distribution may result in a small increase in the frequency of load drop from the transmission system.
- **Summer operations and voltage reductions:** When summer temperatures soar, Con Edison implements a set of procedures to avoid voltage and thermal stresses on the system. These procedures are triggered by a threshold (e.g., TV 86, which is the 1-in-3 peak load-producing TV). The Study team found that there could be a significant increase in the number of days with voltage reductions and summer work restrictions. However, if Con Edison continues to invest in the system to ensure operational capacity during the 2050 1-in-3 TV event, then there will be a drop in the frequency of voltage reductions and summer work restrictions, relative to today.
- **Corporate Emergency Response Plan:** Con Edison also uses TV thresholds to trigger elevated threat levels under its Corporate Emergency Response Plan (CERP). The Study team conducted an analysis to understand how the projected changes in TV will affect the exceedance of current CERP threat levels. The analysis indicates that TV conditions exceeding current thresholds will increase in both the lower (RCP 4.5 10th percentile) and higher (RCP 8.5 90th percentile) climate change scenario. The conditions for reaching a "Serious" threat level based on the current thresholds, for example, would increase from 0.4 days per summer, on average, to 1.8 days under RCP 4.5, and 12.8 days under RCP 8.5.
- **Volume forecasting:** Con Edison conducts volume forecasting to estimate the volume of energy the company needs to purchase, a portion of which is weather-sensitive. The calculation for this portion relies primarily on heating degree-days (HDDs) for the winter and cooling degree-days (CDDs) for the summer. The Study team estimated that Con Edison could experience an increase in summertime CDDs, which could result in the energy delivery increasing from 43,077 gigawatt-hours (GWh) in 2050 under the base case to 43,685 GWh under the RCP 4.5 scenario (a 1.4% increase), and to 45,394 GWh under the RCP 8.5 scenario (a 5.4% increase). The Study team found a less significant decrease in HDDs due to climate change.

Sea Level Rise

RCP 4.5 and RCP 8.5 projections indicate that sea level rise may exceed Con Edison's current design standard for coastal flood protection (i.e., a 100-year storm with 1 foot of sea level rise and 2 feet of freeboard) between 2030 and 2080. The Study team analyzed the exposure of Con Edison's assets to 3 feet of sea level rise (i.e., the 2080 RCP 8.5 83rd percentile sea level rise projection), keeping the other elements of Con Edison's existing risk tolerance constant (i.e., a 100-year storm with 2 feet of freeboard). By summing the freeboard and sea level rise values, this equates to FEMA's 100-year floodplain elevation plus 5 additional feet.

Of the 324 electric substations (encompassing generating stations, area substations, transmission stations, unit substations, and Public Utility Regulating Stations [PURS]), 75 would be vulnerable to flooding during a 100-year storm if sea level rose 3 feet. Three of these potentially exposed substations would only require minimal modifications to protect them, 16 would require an extension of existing protections, eight would require a new protection approach (i.e., the existing protections cannot be extended), and 48 do not have existing protections because they are outside of the floodplain. Hardening all these substations is estimated to cost $636 million.

Precipitation

The Study team found that substations, overhead distribution, underground distribution, and the transmission system are most at risk for precipitation-based hazards.

Substations may experience an overflow of water from transformer spill moats, which could release oil-contaminated water within the substation. However, the risk of such an event is low, as transformer spill moats are built at a level that is robust to all but a severe and highly improbably conjunction of events.[18]

The transmission and overhead distribution systems are both vulnerable to the accumulation of radial ice, which can build up on lines and towers during winter precipitation events. In extreme scenarios, accumulation of radial ice can result in unbalanced structural loading and subsequent transmission line failure, especially when accompanied by heavy winds (Nasim Rezaei, Chouinard, Legeron, & Langlois, 2015). Con Edison's current system meets the National Electrical Safety Code standard for radial ice and is robust to ice accumulation. It is uncertain whether climate change will increase or decrease the intensity of future icing events.

The underground distribution system is vulnerable to flooding and salt runoff from snowfall and ice events. Flooding can damage non-submersible electrical equipment. This risk is mitigated through Con Edison's designs: All underground cables and splices operate while submerged in water, and all underground distribution equipment installed in current flood zones (and all new installations) are submersible. Snowfall and ice require municipalities to spread salt on roads, which eventually seeps into the ground with runoff water. Road salt can degrade wire insulation and lead to insulation burning and arcing, potentially causing safety concerns and customer outages. It is currently unclear how salting frequency will change over time.

Extreme Events

Hurricanes and nor'easters present physical risks associated with heavy winds, precipitation, and flooding, which can lead to widespread system outages and, at worst, physical destruction. During hurricanes, wind stress and windblown debris can lead to tower and/or line failure of the overhead transmission system

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[18] In accordance with New York State code and federal Spill Prevention, Control, and Countermeasure recommendations, Con Edison's transformers are protected by moats designed to hold water from a 6-inch, 1-day storm event, in addition to the gallons of oil that may be released during a spill event and a further 50,000–60,000 gallons of fire suppression fluid. Based on this standard, Con Edison's substation transformer moats are robust to 6 inches of rain during a catastrophic emergency, and significantly more than that at all other times.

and damage overhead distribution infrastructure, which could cause widespread customer outages. Intense rain during hurricanes can also flood substations, which may cause an overflow of oil-contaminated water from transformer spill moats. A Category 4 hurricane could very likely lead to outages for more than 600,000 non-network customers and more than 1.6 million network customers.

During nor'easters, accumulation of radial ice can cause tower or line failure of the overhead transmission system. Similarly, snow, ice, and wind can damage the overhead distribution system. Indirectly, salt put down by the city to contend with snow and ice accumulation on roads could infiltrate the underground distribution system, causing arcing and failure of underground components.

Extreme heat waves present a range of effects that can contribute to failures, including a lower ampacity rating while increasing load demand, causing cables and splices to overheat, transformers to overheat, and transmission and distribution line sag. Distribution network component failures can cause Con Edison to exceed the network reliability design standard. Greater line sag can lead to flashovers and line trips.

Adaptation Options for the Electric System

Withstand

In the short term, Con Edison can work to address the vulnerabilities of the electric system by integrating climate hazard considerations into planning, collecting data on priority hazards, and updating design strategies.

There are several opportunities to integrate climate change data into planning processes. For example, Con Edison could integrate climate change projections into long-term load forecasts, consult utilities in cities with higher temperatures to refine the load forecast equation for high TV numbers, and develop a load relief plan that integrates future changes in temperature and TV into asset capacity and load projections. During load relief planning, Con Edison could also consider whether extreme events may shift the preferred load relief option—frequent extreme heat could reduce the effectiveness of demand response programs. For the transmission system, Con Edison could integrate considerations of climate change into the long-range transmission plan. For the distribution system, Con Edison could integrate climate projections into NRI modeling and install high-reliability components,[19] as needed.

Given the potential risks that temperature and heat waves pose to the electric system, the Study team suggests that Con Edison could collect data on these hazards to build greater awareness of their impacts to the system, as well as to monitor for signposts that would trigger additional action. Specifically, Con Edison could:

[19] System components vary in their reliability. For example, PILC cable performs more poorly than solid dielectric cable.

- Install equipment capable of collecting, tracking, and organizing temperature data at substations to allow for location-specific ratings and operations.
- Make ground temperature data more accessible and track increases over time.
- Expand monitoring and targeting of high-risk vegetation areas.
- Continue to track line sag and areas of vegetation change via light detection and ranging (LiDAR) flyovers to identify new segments that may require adaptation.

These data could be used to routinely review asset ratings in light of observed temperatures. Con Edison could also incorporate heat wave projections into reliability planning for the network system.

Hurricanes are another priority hazard for the electric system and therefore warrant robust planning tools that capture potential changes in climate. Con Edison could complement their existing model used to predict work crews required to service weather-driven outages with an updated model that better resolves extreme weather events and extreme weather impacts on customers in the service territory.

Design standards are a way to help standardize resilience by ensuring that new assets are built to withstand the impacts of climate change hazards. The Study team suggests a variety of design standards:

- **Temperature:** Standardize ambient reference temperatures across all assets for development ratings.
- **Precipitation:** Update precipitation design standards to reference National Oceanic and Atmospheric Administration (NOAA) Atlas 14 for up-to-date precipitation data. Consider updating the design storm from the 25-year precipitation event to the 50-year event to account for future increases in heavy rain events.
- **Sea Level Rise:** Revise design guidelines to consider sea level rise projections and facility useful life. Continue to build to the higher of the FEMA + 3′ level and the Category 2 storm surge levels at new-build sites, as is current practice. Add sea level rise to the Category 2 maps to account for future changes and a greater flood height/frequency.

In addition to these systematic approaches, Con Edison can also help the electric system better withstand climate hazards through asset-specific physical adaptation measures, when needed. Table 6 illustrates these physical options.

Table 6 ■ Potential physical adaptation options for electric assets

Main Hazard(s)	Vulnerable Assets or Plan	Adaptation Option	Implementation Timeframe	Signpost or Threshold
Temperature	Grid modernization	Continue to invest in grid modernization to increase resilience to climate change through new technology and increased data acquisition. Efforts include distribution automation, grid-edge sensing (environmental, AMI), asset health monitoring, conservation voltage optimization, and targeted system upgrades.	Continuous	Change in ambient operating temperatures, including changes in science-based projections
Heat Waves	Network system, which may experience reduced reliability (and therefore increased NRI) due to heat waves	Complete PILC cable replacements.	2030	Increased frequency or duration of heatwaves
		Continue implementing load relief strategies to keep NRI ratings below 1. Options include: • Split the network into two smaller networks. • Create primary feeder loops within and between networks. • Install a distribution substation. • Incorporate distr buted energy resources and non-wire solutions. • Design complex networks that consider combinations of adaptation measures.	Continuous	NRI value over 1 p.u.
	Non-network distr bution system	Maintain non-network reliability in higher temperatures by implementing the following: • Autoloop sectionalizing • Increased feeder diversity	2080	Forecasted System Average Interruption Frequency Index (SAIFI) ratings (incorporating climate change projections) above established thresholds
	Overhead transmission	Replace limiting wire sections with higher rated wire to reduce overhead transmission line sag during extreme heat wave events. Alternatively, remove obstacles or raise towers to reduce line sag issues.	Continuous	Increased incidence of line sag; higher operating temperatures
		Explore incorporating higher temperature-rated conductors.	2050	Existing asset replacement
	Area and transmission substation transformers	Undertake measures that contr bute to load relief, such as energy efficiency, demand response, adding capacitor banks, or upgrading limiting components, such as circuit breakers, or disconnect switches and buses.	2030/2050	Ambient temperatures exceeding asset specifications
		Gradually install transformer cooling, or replace existing limiting transformers within substations.	2050/2080	Ambient temperatures exceeding asset specifications
Precipitation	Substations	Harden electric substations from an increased incidence of heavy rain events by doing the following: • Raising the height of transformer moats • Installing additional oil-water separator capacity • Increasing "trash pumps" behind flood walls to pump water out of substations	2080	Changes in the 25-year return period storm
	Transmission and overhead distr bution	Underground critical transmission and distr bution lines.	2080	Increased incidence of icing

Main Hazard(s)	Vulnerable Assets or Plan	Adaptation Option	Implementation Timeframe	Signpost or Threshold
	Underground distr bution	Retrofit ventilated equipment with submersible equipment to eliminate the risk of damage from water intrusion.	2050	Expanded area of precipitation-based flooding; better maps of areas at risk for current and future precipitation-based flooding
		Reduce the incidence of manhole events due to increased precipitation and salting by doing the following: • Expanding Con Edison's underground secondary reliability program • Accelerated deployment of vented manhole covers • Replacement of underground cable with dual-layered and insulated cable, which is more resistant to damage • Installation of sensors in manholes to detect conditions indicating a potential manhole event	2050	Increase in the City's use of salt over the winter period; increased rate of winter precipitation
Hurricanes	Overhead transmission	Continue to expand existing programs to reinforce transmission structures; address problems with known components.	Continuous	Increased frequency/severity of heavy winds; existing asset replacement
	Overhead distr bution	Invest in retrofits for open wire design with aerial cable and stronger poles.	2080	Increased frequency/severity of heavy winds; existing asset replacement
		Underground critical sections of the overhead distr bution system to ensure resilience against hurricane force winds and storm surge.	2080	Increased frequency/severity of heavy winds
Nor'easters	Overhead transmission and distr bution	Continue to expand programs to reinforce transmission and distribution structures and expand the number of compression fittings used to address weak points in transmission lines.	Continuous	Increased incidence of icing; existing asset replacement
	Underground distr bution	Upgrade high failure rate components.	Continuous	Increased frequency/severity of nor'easter events

Of course, it is neither practical nor feasible for Con Edison to build resilience to the point that its electric system can fully withstand the impacts of all climate hazards. The Study team thus suggests that Con Edison consider the following strategies to help the electric system better absorb and recover from impacts:

Absorb

- **Temperature:** Increase capabilities to provide flexible, dynamic, and real-time line ratings.
- **TV:** Routinely update voltage reduction thresholds and hands-off thresholds to account for changes in climate and the changing design of the system.
- **Hurricanes:** Continue to explore and expand operational measures to increase the resiliency of the overhead distribution system by increasing spare pole inventories to replace critical lines that are compromised during extreme weather events.
- **Heat waves:** Stagger demand response consecutive event days across different customer groups to increase participation; ensure that demand response program participants understand the purpose/cause of the event; use technology to more efficiently regulate load/use AMI to rapidly shed

load on a targeted network to help ensure that demand does not exceed supply; and continue installation of energy storage strategies, including on-site generation at substations or mobile storage on demand/transportable energy storage system (TESS) units, and compressed natural gas tank stations.

Recover

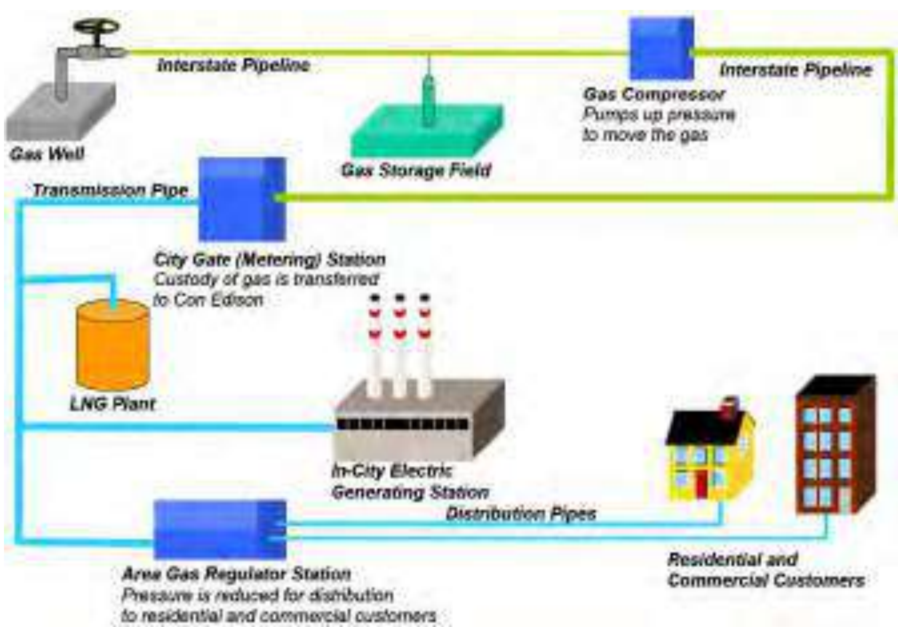
- **Heat waves:** Continue to actively engage forward-looking technologies to improve extreme recovery time for distribution systems, such as automated splicing systems to reduce feeder processing times.
- **Extreme events:** Support additional deployment of hybrid energy generation and storage systems at critical community locations and resilience hubs; support increasing the percentage of solar/other distributed generation projects to allow for islanding; encourage on-site generation for individual businesses and residential buildings; and increase the use of LiDAR and drones to assess damage and reduce manual labor.

Gas System

Gas System Overview

Con Edison's gas service territory covers Manhattan, Bronx, Westchester, and parts of Queens. Con Edison serves approximately 1.1 million firm customers and 900 large-volume interruptible customers who can alternate fuel sources. The natural gas system consists of more than 4,359 miles of pipe transporting approximately 300 million dekatherms (MMdt) of natural gas annually. About 56% of the system operates at low pressure, 11% operates at medium pressure, and 33% operates at high pressure. Figure 20 depicts the Con Edison natural gas delivery chain.

Figure 20 ■ Con Edison natural gas delivery chain



Gas Vulnerabilities

Most of Con Edison's gas assets are underground, and gas load peaks in the winter rather than in the summer, which means that gas assets are less likely to be damaged by subaerial extreme events, such as heat waves, lightning, and strong winds. As discussed in Con Edison's Post Sandy Enhancement Plan, Con Edison's gas assets are most vulnerable to underground water intrusion caused by flooding, and thus projected increases in the frequency of heavy precipitation and downpours, sea level rise and storm surge, and hurricanes and nor'easters pose a significant risk (Con Edison, 2013).

Water intrusion can occur if underground water enters gas pipes or mains and may result in a drop in pressure and lead to scattered service interruptions; low-pressure segments of the system and cast iron pipes are particularly vulnerable to this risk. In addition, pipe sections near open-pit construction projects may also be more vulnerable, because open excavation work can create opportunities for water intrusion if flood protection measures are not consistently used. Con Edison has already developed operational protocols that require crews working on open excavation sites to secure them to minimize water intrusion risk.

Water intrusion into gas regulators through aboveground vents may also cause damage. This intrusion could lead to water sitting on top of the diaphragm that allows each regulator to function and exerting additional pressure on the diaphragm that could, in turn, over-pressurize the regulator. Over-pressurized gas flowing through a system designed for lower pressure gas increases the possibility of tearing leaks in distribution piping, and in the worst-case scenario, could blow out pilot lights.

For the gas distribution system to function at full capacity and to be able to provide customers with desired gas supply, Con Edison must keep gas moving through the system at the intended flow rate, or pressure level, of each system segment. Once water enters the gas system, it is difficult to pinpoint the location and remove the water, which can increase the durations of resulting service interruptions.

Con Edison is currently undertaking several measures to manage underground water intrusion:

- Using drip pots to collect water at low points in the system (approximately 8,000 are currently in place)
- Developing a program to better prioritize gas infrastructure replacements. Remote sensors and machine learning could identify leak-prone areas to prioritize for upgrades intended to mitigate increasing precipitation risks in the face of climate change
- Developing a drip pot remote monitoring program using sensors, which would increase the efficiency of periodic emptying of drip pots and reduce the effort needed to monitor drip pots during the period of planned pipe replacement
- Shifting toward constructing and repairing infrastructure with more leak-resistant equipment, when possible

A climate change-driven increase in the frequency and intensity of flood events, such as heavy rain events or snow events followed by rapid snow melt, or coastal storm surge, may elevate the risk of water infiltration into the low-pressure gas system. The precipitation threshold currently used as a benchmark for monitoring and emptying drip pots is ½ inch of rain in 24 hours. Under the RCP 8.5 scenario, this threshold is projected to be exceeded 37 days per year in Central Park by the latter part of the century, which is nearly 20% more than the 31 days observed over the baseline period.

Low-probability, high-impact extreme events may also include heavy rainfall and storm surge that could increase the risk of water entering the distribution system. An increase in the frequency and intensity of extreme events may make water infiltration into the gas distribution system more likely. Con Edison's gas system has established criteria to ensure that new equipment, such as gas regulator line vents, is resilient against a 100-year storm and 1 foot of sea level rise. After Superstorm Sandy, Con Edison upgraded two regulator stations to meet this standard. The Study team determined that to protect regulator stations against 3 feet of sea level rise, Con Edison would need to update 32 regulator stations, at a cost of $13.8 million.

The gas transmission system is vulnerable to cold snaps associated with nor'easters, when temperatures can drop below 0°F for multiple days. Transmission system capacity is designed to meet demand projected for weather conditions at or above 0°F. Temperatures below that threshold may increase demand to a level that exceeds system capacity; in such an event, system pressure may decrease, resulting in customer service loss.

In a generally warmer climate, the gas sector could experience significant decreases in winter energy sales for heating. There could be up to a 33% decrease by 2050 and a 49% decrease by 2080. Similarly, under the RCP 8.5 scenario, winter gas peak load is projected to decrease by 144 MMdt in 2050, compared to the base case.

Adaptation Options for the Gas System

In addition to Con Edison's existing efforts, the Study team identified several additional adaptation options that the company could consider. Some measures proposed, such as remote information monitoring and analysis, address vulnerabilities in operations and planning processes. Most measures proposed address physical vulnerabilities (see Table 7), which fall within the "withstand" adaptation category.

In the short term, Con Edison could focus on expanding its monitoring capabilities, particularly through programs that use machine learning and remote monitoring to identify vulnerable areas of the distribution system, and remote drip pot monitoring sensors.

To account for changing temperatures, Con Edison could integrate climate change data on changes in the winter gas TV into gas volume and peak load forecasting so that the company is continuously planning for future changes in climate.

To address physical risks to existing infrastructure, Con Edison may need to invest in the system at strategic points in time, as described in Table 7.

Distribution system measures focus on minimizing the risk of flood water entering and depressurizing gas mains and pipes, and measures to more easily re-elevate pressure if water does enter the system.

Adaptation measures identified to address transmission system vulnerabilities primarily focus on diversifying the system and strengthening load management when capacity is constrained.

Table 7 ■ Physical adaptation options for gas commodities

Hazard	Asset	Adaptation Option	Implementation Timeframe	Signpost or Threshold
Extreme Hurricane (Category 4)	Transmission System	Procure additional compressed natural gas tank stations.	Designing for a future Category 4 hurricane	Increased frequency and severity of storms that could cut supply, including from science-based projections
	Gas Regulators	Install vent line protectors, extend vent lines and posts, seal all penetrations, and/or elevate key electric and communications equipment to protect vent lines.	2050	When sea level rise exceeds 1 foot, or if flooding is reported and the regulators do not have vent line protectors
	Distribution System	Continue targeted Main Replacement Program (planned completion by 2036) to harden gas mains against depressurization by water intrusion or other concerns.	~2030 (goal to complete program by 2036)	Increase in flooding events
Extreme Nor'easter	Transmission System	Construct additional gate stations.	Designing for a future worst-case nor'easter	More frequent or intense cold spells that drop temperatures below the design threshold for consecutive days and threaten supply
		Build larger and/or additional transmission mains.		
		Create ties between mains to diversify the transmission system.		
		Install remote operated valves to more efficiently isolate load for load management (temporarily disconnecting gas customers) during peak events.		

In addition, given the increasing potential for extreme events, Con Edison could consider distribution system resilience options such as exploring and implementing ways to elevate system pressure in low-flow conditions.

Steam System

Steam System Overview

Con Edison's steam system provides service to more than 3 million Manhattan residents (including approximately 1,720 metered customers) south of 96th Street. Total system capacity is about 11,676 thousand pounds per hour (Mlb/hr). The distribution system is comprised of a continuous network of pipes (steel main pipes and steel and brass service and condensate piping)—in aggregate, about 105 miles of piping. The pipes' physical location is directly correlated with the locations of generation sources and regional customer demand. Figure 21 shows the locations of several steam system assets.

Figure 21 ■ Key assets included in the Con Edison steam system

Steam Vulnerabilities

Like the gas system, much of Con Edison's steam system is underground, and steam is also a winter-peaking rather than a summer-peaking commodity. As such, steam generation and distribution assets are generally less prone to damage by shifts and extremes in temperature, humidity, and wind, and more vulnerable to flooding, which may be caused by increased precipitation, coastal inundation, snow melt, or storm surge in extreme events. Severe flooding impacts, such as broken distribution pipes and damaged steam generation stations, can take significant time to repair, further increasing the duration of customer impacts.

Increased frequency and intensity of precipitation events may increase the vulnerability of steam system manholes to "water hammer" events. When a high volume of water collects around a manhole, steam in the pipes underneath may cool and condense. Interaction between steam and the built-up condensate may cause a rupture in a steam pipe. One such water hammer event occurred in 2007 when a steam pipe at Lexington Avenue and 41st Street exploded during a period of heavy rainfall (Figure 22). Con Edison responded to that event by implementing a precautionary rain event threshold. If more than ¾ inch of rain is forecasted to fall within 3 hours, Con Edison will begin to proactively monitor and address flooding before it can cause a water hammer event. The key measure used to address flooding to prevent water hammer events is pumping water out of manholes and into the city sewer. In turn, Con Edison's capacity to manage flooding events that threaten steam generation and distribution assets depends on the capacity of the city's stormwater system to handle high volumes of water that Con Edison may need to pump away from assets under a changing climate.

Steam generation and distribution system assets are also vulnerable to projected increases in sea level and coastal inundation. Five out of six steam generating plants would be exposed to a 100-year storm if sea level rose by 3 feet. If water enters the steam generation system, it can degrade plant capacity or force unit or plant outages. Significant damage to steam generation systems would likely require long repair times, which could increase the duration of customer impacts. Hardening several of the generating stations to a higher level of protection would be difficult and costly. For example, at the East River Generating Station, raising mechanical equipment would require significant and costly alterations to the hydraulics of the steam system. Similarly, at East 13th Street, flood waters associated with a 100-year storm and 3 feet of sea level rise would reach the tertiary bushings on some 345-kV transformers, resulting in arcing and critical failure of the unit. The total estimated cost to harden the five steam generation plants against a 100-year storm and 3 feet of sea level rise is $30 million.

Figure 22 2007 steam pipe explosion

Con Edison has adopted storm hardening measures to protect the steam system in response to recent storms such as Superstorm Sandy. Those measures include developing location-specific plans and drills in preparation for storms, implementing physical hardening measures at steam generating stations, protecting critical equipment by waterproofing or relocating it, installing a new steam main to ensure that hospitals receive continued service, and introducing isolation valves in strategic locations to reduce the number of customers impacted by flooding in future extreme events. Because isolating steam lines is key to managing flooding impacts, Con Edison considers several potential flood sources (e.g., rainfall deluges, storm tides, water main breaks) when evaluating hardening options, and periodically reviews and updates both operational and physical risk mitigation strategies. The company is also investing in steam system resilience through measures such as waterproofing system components in the normal course of upgrades, prioritizing hardening steam mains by prior flooding issues (fewer than 10 of the original 86 locations identified are still vulnerable), and using remote monitoring to monitor manhole water level and steam trap operation (a system is currently under design and expected to be operational by 2021).

Extreme and multi-hazard events could also increase the vulnerability of the steam distribution system to salt damage and flood damage. During nor'easters and extreme ice storms, the City of New York and jurisdictions in Westchester County conduct widespread street-salting operations to mitigate ice build-up on roads and sidewalks. Rapid melt after nor'easters and extreme ice storms can lead to an influx of salt-saturated runoff into manholes, in turn causing equipment degradation and, in some cases, manhole fires or explosions.

In a generally warmer climate, the steam system could experience significant decreases in winter energy sales for heating. There could be up to a 33% decrease by 2050 and a 49% decrease by

2080. Similarly, under the RCP 8.5 scenario, winter gas peak load is projected to decrease by 891 Mlb/hr in the winter of 2050 compared to the base case.

Adaptation Options for the Steam System

To determine when to implement various adaptation strategies, Con Edison could track climate trends, including TV, precipitation, sea level rise and storm surge, and extreme events, as described in prior vulnerability and adaptation sections.

The Study team suggests that Con Edison could continue to work collaboratively with other city actors on initiatives that could help strengthen the resilience of the steam system. Specifically, the company could take measures, including the following:

- Strengthen collaboration with the city to improve citywide stormwater design to alleviate flooding impacts and make adaptation measures implemented by Con Edison, such as drain pumps at manholes, more effective.
- Discuss ways to minimize salt use during the winter.
- Incorporate considerations of New York City initiatives in coastal resiliency plans for lower Manhattan to re-evaluate Con Edison's storm response plans and stages of pre-emptive main shutoffs.

In addition to engaging in these monitoring and coordination efforts, the company could also consider taking measures to address physical vulnerabilities in existing infrastructure by strategically investing in the system. Physical measures developed by the Study team are listed in Table 8.

Table 8 ■ Physical adaptation options for steam commodities

Hazard	Asset	Adaptation Option	Implementation Timeframe	Signpost or Threshold
Extreme Hurricane (e.g., Category 4)	Generation System	Invest in additional storm hardening investment measures to protect generation sites against extreme hurricane-driven storm surge. Leverage new innovations and advancements in flood protection over time and raise moated walls around current generation sites.	2050	When sea level rise exceeds 1 foot
	Distribution System	Continue to segment the steam system to limit customer outages in flood-prone areas.	In preparation for a Category 4 hurricane	Increased frequency and severity of storms, including from science-based projections
	Distribution System	Expand programs to harden steam mains (waterproofing pipes and raising mains).	In preparation for a Category 4 hurricane	Increased frequency and severity of storms, including from science-based projections
		Pre-stage a greater number of drain pumps at critical or flood-prone manholes.		

As it is neither practical nor feasible for Con Edison to build resilience to the point that its steam system can fully withstand the impacts of extreme events, Con Edison could also consider implementing additional strategies to better absorb and recover from impacts, such as improving systems for crowd-sourcing steam system leak detection.

Moving Towards Implementation

Initial Climate Projection Design Pathway

Implementation of adaptation options to mitigate vulnerabilities requires clear climate design guidelines that incorporate forward-looking regional climate change projections. To this end, the Study team suggests that Con Edison could establish an "initial climate projection design pathway" that considers appropriate risk tolerance levels within the range of climate change projections. The initial climate projection design pathway is meant to guide preliminary planning and investments until and if Con Edison can refine the pathway to reflect new climate projections with reduced uncertainties, changes to Con Edison's operating environment, and changes in city guidance. The following section outlines an adaptive management approach that allows Con Edison to monitor, manage, and design to acceptable levels of climate risk through time.

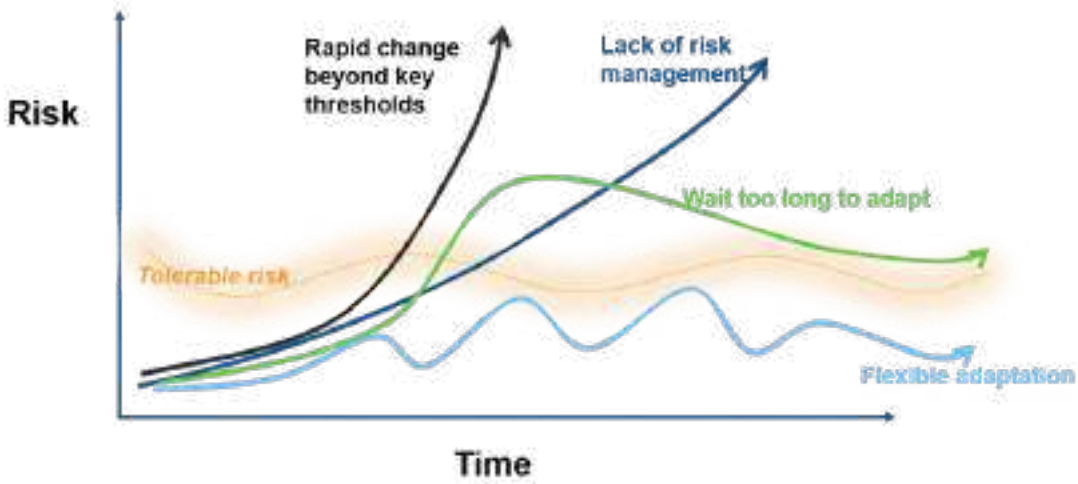
As an initial climate projection design pathway for decisions that require it, Con Edison will follow the conservative precedent set by the city's climate resiliency design standards (e.g., Mayor's Office of Recovery and Resiliency, 2019), combined with the state-of-the-art climate projections produced for this Study. Corresponding to city guidance, the same pathway may not apply uniformly across different climate change projections and hazards. More specifically, multiple climate projection design pathways may be required to address differences in the risk tolerance and projection uncertainty associated with different climate hazards. Under this framework, initial pathways could use the 50th percentile merged RCP 4.5 and 8.5 projections for sea level rise and high-end 90th percentile merged RCP 4.5 and 8.5 projections for heat and precipitation. Climate projection design pathways will be finalized for Con Edison's Climate Change Implementation Plan.

Alternative considerations are necessary to inform pathways for rare and difficult-to-model extreme events without probabilistic projections, such as 1-in-100-year heat waves and strong, multi-faceted hurricanes. Rather than prescribing statements of probability, these types of extremes require the blending of plausible worst-case scenarios from a climate perspective with stakeholder-driven worst-case scenarios from an impact perspective. Until climate modeling can better resolve and simulate these types of rare extreme events, the union of these two perspectives is critical for determining acceptable risk tolerance levels and setting initial pathways.

Flexible Adaptation Pathways Approach

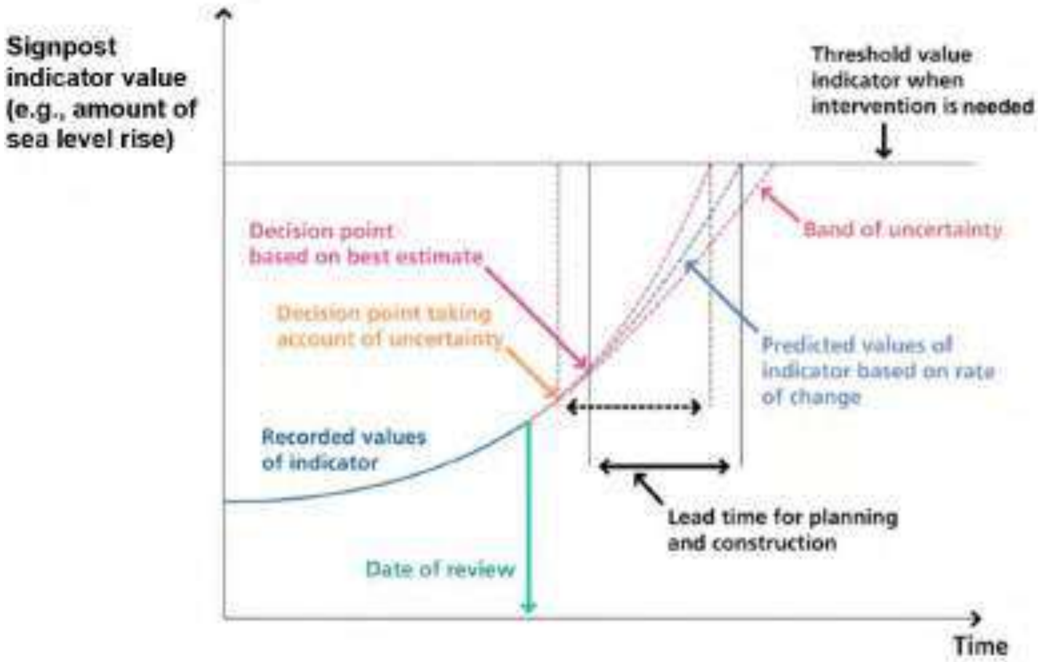
While the initial climate design pathway can inform asset design, a complementary approach is needed to ensure resilience over the lifetime of that asset. A flexible and adaptive approach will allow Con Edison to manage risks from climate change at acceptable levels, despite uncertainties about future conditions. The flexible adaptation pathways approach ensures continued adaptability over time as more information about climate change and external conditions is learned. Figure 23 depicts how flexible adaptation pathways are used to maintain tolerable levels of risk.

Figure 23 ■ Flexible adaptation pathways in the context of tolerable risk and risk management challenges to non-flexible adaptation. Adapted from Rosenzweig & Solecki, 2014.



Con Edison will need to consistently track changing conditions over time to identify when additional adaptation strategies are required. This approach relies on (1) monitoring indicators ("signposts") related to climate conditions, climate impacts, and external conditions that affect system resilience, and (2) pre-determined thresholds to signal the need for a change in risk management approaches ("transformation points"). This approach can support decisions on when, where, and how Con Edison can take action to continue to manage its climate risks at an acceptable level. Figure 24 depicts how a signpost indicator and a predefined threshold can be applied in the adaptation pathways approach to inform the timing of action given uncertainty.

Figure 24 ■ Schematic diagram of how an indicator of change for a particular signpost (e.g., amount of sea level rise) informs decision lead times that take into account uncertainty (Ranger et al., 2012).



Con Edison is already familiar with monitoring signposts to manage planning uncertainties and guide adjustments to its Electric, Gas, and Steam Long Range Plans.[20] Con Edison currently monitors signposts related to the pace of technology innovation (e.g., energy management technologies), the nature of regulation and legislation (e.g., new or revised greenhouse gas reduction policy targets), and the future of the economy (e.g., higher economic growth and impacts on demand), among others. In addition, the flexible adaptation pathways approach to manage climate change risks has been applied more widely by New York City and New York State (New York City Mayor's Office of Resiliency, 2019; Rosenzweig & Solecki, 2014) and utilities and infrastructure agencies across the United States, including San Diego Gas & Electric (Bruzgul et al., 2018; SDG&E, 2019) and Los Angeles Metro (Metro ECSD, 2019).

This flexible adaptation pathways approach allows Con Edison to develop an adaptation implementation plan in the near term, while adjusting adaptation strategies based on the actual climate conditions that emerge, thus reducing the cost of managing uncertainty. Under this adaptive approach, resilience measures can be sequenced over time to respond to changing conditions. For example, Con Edison may identify actions to implement now that protect against near-term climate changes and actions that are low and no regret, while leaving options open to protect against the wide range of plausible changes emerging later in the century. This implementation approach is preferred to implementing actions now that are optimized for present-day conditions or a single future outcome that ignores uncertainty.

[20] Long Range Plans are available at: https://www.coned.com/en/our-energy-future/our-energy-vision/long-range-plans

Illustrative Adaptation Pathway: Sea Level Rise Adaptation for Substation in FEMA + 3' Floodplain

Flexible adaptation pathways could be developed for guiding the management and protection of specific assets or types of assets. Here, we consider a hypothetical electric substation that is potentially vulnerable to sea level rise, as it is located within the FEMA + 3' floodplain (and, as such, is protected up to FEMA + 3' flood heights based on Con Edison's current design standards). This adaptation pathway is presented as *illustrative*; while it is grounded in the types of strategies that Con Edison would use for substation flood defense, a ready-to-implement pathway for implementation would require site-specific analysis and may differ from this configuration.

Figure 25 ■ Illustrative flexible adaptation pathway for a hypothetical Con Edison substation in a current FEMA + 3' floodplain

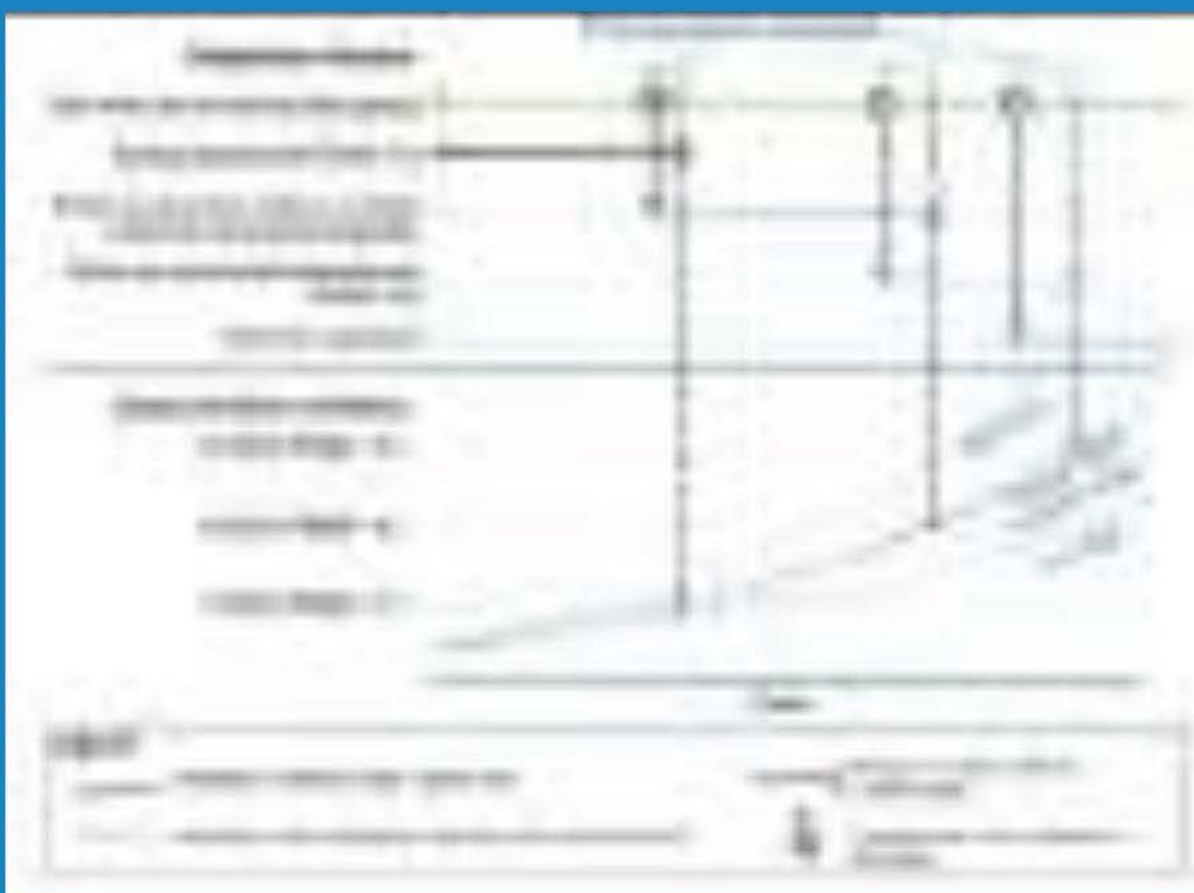


Figure 25 illustrates how the implementation of adaptation actions can be phased over time, with the implementation of new measures being triggered by observed sea level rise in excess of certain thresholds (transformation points). The timing of these transformation points is indicated by monitoring the rate of sea level rise at a local tide gauge (green line). Transformation points are set based on the point at which Con Edison needs to take action in order to implement a higher standard of protection before existing protections become insufficient.

In this adaptation pathway diagram, the implementation schedule of adaptation measures is illustrated based on a "central" sea level rise case. Measures based on this central scenario are illustrated with solid lines. If the actual pace of sea level rise deviates from the central case, monitoring of sea level rise may necessitate an accelerated or delayed implementation schedule

In this example, it is assumed that the substation already has existing protections to FEMA + 3' based on Con Edison's post-Superstorm Sandy hardening measures (black line). However, these protections will no longer be sufficient to provide the requisite 2 feet of freeboard under a 100-year flood scenario once sea level rise surpasses 1 foot.

- A trigger slightly under 1 foot leads to the first adaptation option, which is to supplement the substation's defense-in-depth strategy with additional sump pump capacity.
- The second adaptation option is triggered when sea level rise approaches 2 feet, and includes building new permanent flood barriers to a FEMA + 5' level.
- The final adaptation option, relocating the substation entirely, is triggered when sea level rise approaches 3 feet.

Each trigger is far enough in advance of the critical risk threshold (each foot of sea level rise, in this case) to have time for full implementation of the adaptation option.

Such a flexible adaptation pathway can allow Con Edison to better manage the costs of adaptation in the face of uncertainty, facilitating a prudent approach that avoids adapting too early or too late.

Signposts provide information that is critical for adaptive management decisions. Broad categories of signposts that Con Edison could consider monitoring include:

- **Climate variable observations and best available climate projections:** An awareness of recent and present climate conditions and their rates of change are key when determining potential asset exposure and risk. As described above, Con Edison currently operates a number of stations that monitor climate variables and is finalizing plans to expand the number of monitoring locations. Furthermore, access to the most recent and best available climate projections and expert knowledge is critical when updating plans for potential future scenarios as the science advances. In some cases, thresholds for action under climate variable and projection signposts may be determined by how quickly changes in climate conditions are approaching existing design or operational specifications.
- **Climate impacts:** Con Edison is already experiencing extreme weather and climate impacts to assets, operations and internal processes, and customers. Recognizing the risks, Con Edison is already conducting monitoring to identify areas of heightened vulnerability in its systems. Continued monitoring and evaluation of highest risk assets for impacts or near impacts can provide information about when and where additional adaptation options may be required.
- **Policy, societal, and economic conditions:** Evolving external conditions may affect climate-related decision making and areas of need throughout the service territory. Con Edison is already monitoring signposts for external conditions related to policies, society, and economies as part of its long-range plans. Additional external conditions may shift with a changing climate, such as adaptation strategies and investments led by the city.

The Study team identified a set of example signposts within each category, summarized in Table 9. Con Edison could consider coordinating with the city on NPCC's proposed New York City Climate Change Resilience Indicators and Monitoring System (Blake et al., 2019), where overlap and efficiencies in monitoring signposts may exist.

Table 9 ■ Example signposts for a flexible adaptation pathways approach

Category	Example Signposts
Climate variable observations and best available climate projections	• *Chronic variables:* Rate of change in TV, cooling degree-days, heating degree-days, sea levels, etc. relative to historical • *Extreme weather variables:* Number of days overheat index thresholds, storm surge levels, frequency of various storm types in the greater region, wind speeds, heat wave intensity and duration, intense precipitation levels, etc. • Updates to the best available climate projections: NPCC, IPCC, National Climate Assessment, etc.
Climate impacts	• *Assets:* Extent and magnitude of the costs of keystone asset damages (e.g., substations or power lines downed), damages incurred by events with different combinations of extreme weather, etc. • *Operations and internal processes:* Frequency of heat-related contingencies in the network and non-network systems, etc. • *Customers:* Number, spatial extent, and duration of outages caused by extreme weather, especially noting outages experienced by critical infrastructure and interdependent systems, etc.
Policy, societal, and economic conditions	• *Policy:* Updates to New York City design guidelines, etc. • *Societal:* Community-scale flood protection strategies led by New York City (e.g., East Side Coastal Resiliency Project), population shifts (e.g., retreat), etc. • *Economic:* Insurance prices and availability, etc.

Selecting Cost-Effective Solutions

As outlined in this Study, adapting to climate change will require investments in infrastructure and processes. Although some adaptation will be achieved through co-benefits from investments that Con Edison makes under existing processes, such as using distributed energy resources to meet growing electricity demand, other adaptation will require investments over and above those previously planned. The costs of those investments will ultimately be reflected in customers' bills. In order to minimize the financial impact of adapting to climate change, a cost-effective resilience planning process should identify a target level of resilience along with associated metrics, strike a balance between proactive and reactive spending, consider both the costs and benefits to customers, and select adaptation strategies that provide optimal benefit at the lowest cost.

As the energy industry grapples with how best to build resilience to the changing climate, the issue of how to quantify the resilience of energy systems is front and center. There is currently no standard *set of metrics* for the resilience of energy systems. A 2017 report from the National Academies of Sciences, Engineering, and Medicine found that "there are no generally agreed-upon resilience metrics [for the electricity sector] that are widely used today," also noting a contrast with the well-established set of electricity reliability metrics (NAS, 2017).

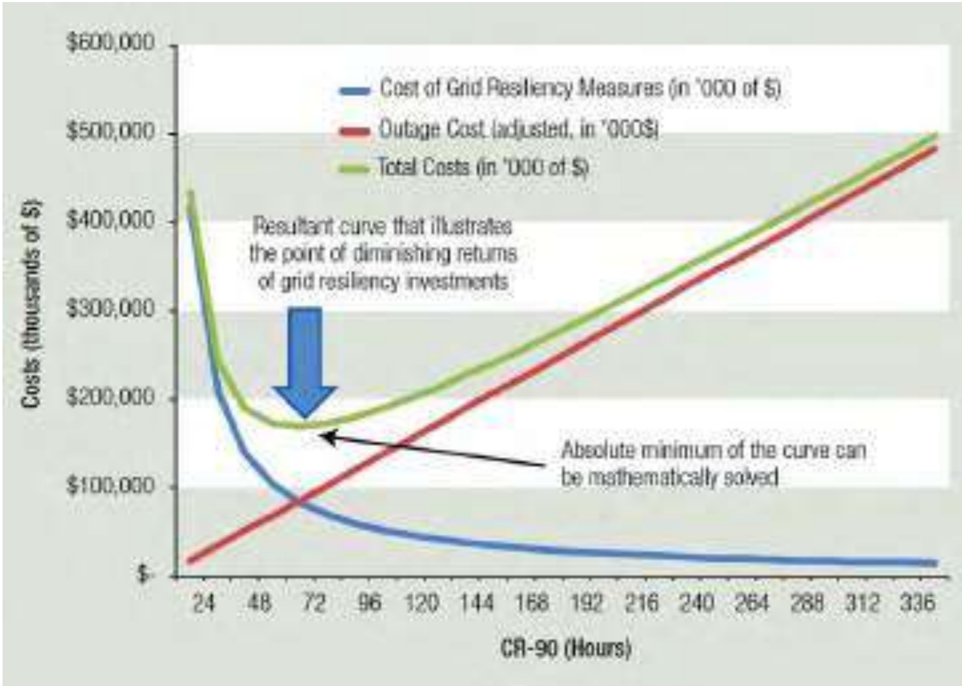
While there are a wide variety of energy resilience metrics that have been proposed or piloted in various contexts, most of these metrics fit within one of two broad categories. *Performance-based* metrics seek to quantify the resilience of the system through measurement of infrastructure performance during actual or modeled disruptive events. *Attribute-based* metrics, on the other hand, measure the presence of characteristics or features that are known or predicted to increase resilience performance in the event of a disruption. (Vugrin, Castillo, & Silva-Monroy, 2017).

Con Edison's storm hardening investments after Superstorm Sandy were guided by a combination of performance-based metrics, such as "past performance" in the selective undergrounding of feeders, and attribute-based metrics, such as "reducing the number of customers served by a single circuit to fewer than 500 customers," and adding "isolation devices to spurs and sub-spurs with open wire that are more than 2 spans in length" (Con Edison, 2013). Since the development of metrics is an active area of research and discussion, Con Edison could keep abreast of industry advances in resilience metrics for energy systems and incorporate those advances, where applicable, into its planning framework.

Even after a resilience metric(s) is selected, the question of exactly *how much* to spend on resilience or what the *right* level of resilience is, remains. One approach is to compare the societal cost of an outage against the cost of resiliency measures to shorten that outage. The total cost curve developed by ICF's Mihlmester and Kumaraswamy (Figure 26) is one example of such an approach (Mihlmester & Kumaraswamy, 2013). It shows for a hypothetical utility the post-outage time needed to restore service to 90% of customers, known in the industry as "CR-90." In this case, the lowest total costs, combining customer outage and grid-hardening costs, would be about $169 million for a 65-hour CR-90 restoration time. The graph also shows that getting the CR-90 time to less than a day would cost more than twice that amount.

For Con Edison, the "right" level of resiliency investment will be strongly linked to the climate projection design pathway selected for each of the climate stressors identified for resiliency planning.

Figure 26 ■ Total cost of resiliency (Mihlmester & Kumaraswamy, 2013)



Utilities have historically *reacted* to events, primarily because they lacked relevant climate projections and clear guidance or best practices for a methodology necessary to inform *proactive* adaptation and resiliency investments in infrastructure (California Energy Commission, 2018). Similarly, prior to conducting this study, Con Edison had limited information to guide proactive investments. The U.S. Department of Energy's North American Energy Resilience Model (U.S. DOE, 2019) highlights the need to "transition from the current reactive state-of-practice to a new energy planning and operations paradigm in which we proactively anticipate damage to energy system equipment, predict associated outages and lack of service, and recommend optimal mitigation strategies."

The Study team has described an overarching resilience management framework in Figure 12, designed to minimize the impacts of extreme events throughout asset life cycles. The framework considers how the system can withstand, absorb, recover, and adapt to risks posed by extreme events. To succeed, each measure of a resilient system requires *proactive planning and investments*.

Consideration of the *costs and benefits to customers* is a key component in the selection of adaptation options. Con Edison's capital budget cycle currently considers costs and benefits through an investment optimization and management process that compares the wide array of capital investments the company makes across its various business units. The process calculates a "strategic value" for each project to compare the benefit of investing in one capital project or program over another and to ensure that spend is in alignment with the company's corporate strategy. The strategic value is conveyed by a set of strategic drivers, each with relative weights, based on the company's long-term objectives. The strategic value of each capital project is assessed against that of other projects, and an optimized portfolio of capital projects is generated. While the strategic drivers include *reliability* and customer satisfaction components, the drivers do not include or consider the *resiliency* benefit of a project.

Con Edison developed and used a cost-benefit calculation model to prioritize storm hardening investments after Superstorm Sandy. The model estimated "the vulnerability of individual electric system assets based on the impact of electric system damage to customers and supporting critical infrastructure, the duration of an electric service outage, the likelihood of those assets being affected by either flooding or wind damage, and the reduction in vulnerability of those assets because of storm hardening initiatives." (Con Edison, 2014)

Con Edison's current distribution system planning process includes an evaluation of customer benefits resulting from investments. Con Edison's Distributed System Implementation Plan (DSIP) (Con Edison, 2016) includes the consideration of distributed energy resources as one option to meeting growing demand. As part of Con Edison's DSIP, the company has developed a Benefit Cost Analysis (BCA) Handbook that describes how to calculate individual benefits and costs. The BCA includes consideration of the unit cost of a particular option, per megawatt of delivery capacity, as well as an option's "social cost." Social cost accounts for the monetization of air pollution and carbon dioxide, using 20-year forecasts of marginal energy prices, the cost of complying with regulatory programs for constraining these pollutants, and the price paid for renewable energy credits. The social cost metric also qualitatively accounts for avoided water and land impacts. Beyond these environmental aspects, social cost accounts for net avoided restoration and outage costs to Con Edison, as well as net non-energy benefits (such as avoided service terminations, avoided uncollectable bills, and avoided noise and odor impacts).

This Study illustrates the use of multi-criteria analysis to compare criteria that may be difficult to quantify or monetize, or that may not be effectively highlighted in the financial analysis. This process identified additional complementary metrics that could be included in Con Edison's planning and budget prioritization process to account for uncertainty in climate outcomes. These metrics fall into two categories: co-benefits and adaptation benefits. Under a non-stationary climate, co-benefits (environmental, reputational, safety, and customer financial benefits) can help planners more comprehensively evaluate response options considering the additional challenges that climate change can pose on the system. In addition, consideration of adaptation benefits (flexibility, reversibility, robustness, proven technology, and customer's resilience) support long-term planning under climate uncertainty. These metrics allow for effective implementation of adaptation measures over time to achieve resilience. Con Edison's current processes include some of the metrics identified in the multi-criteria analysis (environmental and safety) but not others (customer's resilience and reversibility). Con Edison could work to incorporate this wider set of metrics as it incorporates resiliency planning into its broader capital budgeting process.

Key Issues to Be Addressed for Effective Implementation

Changes in the Policy/Regulatory and Operating Environment

Changes in the policy/regulatory and operating environment other than climate change were not accounted for in this Study but will be an important consideration when moving toward implementation. For example, the prioritization of adaptation strategies, and even the understanding of vulnerabilities, will need to consider these other drivers of change. Likewise, as Con Edison undertakes studies on how these factors will impact its business, climate change impacts could be factored into those studies. Some examples of possible changes in Con Edison's operating environment include:

- **Climate change and clean energy targets:** New York State and New York City have both adopted ambitious greenhouse gas emissions reduction targets (State of New York, 2019; City of New York, 2014), which will drive changes in the adoption of renewables, transportation electrification, energy storage, and so forth. It will also impact relative demand across the commodities (e.g., decreasing gas demand and increasing electricity demand).

- **Technological advances:** Advances in solar photovoltaics, energy storage, electric vehicles, and electrification of space heating are changing how and where electricity is generated and used.
- **Customer response to climate change impacts:** Customers will also have to respond to climate change impacts. This may include shifting away from flooded coastlines (depending on city-scale investments in coastal protection) and, with it, shifting demand away from portions of Con Edison's system.

Coordination with External Entities

Another critical need for effective implementation is coordination with external entities, including the City of New York and Westchester County, industry groups, equipment manufacturers, and others. Con Edison has limited authority to address certain vulnerabilities, such as the capacity of the city's stormwater system, so coordination is necessary for developing a more resilient system. In addition, coordination is needed to ensure that Con Edison is not over-investing in locations that the city plans to protect or retreat from. This project seeded the necessary relationships; however, the continuation of the interactions will need to be specified in the governance section of the upcoming implementation plan.

Establishing a Reporting and Governance Structure

Con Edison will need a continuing approach to updating stakeholders on climate risk management progress. Of the various reporting options, many companies are opting to follow the relatively new framework outlined by the Task Force on Climate-Related Financial Disclosures (TCFD).[21] This framework emphasizes the need to assess both the physical risks of climate change, which is covered in this study, as well as the risks and opportunities presented by transition to a low-carbon economy. It requires consideration of the financial implications of the risks and opportunities, as well as a measurable risk management plan that is integrated with a strong governance structure.

Two risks that were not explored in this study, but would fit well in the TCFD framework, include:

- **Costs and penalizations from service failure and outages:** Costs associated with an outage event include restoration; collateral damage; customer claims; penalties, fines, audits, remediation, and reporting; and the financial impact of lost confidence. For example, in 2007, Con Edison was penalized $18 million for its 2006 service disruptions, which included a 9-day blackout in western Queens.
- **Credit rating:** Increasingly frequent and intense extreme weather events could also impact credit rating risks and insurance liabilities. Credit rating agencies like Standard & Poor's and Moody's have added "resiliency" as a component of their rating criteria, indicating the relevance of climate risk for creditworthiness (Shafroth, 2016). Similarly, utilities may be increasingly choosing to retain a higher level of insurance to cope with more frequent and destructive weather-related events. However, a higher level of insurance protection leads to higher costs that may ultimately be reflected on customers' bills. Thus, while not as visible as physical asset or planning vulnerabilities, climate risks related to credit and insurance can have an impact on the utility.

Establishing a governance structure will be crucial for the successful continuation of Con Edison's climate change adaptation work. The governance structure can be used to encourage and track progress on the implementation of adaptation strategies (i.e., performance against set metrics and targets), ensure specific

[21] For more information on the Task Force on Climate-Related Financial Disclosures, see https://www.fsb-tcfd.org/

people are on point for monitoring and implementing various strategies, and establish a frequency and process for reporting on risks and adaptation actions from individual employees to senior managers to Con Edison's board of directors.

Next Steps

As a next step from this Study, Con Edison will develop a detailed Climate Change Implementation Plan to operationalize the suggestions from this Climate Change Vulnerability Study. The implementation plan will:

- Review the Study and investigate whether recent progress in climate science may warrant inclusion.
- Select climate change pathway(s) to incorporate into design standards and procedures.
- Establish life cycle tables that provide timeframes of reference climate variables through 2080.
- Aggregate input from subject matter experts on changes required for specifications/procedures and choices for risk mitigation measures.
- Develop a timeline and written plan for the implementation of risk mitigation measures.
- Identify the scope and cost within the 5-year capital plan and 10- and 20-year long-range plans.
- Establish signposts for the re-evaluation of measure installation schedules.
- Conduct periodic progress meetings for external stakeholders.
- Recommend a governance structure for climate change monitoring and updating.

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APPENDICES

Appendices

To inform the conclusions of this Study, the Study team undertook a series of in-depth vulnerability assessments corresponding to the climate hazards representing outsized risks to Con Edison: temperature, humidity, precipitation, sea level rise, and extreme events. These are included as appendices. Each appendix includes detailed historical and projected climate conditions; corresponding climate-driven vulnerabilities to operations, planning, and infrastructure across the company's electric, gas, and steam systems; and potential adaptation strategies to mitigate vulnerabilities.

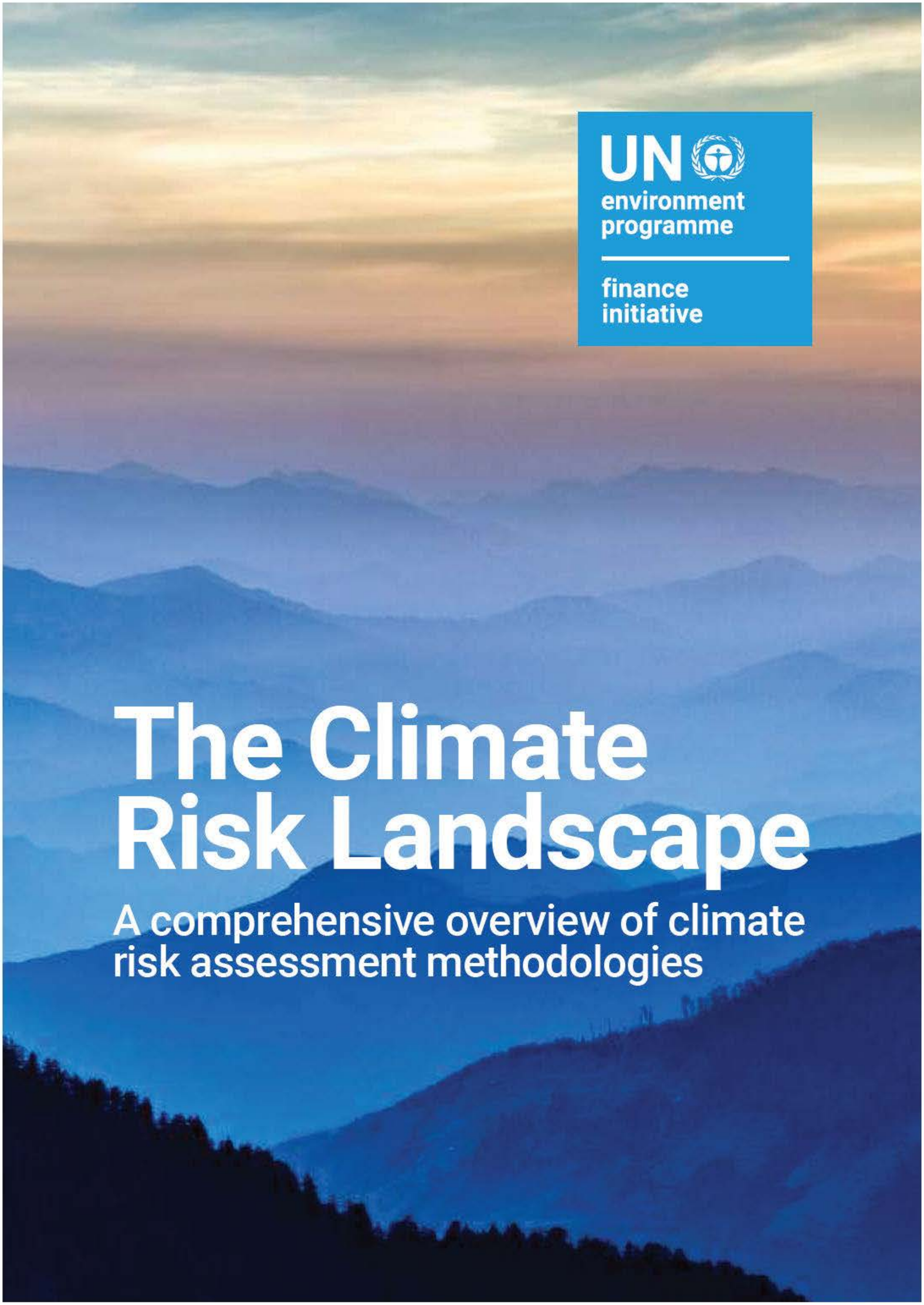
For each hazard, the Study team collaborated with Con Edison subject matter experts to conduct a rapid screen of the sensitivity of operations, planning, and infrastructure to support a risk-first approach. Vulnerabilities were then selected for more detailed analyses, which focused on understanding asset vulnerabilities to climate change and, in turn, relevant adaptation options and evaluation of their costs and co-benefits. These analyses informed the development of flexible solutions and signposts to guide implementation of potential adaptation options through time.

Ultimately, the five appendices provide key context for the climate science, vulnerabilities, and adaptation strategies discussed in this report, and as such, can be referenced for more comprehensive information in each subject area.

- **Appendix 1 – Temperature:** Identifies how projected gradual trends in increasing temperature may affect operations, planning, and infrastructure across the electric, gas, and steam segments of Con Edison's business.
- **Appendix 2 – Humidity, Temperature Variable, and Load:** Addresses climate variables—humidity (expressed through wet bulb temperature), heat waves, cooling degree-days, heating degree-days, and the combination of projected changes in wet and dry bulb temperatures—that have a direct effect on system loads and reliability. These variables are also specifically addressed in specifications and procedures associated with upgrading system capacity and maintaining system reliability.
- **Appendix 3 – Changes in Precipitation Patterns:** Discusses the potential for climate-driven changes in rainfall and frozen precipitation in Con Edison's service territory, and the potential impacts of those changes on Con Edison's assets and operations.
- **Appendix 4 – Sea Level Rise and Changes in Coastal Storm Surge Potential:** Examines the ways in which changes in sea level may affect operations, planning, and infrastructure across the electric, gas, and steam segments of Con Edison's business.
- **Appendix 5 – Extreme Events:** Describes how extreme weather events (hurricanes, nor'easters, and heat waves), as well as concurrent or consecutive extreme events, may become more frequent and severe due to climate change, and considers their potential impact on operations, planning, and infrastructure across the electric, gas, and steam segments of Con Edison's business over the coming century.

ATTACHMENT 2

Paul Smith, UNEP FI, The Climate Risk Landscape: A Comprehensive Overview of Climate Risk Assessment Methodologies (2021)



UN environment programme

finance initiative

The Climate Risk Landscape

A comprehensive overview of climate risk assessment methodologies

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1. Introduction

The forward-looking nature of climate risk assessments imply a myriad of assumptions, baselines, inputs and modelling choices that result in a great diversity of methodologies and tools available to financial institutions. This in turn leads to some difficulties for banks and investors to make transparent, informative choices on climate risk modelling approaches, while standardisation is hampered by the great uncertainty over the most appropriate model choices in a forward-looking risk assessment.

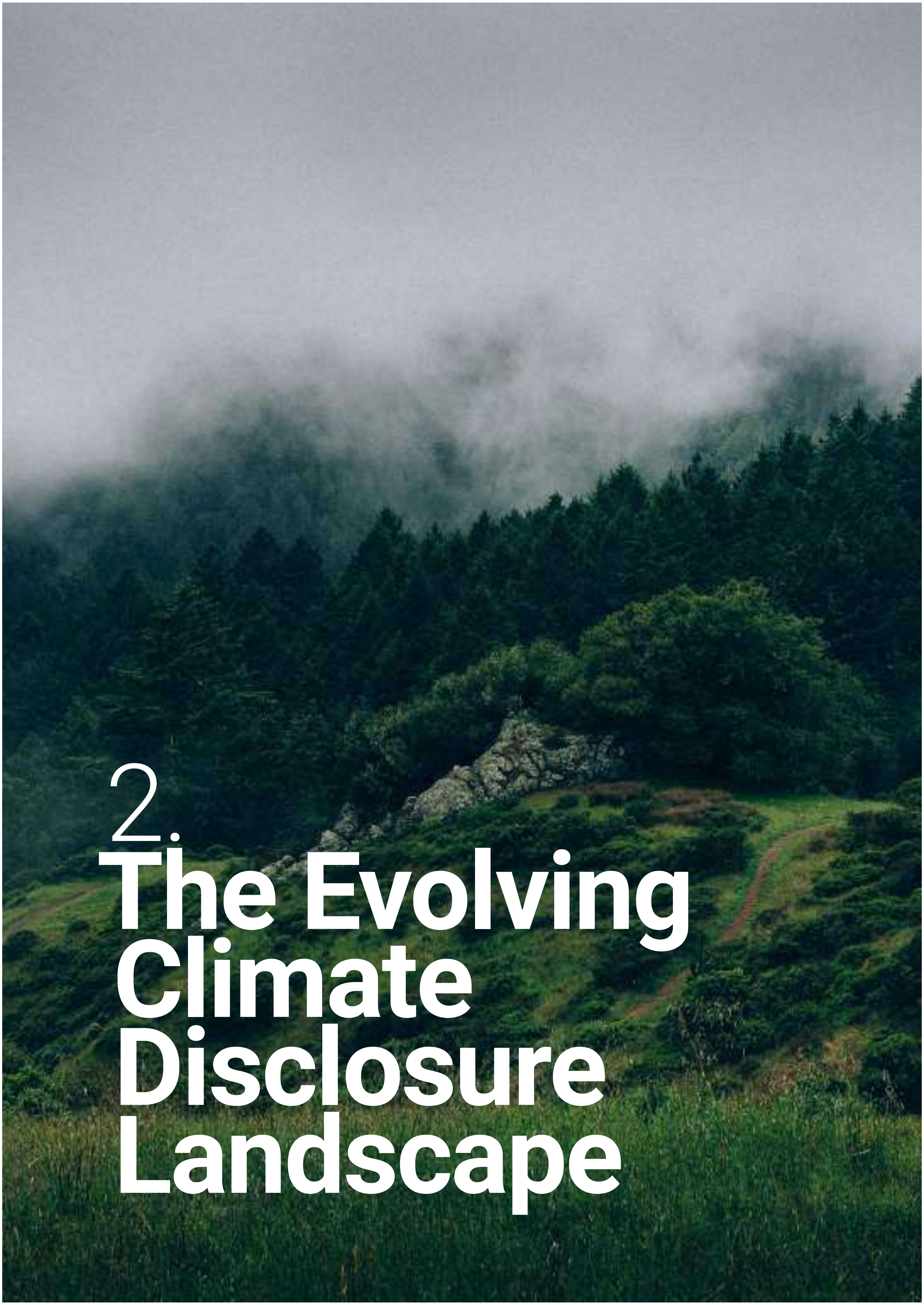
Since the publication of UNEP FI's 'Changing Course' report in May 2019, the tools available to financial institutions that wish to use scenario analysis to reinforce their climate-related risk assessments and disclosures have developed and expanded rapidly. This report is intended, not to provide a comprehensive guide to scenario analysis and risk assessment, but rather a summary of the key developments of the climate risk assessment landscape since May 2019, including new and updated scenarios, methodological tools, key guidelines, as well as an overview of the changing regulatory landscape and potential developments into 2021.

This report covers both physical and transition risks, though the headline results on physical risks have incorporated the results of an analysis of physical risk methodologies and data sources in chapters 2 (Data portals) and 4 (Methodologies) of Acclimatise's recently released report, 'Charting a New Climate' (2020) developed for UNEP FI's TCFD Banking Pilot Project Phase II. This overview has adopted a two-step process by engaging with methodology developers to provide information on their tools and methodologies, which have been subsequently verified through objective research.

The report opens with a chapter on the evolving landscape of climate disclosure since May 2019, taking a brief look at how new regulations and reporting guidelines have emerged, and the increasing regulatory push for climate stress-testing, as well as the development of portfolio temperature assessments.

The second and third chapters provide a broad overview of the landscape of scenario analysis methodologies for the estimation of transition and physical risks from climate change. The intention here is not to provide an endorsement of one methodology over another but to present some of the key strengths and differences in approaches.

The report concludes with an overview of advances in scenario development, a review of emerging trends and what financial institutions should look out for in 2021.



2. The Evolving Climate Disclosure Landscape

2.1 Recent developments in regulation

Over the past year, the number of climate risk reports has increased in quality and number (Carlin, 2020). However, as highlighted in 'Changing Course' and in the TCFD's own 2019 Status Report, scenario analysis remains far from commonplace aside from larger, more climate-aware institutions in leading countries (UNEP FI, 2019). Despite the relatively high interest – as of September 2020, 739 financial institutions had signed up as supporters of the recommendations of the TCFD (Mitchell et al, 2020) – very few financial firms are actively disclosing. Those institutions that do disclose have not been able to follow harmonised standards while the difficulty of accessing robust, high-quality data and scenarios has compromised the quality and usefulness of their disclosures. The COP26 Secretariat's Financial Coalition Coordination Mechanism is encouraging financial firms to conduct scenario analysis and implement climate-risk reporting, while the Principles for Responsible Investment (PRI, 2020) have made reporting on certain climate indicators mandatory – though disclosure remains voluntary.

2.1.1. Risk disclosure mandates

With the voluntary disclosure framework only providing piecemeal disclosures and limited data on the financial impacts of climate change so far, regulators, central banks and ratings agencies are increasingly under pressure to introduce mandatory climate risk disclosure frameworks. Mark Carney, the former chair of the Financial Stability Board and catalyst for the establishment of the TCFD, has advocated for a mandate (TCFD, 2019), while Ceres has called on the SEC to implement more stringent climate-related reporting (Ceres, 2020). The Basel Committee on Banking Supervision (BCBS) established the Task Force on Climate-related Financial Risks (TFCR) in February 2020, to maintain the stability of global financial systems in the face of climate-related risks, commencing with a stocktake of member initiatives on climate-related financial risks. In September 2020, the government of New Zealand became the first country to announce mandatory climate-related financial disclosures for publicly listed companies and large banks, investors and insurers (NZMFE, 2020). The following table gives a flavour of the status of the climate-related reporting mandates and voluntary initiatives in selected jurisdictions worldwide:

USA	2020	Commodity Futures Trading Commission (CFTC)	Establishment of Climate-related Market Risk Subcommittee (CRMS) and release of the Managing Climate Risk in the U.S. Financial System report (2020) urging financial regulators in the U.S. to "move urgently and decisively to measure, understand, and address these risks", taking advantage of "existing statutes".
	2019	New York State Department of Financial Services (NYDFS)	Non-binding expectations of insurers to consider "the financial risks from climate change into their governance frameworks, risk management processes, and business strategies" and to "start developing their approach to climate-related financial disclosure." (NYDFS, 2020)
UK	2019	Bank of England, Prudential Regulation Authority (PRA)	PRA supervisory statement SS3/19, "Enhancing banks' and insurers' approaches to managing the financial risks from climate change"
	2019	Department for Business, Energy and Industrial Strategy (BEIS)	Green Finance Strategy: Expectation for all companies to disclose in line with TCFD recommendations by 2022 (BEIS, 2019).
	2020	HM Treasury	Interim Report of the UK's Joint Government Regulator TCFD Taskforce, publishes a roadmap towards mandatory climate-related disclosures by 2025, with the majority of measures implemented by 2023.
European Union	2020	Non-Financial Reporting Directive (NFRD)	Targeted consultation on strengthening reporting of sustainability and climate-related information in the NFRD (2014/95/EU).
	2019	European Banking Authority (EBA)	Article 98.8 of the Capital Requirements Directive (CRD5) requires EBA to assess the inclusion of ESG risks in performance & evaluation.
France	2016	Article 173	Non-mandatory financial reporting, including climate.
Hong Kong	2020	HKEX	Mandatory ESG governance and reporting
New Zealand	2020	Ministry for the Environment	Mandatory climate risk reporting legislation to be presented to Parliament following 2020 general election. Disclosure by all registered banks, credit unions, building societies, managers of investment schemes, and licensed insurers with total assets of more than NZ$1bn and all equity and debt issuers listed on the NZX by 2023.
Canada	2020	Bank of Canada Canada Development Investment Consortium (CDEV)	Discussion / exploratory paper on scenario analysis. TCFD reporting mandatory for companies receiving emergency funding during the pandemic: Large Employer Emergency Financing Facility (LEEFF) (CDEV, 2020)
Japan	2019	Japan TCFD Consortium	The Consortium is a public-private partnership to promote TCFD disclosure. This has led to higher voluntary corporate TCFD reporting than in any other country (Ikeda, S., 2020).

Switzerland	2019	Federal Office for the Environment (BAFU)	Legal opinion shows that climate-related risks need to be taken into account according to existing law (Eggen & Stengel, 2019) Switzerland became a supporter of the TCFD in January 2021 and has launched a consultation on mandatory climate-related risk disclosure.
Australia	2020	Australian Pruden-tial Regulation Authority (APRA)	2021 Climate Risk Vulnerability Assessment, for major banks (Australia's largest deposit-taking institutions, ADIs). Climate risk disclosure remains voluntary, however (APRA, 2020).

Table 1: Overview of mandatory and voluntary disclosure recommendations on climate-related risk from a selection of regulators and policy makers

Some private investors are starting to move the dial, particularly in jurisdictions where there has been relatively little regulatory guidance on climate risk disclosure in recent years, such as in the United States. BlackRock, the world's largest asset manager, has requested TCFD-aligned climate-related risk disclosures from all their investee companies by the end of 2020, holding board members of those companies directly accountable for reporting (Fink, 2020). To give one high profile example of this new approach, BlackRock issued a statement voting against Exxon Mobil directors for not taking sufficient action on TCFD-aligned risk disclosure (BlackRock, 2020). State Street Global Advisors are also threatening voting action against major publicly listed investees that fail to improve poor sustainability ratings, based on SSGA's proprietary R-Factor rating, including climate-related risk (SSGA, 2020).

2.1.2. Risk disclosure standards and guidelines

Figure 1: CDP's 'Building blocks' report showing how CDSB and CDP guidelines allow for the development of TCFD-standard reports

Whether mandated or not, climate-related reporting has come under criticism for its lack of standardisation, making it difficult to compare disclosures. Voluntary reporting frameworks remain the norm in an absence of mandates. In September 2020, several reporting standards organisations, including CDSB, SASB, CDP, GRI and IIRC[1] jointly committed to align their sustainability reporting requirements (CDP, 2020a), building on CDP's work with CDSB to integrate the recommendations of the TCFD (CDP, 2020b). This is certainly a step in the right direction, as they form the basis of voluntary reporting for global financial firms. In parallel, the Network for Greening the Financial System (NGFS) has developed technical guidelines to help its members integrate climate-related and environmental risks into prudential supervision (NGFS, 2020a), as well as working closely with scenario developers to issue a set of standard scenarios (NGFS, 2020b), built on existing well-developed Integrated Assessment Models (IAMs),[2] allowing for assessment of both transition and physical risks. The following table outlines some of the guidelines and standards that have been developed in a handful of jurisdictions, often to accompany mandatory or voluntary reporting:

USA	2010	Securities and Exchange Commission (SEC)	Guidance on Disclosure Related to Climate Change. No recent climate-related risk disclosure updates despite recent amendments to risk disclosure rules (Herren Lee, 2020)
European Union	2020	Disclosures Directive	Regulation 2019/2088 requires annual disclosure standards.
	2020	European Central Bank (ECB)	Draft guide on incorporating climate-related and environmental risks into existing risk framework (ECB, 2020)
	2020	European Insurance and Occupational Pensions Authority (EIOPA)	EIOPA is currently holding a consultation on its expectations of national competent authorities to supervise the integration of climate changes scenarios in their 'Own Risk and Solvency Assessments' (ORSAs).
Singapore	2020	Monetary Authority of Singapore (MAS)	Introducing guidelines on climate risk disclosure, currently under consultation (MAS, 2020).

Table 2: Overview of standards and guidelines on climate-related risk from a selection of regulators and policy makers

Leading climate finance groups such as the Climate Safe Lending Network, suggest that even mandating climate risk disclosure is not enough and financial institutions need to disclose their impact on systemic or planetary climate risks (Vaccaro, 2020) – in other words an "inside-out" risk assessment rather than an "outside-in" assessment.

1 CDSB: Climate Disclosure Standards Board; SASB: Sustainability Accounting Standards Board; GRI: Global Reporting Initiative; IIRC: International Integrated Reporting Council

2 GCAM, MESSAGEix GLOBIOM and REMIND MAgPIE

2.1.3. Stress testing

A handful of central banks are integrating climate change into stress tests to assess the stability of the financial system to these more systemic, longer-term risks:

- The Bank of England has extended its stress testing horizon to 30 years through the Biennial Exploratory Scenario (BES). The BES requires financial firms to run scenarios against their balance sheet exposure and set out management responses. In a second round, the BoE may ask firms for their responses in light of system-wide impacts. The BES is not strictly a stress test as it does not run high-impact scenarios.
- The Netherlands' Central Bank (Den Nederlandsche Bank, DNB) conducted an energy transition stress test in 2018, which has showed that Common Equity Tier 1 (CET1) ratio could drop by over 4 percentage points in a severe but plausible transition scenario.
- The French central bank's regulatory authority (*L'Autorité de contrôle prudentiel et de résolution*, ACPR) has developed stress testing based on the NGFS scenarios (see 3.1), and drilling down to explore national macroeconomic, sector and firm level risks using in-house models (ACPR, 2020b).
- These pilot stress tests by Eurozone national central banks have paved the way for the European Central Bank to integrate climate-related stress tests, integrating macroeconomic factors such as sudden transition risks (capital flight from certain sectors/regions).
- Outside of Europe, strengthening the finance sector's resilience to climate risk is one of the four pillars of the Monetary Authority of Singapore's (MAS) green finance action plan. Under these proposals, the MAS will include climate-related scenarios in its annual financial stress test by 2022.

2.2 Combining physical and transition risks

The physical impacts of climate change are already impacting on our economy and society, and further temperature rise is already baked in. Realistically, not even the most optimistic transition scenario can ignore the risks from the physical impacts of climate change. Therefore, scenario developers and methodology providers are increasingly working towards combined transition and physical risk methodologies to provide a complete picture of climate-related risk. Integration of these two approaches is not straightforward as physical and transition pathways are strongly dependent on different location- and sector-specific variables. Physical hazards are strongly location-specific and dependent on actual temperature rise, while adaptive capacity can vary between sectors. Transition risk is highly sector-specific and relates to politically determined mitigation targets.

The NGFS suite of scenarios aims to bridge the two risk frameworks, with methodologies being developed over 2020-21 to integrate the two aspects. Consolidation is also being delivered by commercial providers, while ratings agencies have moved to integrate climate risk specialists with both physical and transition risk expertise, for example Carbon Delta by MSCI and Moody's Analytics who have brought in physical risk expertise from Four Twenty Seven and transition risk specialists, Vigeo-Eiris (V.E), as part of the climate focus of the newly formed Moody's ESG Solutions Group.

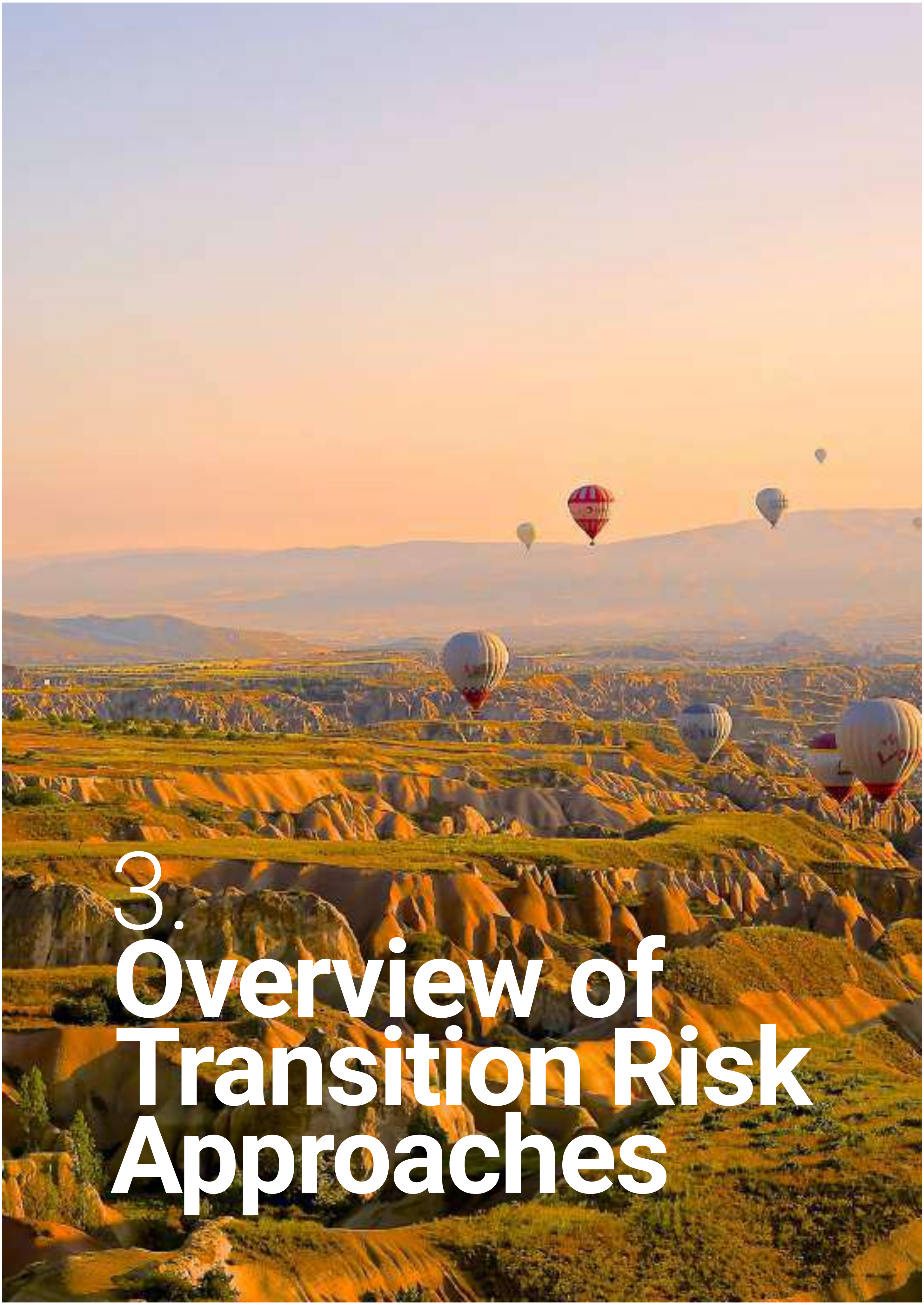
While we focus in this report on scenario-based risk assessments, it must be remembered that the TCFD report also refers to other risks including litigation and reputation. UNEP FI's TCFD Pilot for insurers assesses the exposure of insurers to litigation risk in the face of climate change and UNEP FI are also aiming to publish a high-level briefing on litigation risk and climate change adaptation in March 2021.

2.3 Moving beyond the current risk disclosure framework

Mark Carney has suggested that current disclosure frameworks need to evolve in order to reflect financial institutions' climate-related risk, not only to their own portfolios, which are considered only through the very short-term lens of the investment horizon, but to take into account their contribution to systemic or global risks. In his 'Road to Glasgow' speech in 2020, he posited the need to expand the existing frameworks to adopt more active measures to address systemic risk, such as:

i. the net zero alignment of portfolios,
ii. reporting on transition progress, and
iii. reporting portfolio warming potential.

These approaches could act as a stepping-stone from the current risk assessment paradigm of the TCFD framework to a more active alignment with the key objective of Article 2.1(a) of the Paris Agreement to "hold the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the increase to 1.5°C" (UNFCCC, 2015). The TCFD Secretariat are currently exploring how portfolio warming potential may be integrated into the TCFD framework to better measure the impact of business operations on systemic risk, while the Bank of England's BES adopts a temperature alignment score. For more details on the different types of alignment and impact models, and a discussion on how appropriate these metrics are for measuring portfolio alignment, see the recent study by the Institut Louis Bachelier (Reynaud et al, 2020).



3. Overview of Transition Risk Approaches

3.1 Introduction

Developing a tool or methodology that can provide a robust assessment of climate-related risk, whether transition or physical, is a considerable undertaking. In terms of transition risk, it can require access to considerable data on future technology, access to a wide range of climate and macroeconomic models, and an understanding of forward-looking climate and economic assumptions. A number of proprietary tools and methodologies have been developed by commercial service providers.

This section provides an overview of eighteen transition risk tools and analytics. The set of service providers listed and reviewed in this section is certainly not exhaustive, but is an attempt to include the principal commercially available methodologies.

Almost all of the assessed methodologies' principal function is to analyse transition risk, using climate hazards and forward-looking carbon policy and technology variables as inputs in order to calculate the risk to clients, their operations and value chains, often in terms of financial metrics. A couple of exceptions to these risk assessment approaches have been included, as they may still be of use in assessing a portfolio's exposure to climate change transition. These are Carbone 4's Climate Impact Tool, which measures the impact of assessed portfolios on climate change, and 2DII's PACTA Stress Test Module, which assesses the level of exposure and potential losses of equity and bond portfolios to Paris-aligned transition pathways. Carbon Tracker's 2 Degrees of Separation tool is focused on one single sector (oil & gas), while the others cover all or most of the high emissions sectors.

This survey adopts the assessment framework developed in UNEP FI's Changing Course report last year, with some minor changes and including a number of supplementary criteria in order to complement the format of the overview of physical climate risk assessment tools in Chapter 4 of UNEP FI's Charting a New Climate report (pp. 42-53; UNEP FI, 2020). The information provided in this overview has been obtained firstly from publicly available sources and secondly from survey responses from most of the services providers covered below. Only Moody's Investor Services and PwC failed to respond to our survey.

The brevity of this overview does not allow for an in-depth review of each methodology. For more comprehensive research, the Swiss Federal Institute of Technology has published research on selected transition risk methodologies, including those developed by 2DII, Carbone 4, Climafin, ClimateWise, MSCI-Carbon Delta, Oliver Wyman, Ortec Finance, PwC/CO-Firm and Vivid Economics (now known as Planetrics) (Bingler & Colesanti Senni, 2020).

			Provider																		
			2DII (1)	2DII (2)	BAR	C4	CFIN	CT	CW	MA-VE	MIS	MSCI	OF	OW	OW-S&P	PwC	SP(1)	SP(2)	TCS	VE-PL	VR
Scenario Basis			IEA ETP | (IEA WEO) | (G'peace)	IEA ETP	Bespoke, or | Industry standard, e.g. IEA	Bespoke | (based on IEA ETP, IPCC, ...)	IEA ETP | IEA WEO	IEA WEO | IEA ETP (B2DS)	IEA ETP | IEA WEO		IEA WEO	Bespoke (PIK-REMIND, IIASA, GCAM)	E3ME	NGFS | (PIK, IIASA, GCAM) | IAMC	NGFS Bespoke 3-yr Carbon Tax Scenario	IEA ETP	IEA ETP | IEA WEO | IIASA SSPs | AE[R] | DDD | NGFS	IEA ETP | IEA WEO | IIASA SSPs | AE[R] | DDD | NGFS	SSP3-60 | SSP3-45	Bespoke	Bespoke
Scenarios	<2.0°C (RCP 2.6)		✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	2.0°C (RCP 4.5)		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	3.0°C (RCP 6.0)		✓	✓	✓	✓				✓		✓	(✓)	✓	✓		✓	✓	✓	✓	✓
	>4.0°C (RCP 8.5)				✓	✓			✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
	Disorderly?			✓	✓		✓			✓		✓	✓	✓	✓	(✓)[i]	✓	✓		✓	✓
Time horizons	Near term (2025-2040)		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Medium term (2050)				✓		✓						✓	✓	✓	✓	✓	✓	✓	✓	✓[ii]
	Long-term (2100)						✓[iii]						✓				✓	✓	✓	✓	
Transition Hazards	Policy		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Technology		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Risk analysis	Level of analysis	Asset	✓		✓			✓	✓	✓		✓			✓	✓		✓	✓	✓	✓
		Firm	✓		✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
		Sector	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓			✓	✓	✓
		Country			✓	✓	✓		✓	✓		✓	✓	✓		✓[iv]			✓	✓	✓
	Impact Channel	Macroenvironment		✓	✓	✓	✓		✓	✓		✓	✓		✓		✓	✓		✓	✓
		Supply chain			✓	✓	✓		✓	✓		(✓)[i]	✓	✓	✓		✓	✓	✓	✓	
		Operations and assets	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Markets and clients	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓
	Depth	Exposure	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Sensitivity	✓	✓	✓	✓	✓	(✓)[v]	(✓)[vi]	✓		✓	✓	✓	✓	✓		(✓)[vi]	✓	✓	✓
		Adaptive Capacity		✓	✓	✓	✓			✓			(✓)[vii]	(✓)[vii]	✓	✓		(✓)[v]		✓	(✓)[vi]
	Approach	Top-Down		✓			✓				✓		✓		✓		✓				
		Bottom-Up	✓		✓	✓		✓	✓	✓		✓		✓	✓	✓		✓	✓	✓	✓

		2DII (1)	2DII (2)	BAR	C4	CFIN	CT	CW	MA-VE	MIS	MSCI	OF	OW	OW-S&P	PwC	SP(1)	SP(2)	TCS	VE-PL	VR
		Provider																		
Asset classes	Equity	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	
	Bonds, Corporate	✓	✓	✓	✓	✓			✓	✓	✓	✓		✓	✓	✓	✓		✓	
	Bonds, Government			✓	✓	✓			✓			✓		✓			✓		✓	✓
	Loans, Corporate	✓	✓	✓	✓	✓			✓			✓		✓	✓		✓		✓	
	Loans, Project			✓	✓	✓			✓			✓	✓	✓	✓		✓		✓	✓
	Mortgages			✓	✓				✓			✓			✓		✓	✓	✓	
	Real Estate / Real Assets			✓	✓			(✓)[viii]	✓		✓	✓			✓		✓	✓	✓	✓
User inputs	Counterparty name	✓	✓	✓	✓	✓	✓		✓	✓	✓	x	(✓)[ix]	✓	✓	✓	✓	✓	(✓)[xi]	✓
	Location			✓				✓			✓		(✓)			(✓)[ix]	✓	✓	(✓)	✓
	Value of asset	✓	✓	✓				(✓)[ix]	(✓)[ix]		✓		(✓)			✓	✓	✓	(✓)	✓
Validity	Open-source	✓	✓	(✓)[xii]	(✓)[xii]			✓				(✓)[xiii]		(✓)[xvi]		(✓)[xii]	(✓)[xi]		(✓)[xii]	
	Peer-reviewed	✓		✓	✓			✓				✓		(✓)[xvii]		✓	✓	✓	(✓)[xiv]	
	Source references	✓	✓	✓	✓			✓				✓				✓	✓	✓	✓	✓
Outputs	Quantitative	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Semi-quantitative				✓		✓	✓	✓	✓						✓			✓	✓
	Non-financial metrics	✓	✓	✓	✓		✓	✓	✓	✓		✓						✓		
	Financial metrics		✓	✓		✓			(✓)[i]		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Temperature Alignment	✓	✓	✓	✓						✓	✓			(✓)[xv]				✓	

Table 3: Overview of transition risk assessment tools and analytics

Abbreviation	Service Provider	Tool
2DII (1)	Two Degrees Investing Initiative	PACTA for banks
2DII (2)	Two Degrees Investing Initiative	PACTA stress testing module
BAR	Baringa Partners	Climate Change Scenario Model
C4	Carbone 4	Carbon Impact Analytics
CFIN	Climate Finance Alpha	Transition risk toolbox
CT	Carbon Tracker	2 degrees of separation
CW	ClimateWise (CISL)	Transition risk framework
MA-VE	Moody's Analytics-V.E	On-demand transition climate risk scoring application
MIS	Moody's Investor Services	Carbon transition assessment
MSCI	MSCI-Carbon Delta	Climate Value-at-Risk (CVaR)
OF	Ortec Finance	ClimateMAPS
OW	Oliver Wyman	Transition Check
OW-S&P	Oliver Wyman & S&P Global Market Intelligence	Climate Credit Analytics
PwC-COF	PwC (formerly CO-Firm)	Climate Excellence
SP(1)	South Pole	Risk screening tool
SP(2)	South Pole	Climate risk deep-dive assessment
TCS	The Climate Service	TCS Climanomics
VE-PL	Planetrics	PlanetView
VR	Verisk Analytics	Transition risk

Notes

i. Under development for 2021
ii. Up to 2064
iii. Up to 2080
iv. At regional level
v. Operations only
vi. Not macroenvironment
vii. Macroenvironment only
viii. Infrastructure / real assets only
ix. Optional (but preferable)
x. Top-down approach does not need company/asset information
xi. Outside of ~20,000 company database
xii. Methodology, not source code
xiii. Open-source version will be available on OS-Climate platform
xiv. Within Vivid Economics' academic network
xv. Climate target alignment
xvi. Framework is open-source
xvii. Reviewed and vetted by financial institution, not academic

3.2 Scenarios

The foundation of forward-looking climate risk assessment is the design of a scenario or set of scenarios that best shapes assumptions around the climate, society and the economy. Scenarios are built around the core assumption of a global temperature target or emissions pathway, with temperature pathways being preferred by the TCFD in line with the objectives of the Paris Agreement (TCFD, 2017). However, a number of secondary assumptions including carbon pricing, technological development, consumer behaviour, resource scarcity, energy demand, discount rates and how quickly those assumptions change have a considerable influence on how those pathways develop over time. The Changing Course report focused largely on temperature-based scenarios given the TCFD's recommendations. In terms of the highest transition risk, scenarios tended to focus on 2°C pathways. Furthermore, the most widely available and granular scenarios at the time assumed a considerable contribution from Carbon Dioxide Reduction (CDR), or 'negative emissions' technology.

The availability of scenarios for transition risk analysis has expanded since last year's Changing Course report, in particular because demand for more aggressive transition scenarios has built as firms respond to increasing pressure from clients, investors and governments to meet the objectives of the Paris Agreement. Only 6 countries have implemented net-zero legislation, but many others have committed to Net Zero emissions targets by 2050, and most significantly for global emissions, China committed at the 2020 United Nations General Assembly to 'net carbon neutrality' by 2060 (Economist, 2020). In the finance sector, a number of firms have committed to align their business with the Paris Agreement, for example the Principles for Responsible Banking's Collective Commitment to Climate Action, or to net zero emissions by 2050 in the case of the Net-Zero Asset Owner Alliance.

Policies aiming at a 1.5°C pathway are therefore starting to be shaped and financial institutions need to assess this pathway, which poses the greatest transition risk. Moving to 1.5°C scenarios implies important changes in the rate and timing of decarbonisation, as outlined by Bingler & Colesanti Senni (2020), which will necessarily imply a considerable step change in transition risk. It is therefore important that these scenarios are adopted by service providers and many have already done so.

The IPCC's Special Report on Global Warming of 1.5°C (2018) laid out a number of pathways (P1 to P4) for achieving net zero emissions by 2050, including a pathway which minimises the need for carbon dioxide removal (CDR) technologies, which are currently "unproven and reliance on such technology is a major risk in the ability to limit warming to 1.5°C" (IPCC, 2018). This Special Report also provides a preview into the Shared Socioeconomic Pathways (SSPs), which will be showcased in the IPCC's 6th Assessment Report (AR6), and will provide more nuanced socioeconomic pathways and therefore largely replace the Representative Concentration Pathways (RCPs) outlined in AR5.

Scaling up ambition to align with the Paris Agreement is also the aim of the One Earth Climate Model, which is aiming to set a new standard in identifying a feasible path to 1.5°C with little or no reliance on CDR technologies. The Principles for Responsible Investment (PRI) have also developed a Forecast Policy Scenario, which assumes an "inevitable policy response" (IPR) to net zero in the short term, without necessarily meeting the 1.5°C temperature target, unless a second, medium-term, policy ratchet is initiated. This attempts to respond to criticisms of other <2°C scenarios as 'tail scenarios' that set overambitious and unrealistic short-term policy ambitions and whose modelled transitions are optimal rather than disorderly (Energy Transition Advisors, 2020).

A further development in scenarios over the past year has been the release of the NGFS reference scenarios, which set a standard for climate scenarios for the finance sector (NGFS, 2020b). These integrate both emissions pathways and shared socioeconomic pathways (SSPs) and thus provide a common set of scenarios for assessing both transition and physical risks. The NGFS scenario set includes three principal scenarios:

i. Orderly (1.5-2°C by 2100);
ii. Disorderly (1.5-2°C by 2100, though with greater transition risks than for an orderly transition);
iii. Hothouse world (3°C+ based on current policies, which do not meet even current Nationally Determined Contributions).

The NGFS scenarios have been based on integrated assessment models (IAMs) developed by PIK (REMIND-MagPIE), IIASA (MESSAGEix-GLOBIOM) and the University of Maryland (GCAM). It is likely that these scenarios will be adopted by central banks and regulators and will provide the basis for future climate stress tests for the finance sector. South Pole, Climate Credit Analytics and Oliver Wyman's Transition Check have already added the NGFS scenario set to their analytics.

A summary of available reference scenarios used for transition risk analysis is given in the below table:

Scenario Provider	Year	Name	Sector	Est. implied temp. rise	Basis
IEA World Energy Outlook (WEO) [updated annually]	2020	NZE2050 (Net zero emissions by 2050)	Energy	1.5°C	Outlines necessary technology, policies and behaviour change necessary to bring about net-zero emissions by 2050.
		SDS 2020 (Sustainable Development Scenario)	Energy	1.8°C (66%) 1.5°C (50%)	Takes in to account social (SDG) and climate goals
		STEPS (Stated Policies Scenario)	Energy	2.7-3.3°C	Takes in to account stated policies (replaces the New Policies Scenario, NPS)
		Delayed Recovery Scenario (DRS)	Energy	<2.7°C	STEPS with a delayed recovery from pandemic

IEA Energy Technology Perspec-tives (ETP) [2020 release feeds into SDS scenario]	2017	B2DS (Below 2 Degrees Scenario)	Energy	1.75°C	
		2DS (2 Degrees Scenario)	Energy	2°C	
		RTS (Reference Technology Scenario)	Energy	2.75°C	Takes into account existing energy- and climate-related pledges, including NDCs.
IPCC	2014	RCP (Repre-sentative Concentration Pathways)	All sectors	1.0°C (RCP 2.6) 1.8°C (RCP 4.5) 2.2°C (RCP 6.0) 3.7°C (RCP 8.5)	RCPs outline pathways according to different levels of radiative forcing in the CMIP5
IPCC	2018	SR15	All sectors	1.5°C	Set of P1-4 pathways to meet 1.5°C target, building on RCP 1.9
NGFS	2020	Orderly	All sectors	<2°C	Both orderly and disorderly have alternate scenarios with limited or full CDR
		Disorderly	All sectors	<2°C	Higher transition risk than for Orderly scenario
		Hot-house World	All sectors	3°C+	Only current policies imple-mented, not NDCs, i.e. equiv-alent to IEA STEPS
OECM	2020	One Climate Earth Model	All sectors	1.5°C	Minimal CDR. Released 2020.
PRI Inevita-ble Policy Response (IPR)	2020	Forecast Policy Scenario	All sectors	1.5°C	Based on the inevitable policy response to meeting the Paris Agreement.

Table 4: Overview of climate and transition scenarios

There are a number of other available scenarios, including IRENA's Remap, Greenpeace's Advanced Energy [Revolution] and IDDRI/SDSN's Deep Decarbonisation Pathways, which are less widely used in service providers' models.

In terms of the methodologies surveyed by UNEP FI, all now include a 1.5°C or below 2°C scenario, demonstrating the shift in transition risk analysis to scenarios which imply alignment with the objectives of the Paris Agreement, as well as the 2°C used as the basis for high transition risk scenarios in 2019. All methodologies supplement this with a 3°C or 4°C scenario to provide a comparison with the 'business-as-usual' or 'stated policies' approach, though Carbon Tracker focuses on oil & gas transition risks by using the IEA's STEPS scenario (~2.7°C) as a proxy for 'business-as-usual' by assessing the proportion of company expenditure that goes ahead under the STEPS scenario at the asset level but falls outside lower demand scenarios.

IEA scenarios are used by many methodologies, including 2DII, Carbone 4, Carbon Tracker, Planetrics, ClimateWise, Moody's Investor Services (MIS) and South Pole, as the IEA provides arguably the most granular scenarios for carbon intensive sectors, such as oil and gas, electricity, power generation, heavy manufacturing and automotive. Given the IEA's consistent under-estimation of renewable energy growth and high reliance on CDR, a number of providers use IEA scenarios as a basis for their own bespoke approaches – for example, Carbone 4 uses IEA SDS as a basis for modelling the electricity sector only.

NGFS scenarios will become increasingly important and Oliver Wyman's Transition Check Tool has integrated these scenarios in its initial release, building on Oliver Wyman's collaboration with PIK and IIASA in UNEP FI's first and second phase TCFD pilot. NGFS scenarios have also been integrated into Oliver Wyman and S&P Global Market Intelligence's Climate Credit Analytics.

Forecast Policy Scenario, based on PRI's Inevitable Policy Response (IPR) is adopted by Vivid Economics and Planetrics alongside IEA and IPCC scenarios to inform its 1.5°C transition risk tool.

Bespoke approaches are used in both of Oliver Wyman 's tools, by MSCI-Carbon Delta, in collaboration with PIK, IIASA and GCAM, by Carbone 4, and by Verisk, while Baringa Partners offers bespoke approaches in addition to standard scenario sets. Ortec Finance have developed 3 transition pathways similar to the NGFS scenario set including orderly and disorderly Paris aligned transitions and a business-as-usual, equivalent to a 'hothouse' world. The macroeconomic consequences, including GDP, inflation and sectoral GVA, of these scenarios are taken from Cambridge Econometrics' E3ME model, and cover countries, sectors and asset class risk return expectations, through a top-down approach.

It must be noted that many methodologies still employ scenarios, both sector specific such as the IEA scenarios or the IAMs, which continue to model relatively late emission peaks and CDR. This implies that many risk analyses are still building in a later transition, but with a much steeper decarbonisation and reliance on unproven decarbonisation technologies. Employing more ambitious 1.5°C aligned scenarios that do not rely on CDR, requires confronting technological and societal transformation in a more rapid and ordered manner. The continued use of 2°C scenarios or <2°C scenarios with a heavy reliance on CDR suggests a lack of confidence in the ability of economic governance institutions, businesses and society to confront the low-carbon transition in the medium to long term. Even the IEA's latest Net-Zero Emissions by 2050 scenario estimates that about 1,150 Mt of CO2 would have to be removed by 2030, using technology that does not yet exist.

Further information on scenario selection can be found in :

- *Pathways to net zero: Scenario architecture for strategic resilience testing and planning (Energy Transition Advisors for PRI, 2020)*
- *Navigating Climate Scenario Analysis (IIGCC, 2019)*

3.3 Hazards

As in the 2019 Changing Course report, the focus here is on two types of transition hazards:

i. **Policy** – changes in the counterparty's policy and legislatory environment, for example through direct costs such as carbon pricing, taxation or cap-and-trade, or indirect costs such as changes in subsidies, the introduction of renewables obligations, etc.
ii. **Technology** – changes in the availability and relative costs of technology, for example the lowering costs of renewable technologies and energy storage and the high costs of fossil fuel extraction from shale reservoirs, tar sands or deep offshore fields.

Market hazards are not included in this review, as it is assumed that the market is largely shaped by policy and technology, though recently markets have shifted independently of technology or policy due to the global pandemic, which impacted the demand for fossil fuels in certain sectors. Such changes in demand through changes in behaviour, lifestyle or economic model could be taken into account in these methodologies. Some methodology providers are accounting for pandemic or public health shocks in their risk assessment in response to the considerable demand shock in 2020.

All methodologies employ sector scenarios or integrated assessment models (IAMs) that automatically account for both policy (carbon prices) and shifts in technology, so almost all the methodologies take into account policy and technology hazards. The only exception to this is South Pole's Risk Screening Tool, which is a 'quick' assessment tool assessing only carbon price. South Pole do provide a more comprehensive assessment tool that also covers technological change, the Climate Risk Deep-Dive Assessment.

3.4 Assessment methodologies

Determining financial risk at the sector and firm level, from climate scenarios and associated socioeconomic pathways is dependent on the approach the methodology takes. The methodology has to assess a range of variables and assumptions that affect the economic impact at the macroeconomic or sectoral level and translate those impacts at the firm-level and subsequently estimate the financial impact to the financial institution.

This report bases its methodological assessment on the framework developed in the 2019 Changing Course report, which looks at each methodology's scope and breadth of assessment. The scope of an assessment is across four principal impact channels:

i. **Macro-environment** – economic trends at the macro-level tend to be the starting point for top-down analyses. Policy and technology changes at the country and sector level could impact macroeconomic indicators such as economic growth, the balance of trade and exchange rates, particularly in the case of disorderly transitions or price shocks.

ii. **Supply chain** – policy or technology shifts could see impacts on the upstream or downstream supply chain of counterparties, for example through changing costs of electricity generation or increased demand for certain products such as electric vehicles.
iii. **Operations and assets** – this impact channel directly affects the operations of counterparties, i.e. scope 1 emissions.
iv. **Market** – for emissions-intensive industries, most transition impact will be through the scope 3 emissions of consumers, so for coal mining or oil & gas production, policy or technology changes will lead to changes in market demand.

This overview also looks at three levels of assessment:

i. **Exposure** – determined by location and sector, and therefore exposure to climate policy or technology respectively.
ii. **Sensitivity** – determined by a counterparty's emissions intensity per unit of production and therefore how far it will be affected by a change in costs, or in supply chain terms, by a supplier's emissions intensity. This also affected by the counterparty's ability to absorb costs or to pass them on to consumers.
iii. **Adaptive capacity** – determined by a counterparty's ability to shift away from high emissions technology or suppliers (input substitution), or to develop new technologies or business models through R&D and strategy respectively.

Most of the described methodologies are based on deterministic modelling – where they differ is in how the economic modelling is approached: either bottom-up, which builds the economic impacts up from the firm level, or top-down, which directly models economic impacts at the macroeconomic or sector level. Bingler & Colesanti Senni give a good description of how these methodologies work (pp. 16-20; 2020). Stochastic modelling is integrated into some of the methodologies, such as Ortec Finance's ClimateMAPS, which takes deterministically modelled GDP, inflation and sector GCA shocks from its econometric model and feeds into their stochastically determined financial model.

Bottom-up methodologies provide a more granular assessment with arguably more accurate near-term results. They also tend to provide more detailed information at the firm level and through the supply chain. Such approaches include Baringa Partners' Climate Change Scenario Model, Carbone 4's Climate Impact, PwC/CO-Firm's Climate Excellence, Planetrics' Climate Risk Toolkit, Verisk's Transition Risk Tool and MIS' Carbon Transition Assessment and V.E's Carbon & Energy Transition metrics.

Top-down approaches measure emissions against the global carbon budget as country level emissions data is often more reliable and consistent than firm-level emissions data. Additionally, top-down approaches capture more readily the networked effects of interacting climate risk drivers, including policy, technology and physical risk. Ortec Finance's ClimateMAPS is an example of this approach.

Most of the covered assessment methodologies are able to provide macro-economic level analysis. The only tool not to cover this aspect at all is Carbon Tracker's 2 Degrees of Separation tool which is focused on granular firm-level transition risk analysis in the oil & gas sector. A majority of the methodologies are able to capture sensitivity and adaptive capacity at the macro-level, including Ortec Finance's top-down analysis and Vivid Economics and Planetrics who incorporate top-down macroeconomic assessment into their tool through the Vivid Economy-Wide (ViEW) model, while Baringa Partners' model allows for sector-level impact modelling in addition to their bottom-up analysis. Oliver Wyman and S&P Global Market Intelligence's Climate Credit Analytics also captures top-down macroeconomic impacts alongside its bottom-up analysis.

All methodologies are able to measure the transition risk to counterparty **operations** and to the **market**, while **supply chains** tend to be better modelled by those methodologies with a bottom-up approach that has been extended along upstream and downstream value chains. Top-down approaches can model supply-chain effects at a macro-level, through international trade impacts, for example. Often, however, **supply chain risk, otherwise known as second-order or indirect risk, is modelled using proxies such as vulnerability indicators**. It must be noted that this level of assessment is only as good as the visibility of a company along its upstream and downstream supply chains, while sector-level estimates of indirect risks are likely to increase the error of risk estimates.

In terms of methodologies' **depth of assessment**, exposure and sensitivity to transition risks are modelled across the board, though South Pole's 'light-touch' methodology only covers exposure and not sensitivity or adaptive capacity. Sensitivity tends to be modelled across the board by cost-pass through only. Only Oliver Wyman and the PwC/CO-Firm's models account for a counterparty's ability to absorb costs or to outperform peers (Bingler & Colesanti Senna, 2020).

Adaptive capacity is less well covered, though methodologies have improved over the past year on this score. Adaptive capacity in supply chains, operations and markets is necessarily modelled at the firm level through bottom-up approaches, as it is necessary to either understand the firm's technological and business strategies, or capacity to substitute away from high emissions inputs. Adaptive capacity in supply chains is perhaps the greatest challenge to methodologies given the need to model upstream and downstream. Currently six of the assessed methodologies are able to provide this level of analysis, though a number of other providers are developing this capacity over the coming year.

Transition opportunities are an important aspect of any transition assessment and a number of the methodologies covered here are able to model either patent data, including Carbon Delta's CVaR model, Planetrics' Climate Risk Toolkit and V.E's energy transition and governance data. Oliver Wyman's model is able to assess the capabilities of banks to respond to technological change through Transition Check, as well as in their collaboration with S&P Global Market Intelligence's Climate Credit Analytics. Top-down approaches can also identify sector-level opportunities, for example where, for example, transition technologies may drive sector GVA growth. This is perhaps the key element in a climate risk analysis enabling banks and investors to identify sectors likely to grow as a result of the economic transition, as compared to current focal sectors.

It is important to note that climate risk analysis must be distinguished from alignment, impact or target-setting tools, which have slightly different goals. We continue to include 2DII's PACTA, though in the framing of its recently released Stress Test Module, which was developed in partnership with the Bank of England and has been used to pilot a climate stress test methodology for UK-based insurers and was recently developed and further applied by EIOPA in their climate risk sensitivity analysis. Unlike a risk analysis tool, however, this impact approach focuses on a base case and high transition risk temperature scenarios – 3°C and disorderly <2°C. Other PACTA modules are focused on portfolio alignment for banks and investors and are not included in this overview, though measuring alignment of a portfolio can provide a useful proxy for transition risk.

3.5 Outputs

The majority of methodology providers are able to provide quantitative financial metrics and have expanded the range of outputs they are able to provide in order to meet the needs of different financial institutions – Baringa Partners, South Pole and Ortec Finance have indicated their flexibility in developing a range of financial output metrics. Moody's and Ortec Finance can also provide a range of climate-adjusted macroeconomic indicators using their top-down macroeconomic approach, including climate-adjusted GDP, interest & inflation rate expectations, risk-return/asset class, credit spreads, risk premia, etc. Value at Risk (VaR) from climate change is a widely used output metric used by MSCI-Carbon Delta, Ortec Finance, Planetrics and Verisk, which measure the financial impact of the climate transition against a baseline. South Pole's Risk Screening Tool provides a PRR metric, while Carbon Tracker's oil & gas sector focus provides an estimate of capital expenditure at risk outside the sector carbon budget. Verisk's Transition Risk analysis also provides metrics oriented towards the insurance industry: for example, the Risk Premium Rating.

Some methodologies provide semi-quantitative outputs such as Carbone 4's Carbon Impact Analysis, which provides an overall rating and alignment with 2°C trajectories risk rating (A to E), as well as an assessment of forward-looking company strategy (++ to –), based on quantified induced and avoided emissions, as well as forward-looking emissions. MIS' Carbon Transition Assessment Tool and Verisk provide semi-quantitative emissions intensity scores (0 to 10). 2DII's PACTA Stress Test Module estimates a Loss in Predicted Value, which assesses the level of exposure of equity and corporate bond portfolios to Paris-aligned transition pathways.

Increasingly, methodologies are adopting temperature alignment scores. These semi-quantitative outputs provide an indication of a portfolio's or loan book's implied impact on global warming. This metric is currently being explored by the TCFD Secretariat as an addition to the TCFD recommendations in order to gradually move financial institutions from risk assessment to active portfolio management to align portfolios with international climate objectives. Carbone 4's methodology implicitly assesses climate impact, while other service providers have added implied temperature scores to their services, including Baringa Partners, Moody's (V.E), MSCI-Carbon Delta, Planetrics, Ortec Finance through their ClimateALIGN tool. 2DII's PACTA methodology implicitly calculates the delta with a 2°C scenario, so can be said to calculate a metric alignment. One methodology that is not included in the current assessment as it is not a tool for calculating climate risk *per se*, is *Right.based on science*'s XDC tool, which directly calculates the temperate alignment score for a portfolio.

3.6 Resolution

This is where the difference of top-down vs bottom-up approaches can really come into focus. Bottom-up approaches are generally more granular, but as uncertainties around asset and firm level data increase over the medium to long term, top-down approaches, with their sector overview, may be more credible at these longer timescales. Furthermore, bottom-up approaches are likely to be more readily deployable by larger financial institutions with the reach and means to access more granular data or those institutions with an intimate knowledge of their investment portfolio. Top-down and bottom-up approaches can be complementary allowing for strategic asset allocation through top-down approaches and stock or investment level decision-making supported by bottom-up approaches.

High resolution, bottom-up approaches with facility and firm level analysis include Baringa Partners, Climate Credit Analytics, MSCI-Carbon Delta, Planetrics, Vigeo-Eiris, South Pole, Verisk and PwC/CO-Firm. Carbon Tracker's analysis assesses oil and gas production at the field level to estimate the extent of asset stranding. Carbone 4 assess impact at the firm level, rather than at the facility level. Top-down methodologies, such as Ortec Finance and PACTA can provide granularity at the company, sector and country levels.

3.7 Validity

Given the complexity of climate scenarios, socio-economic models and translating these model outputs into consequences for financial firms and their clients, each tool has its own set of assumptions and simplifications. This inevitably leads to variations in the calculation of financial risk metrics for a given input, so it is important for financial institutions to understand how the models work or at the very least to have confidence in the validity of the tools they are using.

In terms of full public access, only ClimateWise, 2DII and Climafin, as externally funded projects, have made their full source code publicly available. Ortec Finance is engaged in an initiative led by the Linux Foundation to make an open-source version of ClimateMAPS that will be made available on the OS-Climate platform, while their ClimateALIGN is based on the SBTi-FI developed open-source temperature scoring tool. In the majority of cases where access to the model is restricted, it is important to ensure validity through peer review or, at the very least, to understand the scientific basis of a methodology through its source references. Service providers may make elements of the methodologies available to clients under Non-Disclosure Agreements in order for users to have an understanding of key assumptions and parameters and how metrics are calculated.

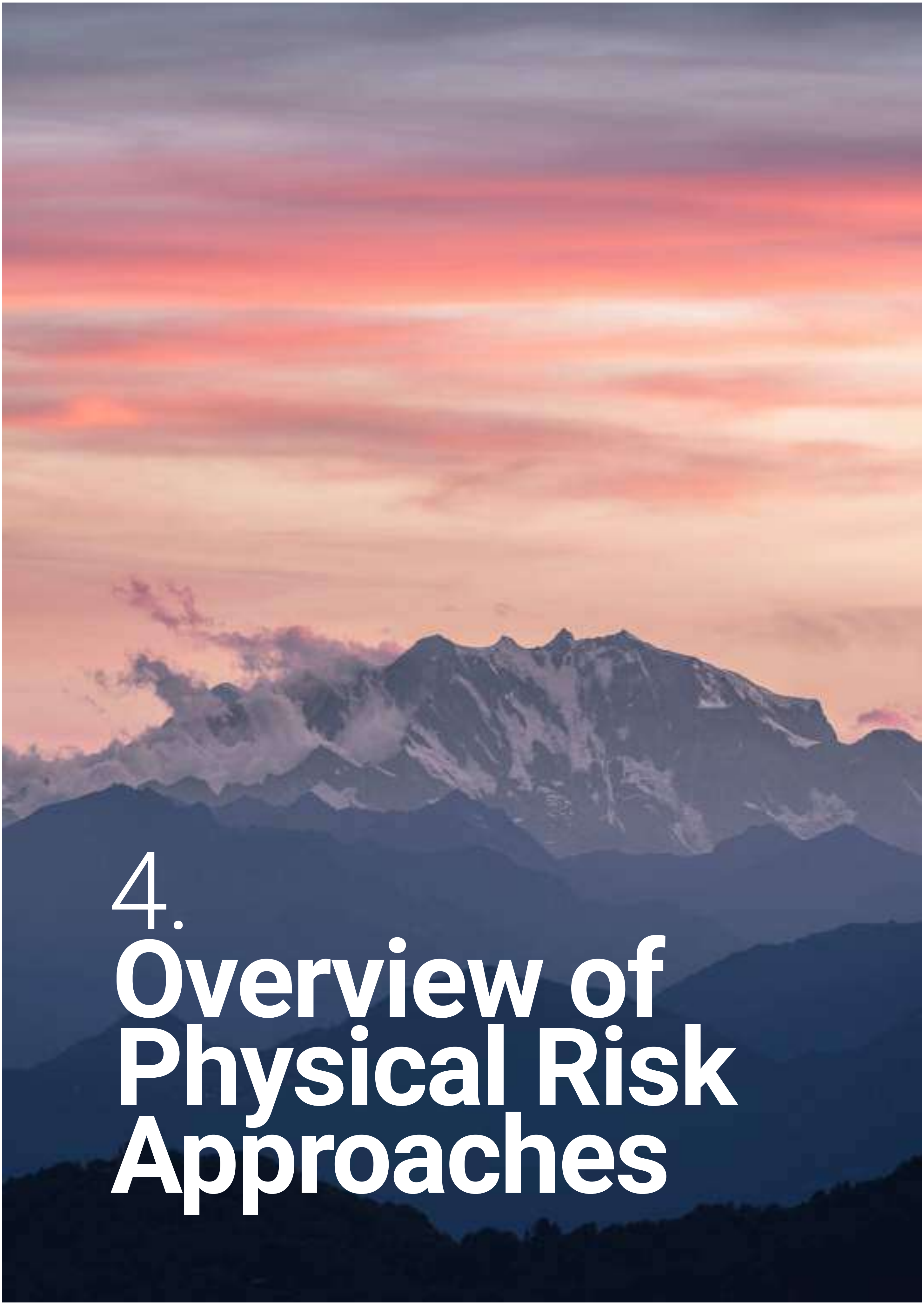
3.8 Usability

Further to the scope of last year's Changing Course report, we provide a brief overview of some additional criteria, including accessibility and coverage, and time horizon.

Accessibility: The majority of these methodologies are fee-based, except for 2DII's and CISL's tools. Oliver Wyman's Transition Check is free for UNEP FI members, while the results from Carbon Tracker's tool are free for all, though PRI members have access to greater functionality. PACTA's Stress Test Module is free to explore and use on transition-monitor.org, as well as access to PACTA's alignment tools for investors and banks. The Cambridge Institute of Sustainability Leadership's ClimateWise tool can provide a free, open-source introduction to scenario analysis. Finally, Carbon Tracker's oil & gas focused tool is free to use for PRI members at 2degreesseparation.unpri.org/.

Coverage: Almost all tools are described as 'global'. Ortec Finance's Climate MAPS, which nominally covers 29 countries worldwide, does integrate global interaction and impacts given its top-down approach, and other countries can be added into the model on a bespoke basis. ClimateWise, which currently only covers the EU, US and India, is looking to scale up its offering to China and Australia in 2021.

Horizon: The time horizon of the methodology varies between methodologies and care needs to be taken that the methodology chosen provides an adequate balance between short-term validity in terms of the estimated uptake of transition-aligned policies and technologies and the investment horizon required by the financial institution. The majority of methodologies provide horizons to 2030-40, with Planetrics and ClimateWise also providing nearer term outputs to 2025. Carbone 4 impact analysis has a near term horizon of 2025. Longer-term horizons are also provided by Oliver Wyman, Baringa Partners, PwC/Co-Firm and Planetrics (2050), Ortec Finance (2060, with narrative outlooks to 2100), Verisk (2064), Climafin (2080) and South Pole and The Climate Service (up to 2100).



4. Overview of Physical Risk Approaches

4.1 Introduction

This section provides an overview of nineteen physical risk tools and analytics and reproduces the comprehensive overview in Acclimatise's *Charting a New Course* report (2020) developed for UNEP FI's TCFD Banking Pilot Project Phase II. The reproduction of this work in this report is firstly for completeness, as many financial institutions will want to assess both their transition and physical risk exposure. Furthermore, a number of providers offer both transition and physical risk methodologies and are aiming to provide combined risk assessments over the coming year. For a thorough and complete overview of physical risk tools and analytics, therefore, it is strongly recommended to also refer to *Charting a New Course*.

Secondly, in order to reflect the sector-wide scope of this report we have included a number of other service providers, including RMS and Verisk. These are firms who have traditionally provided historic risk assessments for (re-)insurance services and engineering projects and who are increasingly scaling their offerings to forward-looking climate change-related risk assessment for the wider finance sector. Their expertise lies largely on the analysis of acute physical risk, though they are developing expertise on chronic risks, such as RMS' collaboration with the Natural Capital Alliance on drought scenarios for Brazil, Mexico, the US and China. Given their recent entry into the sector of climate risk assessment for financial institutions (beyond underwriting), their offering is best suited to products directly associated with physical assets such as mortgages, real estate and project finance, where their analytic approach can provide highly granular analyses. Other service providers have been able to develop a framework to update these natural catastrophe models for climate change – ClimateWise, for example have demonstrated this approach for property portfolios.

Like the transition risk overview in chapter 3, the set of service providers listed and reviewed in this section is certainly not exhaustive, but we have attempted to include the principal commercially available methodologies.

For a detailed overview of the physical risk tools and analytics and a set of case studies by banks using a selection of the methodologies, it is strongly recommended to refer to *Charting a New Climate* (UNEP FI, 2020). Hereunder are a few additions to the commentary provided in the previous report.

			427 (1)	427 (2)	ACC	ACC-WTW	C4 (1)	C4 (2)	CFIN	CW	MSCI	OF (1)	OF (2)	RhG	RMS	SP (1)	SP (2)	TCS	VE-PL	VR	XDI
			Provider																		
Scenarios	<2.0°C (RCP 2.6)				✓	✓			✓		(✓)[i]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	2.0°C (RCP 4.5)		(✓)[i]		✓	✓	✓	✓	✓	✓	(✓)[i]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	3.0°C (RCP 6.0)				✓	✓	✓		✓		(✓)[i]	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	>4.0°C (RCP 8.5)		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Time horizons	Baseline / historical				✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Near term (2025-2040)		✓	✓	✓	✓			✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Medium term (2050)		(✓)[i]		✓	✓	✓	✓	✓	✓[i]		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Long-term (2100)		(✓)[i]				✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Physical Hazards	Chronic		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Acute		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Risk analysis	Level of analysis	Asset	✓	✓	✓	✓	✓	✓		✓			✓	✓	✓		✓	✓	✓	✓	✓
		Firm	✓	✓	✓	✓	✓	✓	✓					✓	✓	✓	✓	✓	✓	✓	✓
		Sector	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓			✓	✓	✓	✓
		Country	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓			✓	✓	✓	✓
		Portfolio	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓		✓	✓	✓	✓	✓
	Impact Channel	Macroenvironment		✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	
		Supply chain		✓	✓	✓	✓		✓			✓	✓		✓	✓	✓	✓	✓	✓	✓
		Operations and assets	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Markets and customers		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
	Method	Physical Exposure	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Vulnerability indicators		✓	✓		✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓
		Physical impact modeling	✓	✓		✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Financial modeling	✓	✓		✓			✓			✓	✓	✓	✓		✓	✓	✓	✓	✓
Physical Hazard Type	Flood, coast		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
	Flood, inland		✓	✓	✓	✓	✓	✓	✓	✓	(✓)[i]	✓	✓		✓		✓	✓	✓	✓	✓
	Extreme weather		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
	Extreme heat		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓			✓	✓	✓	✓	✓
	Extreme precipitation		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓		✓	✓	✓	✓	✓
	Landslide				✓	✓	✓	✓				✓	✓						✓	✓	✓
	Drought		✓	✓	✓	✓	✓	✓			(✓)[i]	✓	✓		✓		✓	✓	✓	✓	✓
	Water scarcity		✓	✓	✓	✓	✓	✓									✓	✓	✓	✓	
	Wildfire		✓	✓	✓	✓	✓	✓	✓		(✓)[i]	✓	✓		✓		✓	✓	✓	✓	✓

		Provider																		
		427 (1)	427 (2)	ACC	ACC-WTW	C4 (1)	C4 (2)	CFIN	CW	MSCI	OF (1)	OF (2)	RhG	RMS	SP (1)	SP (2)	TCS	VE-PL	VR	XDI
Asset classes	Equity	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	✓
	Bonds, Corporate		✓	✓	✓	✓	✓	✓		✓	✓			✓	✓	✓		✓	✓	✓
	Bonds, Government	✓		✓	✓	✓	✓	✓			✓		✓	✓		✓		✓	✓	✓
	Loans, Corporate		✓	✓	✓	✓	✓	✓			✓			✓		✓		✓	✓	✓
	Loans, Project	✓		✓	✓	✓	✓	✓			✓		✓	✓		✓		✓	✓	✓
	Mortgages	✓		✓	✓	✓	✓				✓	✓	✓	✓		✓	✓	✓	✓	✓
	Real Estate / Real Assets	✓		✓	✓	✓	✓	✓	(✓)[iii]	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
User inputs	Counterparty name		✓	✓	✓	✓	✓	✓		✓	v	v	✓	✓	✓	✓	✓	✓	✓	✓
	Location	✓		✓	✓		✓		✓	✓	v	v	✓	✓		✓	✓	✓	✓	✓
	Value of asset			✓	✓		✓		(✓)[iv]	✓	v	v	✓	✓	✓	✓	✓	✓	✓	✓
	Characteristics of asset	✓		✓	✓		✓			✓	v	v	✓	✓		✓		✓	✓	✓
Validity	Open-source	(✓)[vi]						✓	✓		(✓)[viii]				(✓)[ix]	(✓)[ix]		(✓)[ix]		
	Peer-reviewed	(✓)[vii]		✓	✓			✓	✓		✓	✓		✓	✓	✓	✓	(✓)[x]	✓	✓
	Source references	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Outputs	Quantitative	✓	✓	✓		✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
	Semi-quantitative		✓		✓		✓		✓				✓	✓		✓				
	Non-financial metrics	✓		✓		✓	✓		✓		✓	✓		✓		✓	✓	✓		✓
	Financial metrics	(✓)[i]	✓[xi]		✓			✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 5: Overview of physical risk assessment tools and analytics

Abbreviation	Service Provider	Tool
427 (1)	Four Twenty Seven	On-demand physical climate risk scoring application
427 (2)	Four Twenty Seven	Physical climate-risk scores for publicly listed companies
ACC	Acclimatise	Physical climate risk heatmapping tool
ACC-WTW	Acclimatise-Willis Towers Watson	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
CFIN	Climate Finance Alpha	Physical risk toolbox
CW	ClimateWise (CISL)	Physical risk framework
MSCI	MSCI-Carbon Delta	Climate Value-at-Risk (CVaR)
OF (1)	Ortec Finance	ClimateMAPS
OF (2)	Ortec Finance	ClimatePREDICT
RhG	Rhodium Group	Valued asset-level physical risk data
RMS	RMS	Climate risk models and consultancy service
SP (1)	South Pole	Risk screening tool
SP (2)	South Pole	Climate risk deep-dive assessment
TCS	The Climate Service	TCS Climanomics
VE-PL	Planetrics	PlanetView
VR	Verisk Analytics	AIR
XDI	XDI Systems (physical risk only or in partnership with Baringa for physical & transition)	

Notes

i. Under development for 2021
ii. Up to 2080
iii. Infrastructure / real assets only
iv. Optional (but preferable)
v. Top-down approach does not need company/asset information
vi. Methodology available for users
vii. Elements of the methodology are peer-reviewed
viii. Open-source version will be available on OS-Climate platform
ix. Methodology, not source code
x. Within Vivid Economics' academic network
xi. Leveraging Moody's Analytics' Public Expected Default Frequency structural credit risk model, 427's physical climate risk scores for listed companies can be translated into credit metrics such as probability of default term structures, expected loss estimates, credit spread effects, price effects, and value-at-risk. This is currently offered as consultancy services and will be offered in future as an on-demand analytics product.

4.2 Scenarios

All methodologies surveyed adopt an RCP 8.5 (4°C by 2100) scenario to measure the maximum physical risk. There has been discussion as to whether RCP 8.5 can still be considered as a business-as-usual scenario, given the advances in scenario modelling and the trajectory of the energy transition since AR5 was published in 2014 (Hausfather & Peters, 2020; Shwalm, Glendon & Duffy, 2020). A recent study has marginally narrowed the range for global temperature rise by 2100 to a "likely" (66% confidence) range of 2.6-3.9°C, but this is not enough to shift the Business-as-usual case to RCP 6 (Sherwood et al, 2020).

Unusually, MSCI-Carbon Delta employs a stochastic approach to estimating physical risk, based on the 50th and 95th percentile expectancy of a business-as-usual risk distribution, rather than comparing a RCP8.5 scenario against a <2°C objective RCP 2.6 scenario. It is arguable as to whether this approach accounts for more extreme physical risks in the event of tipping points or climate shocks.

4.3 Acute and chronic risks

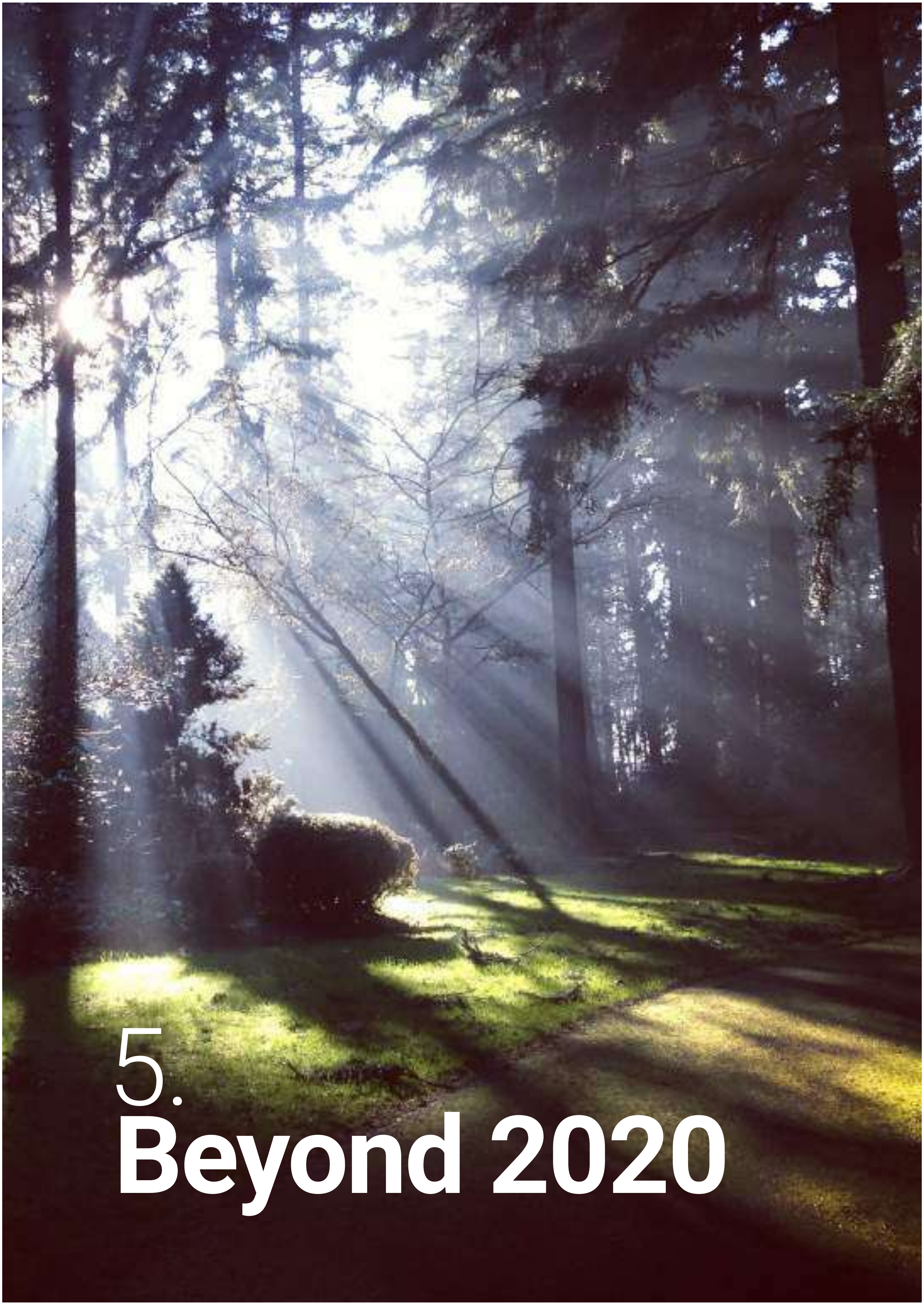
The inclusion of a number of risk assessment firms with experience working in the (re-)insurance industry, such as RMS and Verisk, opens up the risk assessment space to firms that have a history of developing highly granular physical risk models with a focus on acute hazards such as extreme weather, inland and coastal flooding, wild-fires, landslides, etc. With the rise in demand for climate risk assessment, these firms are rapidly developing forward-looking climate scenarios, which provides them with a distinct competitive advantage over other firms that have developed physical climate risk assessments for the financial sector, whose strengths lie more in modelling forward-looking chronic risks and in translating these models into output data of use to financial firms.

Chronic risks are a particular challenge. Approaches to chronic risk have focused either on quantitative analysis such as RMS' collaboration with the Natural Capital Alliance on drought and water scarcity, or on qualitative evaluation based on a comprehensive literature review, for example, by Ortec Finance to assess the impacts of precipitation changes and temperature rise, on industrial, labour and agricultural productivity. One area where chronic impacts are perhaps less of a challenge is in coastal flood risk due to sea level rise. However, sea-level rise has other effects including salination of agricultural land, which is less well modelled.

4.4 Secondary risks from climate change

One area for improvement in physical risk models is assessing the impacts from secondary climate-change driven effects, whether socio-economic, such as migration and conflict, or environmental, such as public health shocks. These secondary impacts are difficult to model given the human behaviour element of socio-economic shocks, and the unpredictable nature of public health impacts. However public research funding is being directed towards modelling limited climate change-induced impact scenarios, such as the CASCADES project. This EU-financed initiative will model trade and supply chains, analysing the impact of acute and physical climate change-related hazards on agricultural production, energy and commodity markets. Combined with "macro-economic modelling, qualitative political analysis and strategic policy simulations", this will enable an assessment of areas of critical concern and potential solutions for Europe and beyond.[3]

3 cascades.eu/



5. Beyond 2020

This review of the available methodologies for physical and transition risk assessment will hopefully be of benefit to financial firms embarking on climate-related risk assessment in order to meet the requirements of a TCFD-aligned climate risk disclosure. As highlighted previously, more in-depth information is available on physical risk methodologies and data sources from UNEP FI and on transition risk methodologies from ETHZ.

5.1 Developments in regulation

Policy makers and regulators are increasingly highlighting the threats from climate change and are pointing the way towards mandatory climate risk through the development of guidelines and standards. In section 2.1.1, a brief overview shows how central banks, regulators and policy makers are responding to climate risk, with New Zealand the first country to announce mandatory climate risk disclosure. Within the next year the European Union can be expected to release an update to the Non-Financial Reporting Directive (NFRD), which is likely to direct member states to implement climate-risk reporting regulation for financial institutions, and the UK's Joint Government Regulator TCFD Taskforce has released a strategy and roadmap to mandatory disclosure by 2025 at the latest, with many requirements in place by 2023 (HM Treasury, 2020).

Central banks and regulators will increasingly pilot and subsequently impose climate stress testing on banks. As described in section 2.1.2, a number of central banks in western Europe have already piloted climate stress tests and some service providers are moving to support the development of these stress tests, such as 2DII in Switzerland and Japan. As central banks move away from piloting individual scenarios, they will increasingly gauge sensitivity by stress testing against a bank of multiple climate scenarios. 2DII have also suggested that stress testing may move away from sector-level shocks to "technology-oriented" shocks, e.g. to renewable energies or to coal power.

Service providers are increasingly pooling resources or are being integrated into larger financial service providers. Trucost, an ESG risk consultancy not covered in this review, was acquired already in 2016 by S&P Global Indices. Over the last year, MSCI purchased Carbon Delta; Willis Towers Watson acquired Acclimatise; 427 and Vigeo-Eiris have come under the umbrella of Moody's Analytics; while 2DII and Carbon Tracker are increasingly collaborating. Firstly, this process of consolidation will allow climate risk specialists greater access to company data and resources to develop their risk tools. Secondly, greater integration will also improve access and usability: for example, Carbon Delta's data will be integrated into MSCI's ESG Manager platform before the end of 2020, while V.E and Four Twenty Seven data is made available on Moody's CreditView.

5.2 Developments in technology

Climate-related risk assessment is still only in its infancy and tools or methodologies are being constantly updated to allow for more granular analysis that takes into account a broader, more plausible set of scenarios, access to more granular datasets. Commercial providers that require a fee to access have a particular incentive to improve their risk forecasts. Below are some of the most important forecast developments:

Most of the service providers are moving away from the use of one scenario provider, if they have not already done so. Up to now, many models have relied on one scenario type, particularly IEA given its focus on high carbon emissions sectors. However, IEA scenarios have consistently had to be updated to account for low emissions technologies developing at a faster rate than predicted by the IEA and this is encouraging a move towards integrating either multiple or bespoke scenarios. For example, South Pole have indicated that they will broaden the scenarios available on their tool, while Moody's ESG Solutions (incorporating Four Twenty Seven and V.E) have indicated that they will expand their range of GCMs from 5 to 18, while also including additional scenarios. Oliver Wyman's online Transition Check tool launched with the three main NGFS scenarios, building on their previous use of PIK, IIASA, GCAM scenarios, but the online scenario module will, over time, integrate other scenarios including IEA, IRENA, OECM, etc. The increasing use of Shared Socioeconomic Pathways (SSPs) is allowing service providers to better model socio-economic inputs and impacts – The Climate Service is already using SSP3-60 and -45.

A number of scenario developers have already developed a bespoke range of transition scenarios, often at sector level, based on existing climate models to improve methodological accuracy or to model alternative transition or demand shocks, including Carbone 4, MSCI-Carbon Delta, Planetrics and Ortec Finance. Baringa Partners also offer bespoke options as well as industry standard scenarios. Bespoke approaches, as well as the use of opaque risk assessment methodologies may reduce the ability of financial institutions or financial regulators to understand the parameters or assumptions used in risk analysis.

Increasing demand for standardisation may move developers towards the use of reference scenarios. This would help to address growing concerns over the transparency and comparability of climate risk assessments (Bingler & Colesanti Senni, 2020). The NGFS reference scenarios, released earlier in 2020, are aiming at standardisation and have already been adopted by Oliver Wyman in their Transition Check tool, released September 2020. It must be noted, however, that the NGFS scenario sets need to be further developed to improve granularity at the sector and regional level, as well as integrating other market drivers such as technological change and alternative policy responses (Pierfederici, 2019).

Transition and physical risk methodologies are being increasingly combined in order to provide financial institutions with an overall picture of climate-related risks for each scenario. Some providers have already achieved this in-house, such as Ortec Finance. Others are pooling resources such as Baringa Partners, who have built on their experience in the energy sector to develop a transition risk tool, and are partnering with physical risk specialists, XDI, to provide a holistic climate risk analysis. Bottom-up assessment methodologies are perhaps more complex to integrate, but many of the service providers covered in this report are moving in this direction, including The Climate Service.

Physical risk models will be able to aggregate greater sources of data, with the use of geospatial and remote sensing data, AI and data mining. Artificial Intelligence will be of increasing importance in accessing data from various sources. For physical risks this could include 'vision learning' from geospatial data. This will also help to expand the range of physical hazards covered – Four Twenty Seven for example will expand their offering to include landslides and wildfire smoke. Jupiter Intel, not included in this current overview, has built a model for physical risk assessment up to 2100 that is constantly updated from real-time satellite and senor data. In terms of transition risk, data mining will enable banks to assess climate risks to a wider range of counterparties, including SMEs.

Increasing granularity of physical risk analysis. Given the increased access to data discussed above, it is likely that physical risk analyses will become far more granular, allowing more accurate risk analysis. Extreme weather and climate hazards are highly location dependent, especially acute risks such as coastal and fluvial flooding and wildfires. Several service providers are scaling up their resolution, including risk specialists such as RMS and Verisk, and XDI who can differentiate changes in impact at up to 1m scale.

Data is likely to become easier to access and in a format more easily usable by financial institutions, as corporates increasingly report on climate risk and respond to data requests, while a number of research projects, including ClimINVEST, are developing open source access to physical risk data, such as the EU's Copernicus Climate Change Service (E3CS). The OS-Climate platform (os-climate.org) initiated by the Linux Foundation, is also aiming to make relevant data publicly available, as well as providing some open-source analytical tools. Meanwhile increasing data availability and higher granularity will reduce errors in risk measurement, making it more likely that financial institutions are able to provide consistent and market-ready disclosures. This will allow analyses to move away from qualitative and exposure-based assessments to more quantitative vulnerability-focused assessments.

5.3 Challenges in 2021

Aside from the regulatory developments described above in 2021, we can expect financial institutions to be faced with the following challenges:

Increasing standardisation and mainstreaming: Industry reporting standards CDSB, CDP, SASB, GRI, and IIRC are moving to align over the coming year and integrate the recommendations of the TCFD, and there will almost certainly be wider uptake of NGFS reference scenarios. Standardisation may follow the guidelines in ISO 14097, the international framework for assessing standards assessing and reporting investments and financing activities related to climate change. Financial institutions will also increasingly want to integrate climate risk into their financial and economic decision-making tools, rather than relying on independent 'black-box' models from climate risk specialist firms.

Presidential transition in the United States: The election of Joe Biden in November will undoubtedly signal a dramatic change in climate policy with the President aiming to: (i) invest up to $2tn on low-carbon energy, (ii) re-join the Paris Agreement, and (iii) achieve net-zero emissions by 2050. Regarding climate risk reporting, the Vice-President, Kamala Harris, is a supporter of climate risk disclosure, e.g. of Sen. Elisabeth Warren's Climate Risk Disclosure Act and Sen. Brian Schatz's Climate Change Financial Risk Act. The change in direction is reflected in the Federal Reserve Board's November 2020 report, which highlights, for the first time, the threat to financial stability posed by uncertain future climate change impacts, and the lack of knowledge on financial sector exposure. The report recommends that, "increased transparency through improved measurement and disclosure could improve the pricing of climate risks" (FRB, 2020).

Methodologies should all take into account carbon lock-in or 'expected greenhouse gas emissions', otherwise approaches that only look at present carbon emissions will ignore the risk of surpassing carbon budgets. This issue has been highlighted in research on climate risk assessment and alignment by financial institutions (Caldecott, 2020; Bingler & Colesanti Senni, 2020) and has been integrated by a number of the methodologies assessed here, including Baringa Partners, PwC, Planetrics, Ortec Finance and 2DII account for this among the models highlighted here.

Knock-on impacts of climate risk are also under-assessed by the existing set of tools and methodologies. Secondary effects of climate change including knock-on economic impacts, public health shocks or migration caused by the physical impacts of climate change have not been adequately modelled by existing methodologies, which may constitute a considerable blind spot in current climate risk methodologies. While there is no evidence for a link between the CoVID-19 pandemic and climate change, it is estimated that climate change will increase the range and survival of vectors that transmit disease and public health will be impacted by higher temperatures, water scarcity and extreme climatic events (Costello et al, 2009).

Integrating biodiversity risk is the next major environmental risk analytics challenge for financial institutions. With the 15th Conference of the Parties of the Convention on Biodiversity taking place this year (CBD, COP15) and the global extinction of flora and fauna worldwide accelerating, UNEP FI, UNDP, WWF and Global Canopy have launched the Taskforce on Nature-related Financial Disclosures (TNFD) together with a working group of around a dozen banks and investors. While this Taskforce was not initiated by the Financial Stability Board as was the case for the TCFD, it is hoped that the momentum of COP15 and widespread awareness of the links between climate change and biodiversity may help TNFD to develop into an industry standard for financial institutions to monitor their impact on biodiversity. Ideally, climate and biodiversity risks should be considered together in the same assessment framework, as climate change will have significant impacts on biodiversity, while biodiversity is a crucial factor in mitigating and adapting to climate change.

Abbreviations

2DII	2 Degrees Investing Initiative
AR5	5th Assessment Report (IPCC)
BCBS	Basel Committee on Banking Supervision
BES	Biennial Exploratory Scenario (Bank of England)
CBD	The United Nations Convention on Biological Diversity
CDR	Carbon Dioxide Removal
CDSB	Carbon Disclosure Standards Board
CET1	Common Equity Tier 1
CISL	Cambridge Institute for Sustainability Leadership
COP	Conference of the Parties (UNFCCC)
CVaR	Climate Value-at-Risk
DNB	Den Nederlandsche Bank
E3CS	EU Copernicus Climate Change Service
ESG	Environmental, Social and Governance
ETHZ	Swiss Federal Institute of Technology, Zurich (Eidgenossische Technische Hochschule Zürich)
FSB	Financial Stability Board
GCAM	Global Change Analysis Model (University of Maryland)
GCM	General Circulation Model
GDP	Gross Domestic Product
GRI	Global Reporting Initiative
GVA	Gross Value Added
IAM	Integrated Assessment Model
IDDRI	Institute for Sustainable Development & International Relations (Institut de Développement Durable et de Relations Internationales)
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IIGCC	The Institutional Investors Group on Climate Change
IIRC	International Integrated Reporting Committee
IPCC	Intergovernmental Panel on Climate Change
IPR	Inevitable Policy Response (PRI)
IRENA	International Renewable Energy Agency
MAS	Monetary Authority of Singapore
MIS	Moody’s Investor Services
NFRD	Non-Financial Reporting Directive
NGFS	The Network for Greening the Financial System
OECM	One Earth Climate Model
PACTA	Paris Agreement Capital Transition Assessment
PIK	Potsdam Institute for Climate Impact Research (Potsdam Institut für Klimafolgenforschung)
PRI	Principles for Responsible Investment

PwC PricewaterhouseCoopers

RCP Representative Concentration Pathway

SASB Sustainability Accounting Standards Board

SDSN Sustainable Development Solutions Network

SME Small and Medium Enterprises

SSP Shared Socioeconomic Pathways

TCFD Task Force on Climate-related Financial Disclosures

TFCR Task Force on Climate-related Financial Risks (BCBS)

TNFD Task Force on Nature-related Financial Disclosures

UNDP United Nations Development Programme

UNEP FI United Nations Environment Programme Finance Initiative

UNFCCC UN Framework Convention on Climate Change

VaR Value-at-Risk

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ATTACHMENT 3

David Carlin & Alexander Stopp, UNEP FI,
The Climate Risk Landscape: 2022 Supplement
(2022)

UN environment programme

finance initiative

The Climate Risk Tool Landscape

2022 Supplement

Featuring an anthology of implementation case studies from financial institutions

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UNEP Finance Initiative

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Project Management

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ABN-AMRO
Access Bank
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NatWest
NIB
Rabobank
RBC
Santander
Scotia Bank
Standard Bank
Storebrand
TD Asset Management
TSKB
UBS
Wells Fargo

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Introduction

The importance of climate risk assessments

Societies, governments, and companies have justifiably recognized the threats climate change poses to the global economy. Physical risks such as droughts, sea level rise, and flooding are likely to increase in the coming years, with consequences for real assets, supply chains, and business operations. While critical, mitigating global warming poses challenges as well. Businesses and countries will experience transition risks in the shift from a fossil fuel-driven economy to a low-carbon one.

The financial sector has a central role to play in managing climate-related risks and providing capital for climate resiliency and the low-carbon transition. As a result, a wide range of stakeholders have shown interest in how financial institutions are preparing to confront climate change.

- Activists and civil society have added public pressure for financial institutions to demonstrate that their activities are contributing to a sustainable future.
- National and local governments that have committed to reducing emissions are looking to the financial sector to catalyse the development and deployment of projects that will help them reach those goals.
- Financial supervisors and policy-makers around the world are aware of how climate change can threaten financial stability and have been increasingly setting climate risk management expectations and mandating climate disclosures, climate transition plans, and climate stress testing.
- Shareholders in financial institutions are eager to understand how firms are preparing to confront both physical and transition risks in their portfolios.
- Internal management within financial institutions want to identify the key risks and opportunities that a changing world presents and ensure that their firm is well-positioned.

In recent years, financial institutions have been exploring data, tools, and analytics that will enable them to meet the needs of these stakeholders. While many institutions are developing in-house climate capabilities, most are also working with outside vendors to obtain the skills, information, and outputs they require. As a result, there is a burgeoning market for climate solution providers for financial institutions to choose from. These providers can range from public data sources from organizations such as the United Nations and the World Bank to paid providers who can create bespoke tools for an institution.

Program and module overview

TCFD program retrospective

The work in this report was carried out as part of UNEP FI's TCFD programme. Since the publication of the FSB's TCFD recommendations in 2017, UNEP FI has run a series of pilot programs to assist members in exploring physical and transition risks and developing practical approaches for evaluating these risks using climate scenario analyses. Over 100 financial institutions (banks, investors, and insurers) from all around the world have participated in these pilots. Participating institutions have been supported by over a dozen technical partners including climate modelers and climate risk experts.

The latest TCFD programme (beginning in March 2021) involved forty-eight global banks and investors. The program contained two parallel components. The first was a climate risk roadmap to empower participants at all stages of their climate disclosure journey. The roadmap featured dozens of interactive discussions with regulators, climate modelers, climate scientists, as well as peer presentations. The second component was a series of "modules" where participants could dive deeply into specific aspects of climate risk. These modules explored topics from the economic impacts of climate change to conducting a climate stress test.

Detail on the Landscape Review Module

The case studies and recommendations for tool providers that comprise this paper were completed as the primary output of the module titled: "Landscape Review of Climate Risk Assessment Methodologies" or the "Landscape Assessment" module. The Landscape Assessment module offered participants hands-on opportunities to learn about and demo the latest physical and transition risk assessment tools. The module allowed participants to explore the range of climate risk tools and determine their strengths, limitations, and areas for potential enhancement. Over a dozen tool and data providers gave presentations to the group about their methodologies and analytics. The module was also supported by expert guidance and insights from the Centre for Economic Research at ETH Zurich.

The module contained three phases:

1. **First phase—background and context**
In the first phase of the module the lead authors of UNEP FI's Climate Risk Landscape report (UNEP FI 2021) discussed the report's key messages and conclusions with participants. The participants then compared methodologies for transition risk assessment based on ETH Zurich's paper: Taming the Green Swan (ETH, 2020). The ETH sessions allowed participants to consider multiple dimensions of existing tools as shown below.

Figure 1: Areas of assessment in ETH tool analysis

I.	**Accountability**
1	**Public transparency**
a	Model modules, code public
b	Study questionnaire completed*
2	**Emission data strategy**
a	Data sources reported
b	Third party verified
c	Missing data strategy explained
3	**Science-based approach**
a	Scientific references
b	Peer-reviewed
II.	**Depth of risk analysis**
4	**Hazard (shock/smooth trnsition)**
a	1.5/<2°C scenario
b	Country=differentited
c	Sector-differentiated
5	**Exposure**
a	Current GHG emissions
b	Expected GHG emissions
6	**Vulnerability & resilince**
a	Profits to cover costs
b	Peers performance. competition
c	Cost pass through
7	**Adaptability**
a	Input substitution
b	Climate strategy, climatee-ligned R&D or future CAPEX plans
8	**Economic Impact**
a	Economic losse and gains
b	Macroeconomic development
9	**Risk amplification**
a	Mutual risj amplification
b	Financial market amplification
III.	**Usability**
10	**Output interpretability**
a	Model structure, scanarios and assump-tions reported
b	Assumptions-based output communica-tion
11	**Uncertainty**
a	Baseline adaptable
b	Scenario-neutal (various risk realistions)
c	Profitability distribution input (timing)
d	Profitability distribution output (values)

Following these background sessions, participants worked with UNEP FI to define a set of criteria for producing a structured case study on the tools they would pilot in the second phase. The agreed-upon structure is referenced in the case study section of this report.

2. Second phase—tool presentations and demos

Figure 2: Tool and data providers which feature in the case studies in this paper

In the second phase of module UNEP FI invited around fifteen tool providers to provide a demonstration of their latest climate risk assessment tools to the participants. In these interactive sessions, participants were able to ask providers about tool methodologies, coverage, and functionality. At the end of these demonstrations tool providers gave details on the potential piloting of their tool (e.g., how many participants could pilot, how many assets would be assessed, what outputs may look like).

Following these demonstrations, module participants decided which tools would be most appropriate for their institution to pilot. UNEP FI then matched up participants with tool providers and held an introductory session to provide the parameters of the pilot and to kick off the collaboration between providers and participants. During the course of the pilot, providers and participants met bilaterally to discuss topics such as data required and interpretation of outputs.

3. Third phase—review and case studies

The third phase of the module allowed participants the opportunity to discuss the piloted tools with the wider group. These post-pilot discussion sessions enabled participants to compare their experiences in the pilot and discuss the strengths and limitations of the tools they had seen. These feedback sessions facilitated the drafting of the case studies found within the report.

Objectives of this report

Given the expanding use cases for climate risk analyses in the financial sector and the growing number of tool providers, over the past few years, UNEP FI has worked to inform financial institutions about the structure, coverage, and methodologies of commonly used tools. This research has encouraged firms to integrate climate risk analyses into their operations and ensure they are informed consumers of climate tools and data.

In 2019, UNEP FI published Changing Course, as an output of the TCFD pilot for investors (UNEP FI, 2019). This report covered the climate risk assessment methodology developed as part of the pilot (in coordination with Carbon Delta), but also explored a selection of other methodologies that analytical tools have deployed to assess climate risks.

Since the release of Changing Course, climate risk analysis has gone mainstream. Demands of regulators and other stakeholders has driven financial institutions to improve their capabilities for conducting physical and transition risk analyses. Financial institutions have also identified new needs such as improved geographic coverage for physical hazards and 1.5°C-aligned scenarios for assessing transition risk. Tool providers have responded by increasing their offerings and developing new approaches to generate decision-useful and actionable outputs for their clients. A number of new providers have entered the market while others have partnered or been acquired in order to enhance their capabilities.

Due to the rapidity of change around climate risk tools, in early 2021, UNEP FI released The Climate Risk Landscape, a report that mapped climate-related financial risk assessment methodologies. The landscape review summarized key developments across third party climate risk assessment providers since the publication of Changing Course, including new and updated scenarios, methodological tools, as well as an overview of the changing regulatory landscape and potential future developments. The report explored almost 40 providers, split between physical and transition risks. These providers completed a detailed survey to inform key conclusions about the state of third party tools. A summary of the assessments is shown below. For physical risk tools, the report built on work within UNEP FI and Acclimatise's 2020 paper, Charting a New Climate (UNEP FI and Acclimatise, 2020). For transition risk tools, the report benefitted from the analyses included in ETH's 2020, Taming the Green Swan, which provided deep methodological assessment of existing transition risk tool providers (ETH, 2020).

Figure 3: Summary table of physical risk tools from The Climate Risk Landscape, 2021

			Provider																		
			427 (1)	427 (2)	ACC	ACC-WTW	C4 (1)	C4 (2)	CFIN	CW	MSCI	OF (1)	OF (2)	RhG	RMS	SP (1)	SP (2)	TCS	VE-PL	VR	XDI
Scenarios	<2.0°C (RCP 2.6)				✓	✓			✓		(✓)!	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	2.0°C (RCP 4.5)		(✓)!		✓	✓	✓	✓	✓	✓	(✓)!	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	3.0°C (RCP 6.0)				✓	✓	✓		✓		(✓)!	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	>4.0°C (RCP 8.5)		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Time horizons	Baseline/historical				✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Near term (2025–2040)		✓	✓	✓	✓			✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Medium term (2050)		(✓)!		✓	✓	✓	✓	✓	✓!		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Long-term (2100)		(✓)!				✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Physical Hazards	Chronic		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Acute		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Risk analysis	Level of analysis	Asset	✓	✓	✓	✓	✓	✓		✓			✓	✓	✓		✓	✓	✓	✓	✓
		Firm	✓	✓	✓	✓	✓	✓	✓					✓	✓	✓	✓	✓	✓	✓	✓
		Sector	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓			✓	✓	✓	✓
		Country	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓			✓	✓	✓	✓
		Portfolio	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓		✓	✓	✓	✓	✓
	Impact Channel	Macroenvironment		✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	
		Supply chain		✓	✓	✓	✓		✓			✓	✓		✓	✓	✓	✓	✓	✓	✓
		Operations and assets	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Markets and customers		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
	Method	Physical Exposure	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Vulnerability indicators		✓	✓		✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓
		Physical impact modeling	✓	✓		✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Financial modeling	✓	✓		✓			✓			✓	✓	✓	✓		✓	✓	✓	✓	✓
Physical Hazard Type	Flood, coast		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
	Flood, inland		✓	✓	✓	✓	✓	✓	✓	✓	(✓)!	✓	✓		✓		✓	✓	✓	✓	✓
	Extreme weather		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
	Extreme heat		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓			✓	✓	✓	✓	✓
	Extreme precipitation		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓		✓	✓	✓	✓	✓
	Landslide				✓	✓	✓	✓				✓	✓						✓	✓	✓
	Drought		✓	✓	✓	✓	✓	✓			(✓)!	✓	✓		✓		✓	✓	✓	✓	✓
	Water scarcity		✓	✓	✓	✓	✓	✓									✓	✓	✓	✓	
	Wildfire		✓	✓	✓	✓	✓	✓	✓		(✓)!	✓	✓		✓		✓	✓	✓	✓	✓

This current report aims to extend the work of The Climate Risk Landscape in a new way. Rather than expanding the number of providers explored (a topic for the next edition of the landscape paper), this report seeks to catalogue the actual experiences that financial users had while piloting different tools. The detailed case studies include insights into the process, challenges, outputs, and learnings related to using selected climate risk tools. These case studies should be seen as a companion to the categorizations provided within The Climate Risk Landscape. Together, the two reports begin the process of providing financial users with a resource for understanding both the theoretical attributes of different tools as well as how they function in practice.

In addition, the case studies were designed to inform tool providers on specific topics and aspects where their tools and services could benefit from additional components, and where they could be enhanced or complemented with further information and features. Finally, the case studies were designed to inform supervisory authorities and regulators about the status quo of tool applicability, possible existing gaps and ways forward in the near future.

Through this piloting process, participants gained deep familiarity with the tools they used and provided feedback and reflections on their experiences. The following section discusses some of the major trends related to climate risk tools observed by UNEP FI and participants as well as areas for further tool development. Given the emerging trends towards better comparability and baseline climate risk metrics in climate risk disclosures, this report could also inform about the status quo of tools coverage and performance, and possible issues to be solved by regulatory guidance in the near term.

Key takeaways on climate risk tools

Major trends to note

- **Tool creators are partnering and larger players are bolstering their capabilities through acquisitions**

With growing demand for climate risk tools and data, mergers & acquisitions are becoming ever more common. These partnerships can be between tool developers and data providers, such as between Oliver Wyman and S&P Global Market Intelligence to launch their Climate Credit Analytics platform. They can also include acquisition of climate expertise into a larger professional services firm. Examples of this include Willis Towers Watson's acquisition of Acclimatise, Moody's Analytics acquisition of Vigeo-Eiris, and McKinsey's acquisition of Vivid Economics. Whether through partnership, joint venture, or acquisition, the moves towards collaboration and consolidation may expand the resources in standard financial service providers capabilities devoted to climate risk tool development. This trend is a signal of growing investment in provider capabilities.

- **Transition and physical risk methodologies are being combined**

In the past, many tools focused exclusively on physical risks or transition risks. However, as financial institutions and supervisors look to assess overall climate strategies and exposure to climate-related risks, a more integrated approach has been required. This has been very much driven by the physical-transition risk-combined reference scenarios of the NGFS. Rather than assessing physical risks and transition risks under different scenarios, some tool providers have sought to provide a holistic view of a firm's climate-related risks under different scenarios. Providers such as ISS-ESG and Moody's Analytics offer combined assessments for both risk types, while other providers calculate risks separately and then aggregate them. While the consideration of interaction effects between transition policies and physical risks is complex, the first steps are being taken in this direction. For example, in the NGFS's latest climate scenarios, the trade-off of impacts between transition and physical risks were incorporated into the reference scenarios.

- **Development of tools to meet regulatory expectations**

In 2021, a handful of jurisdictions announced mandatory climate risk disclosures (often based on the TCFD framework), climate risk management expectations, and climate stress tests. These increased demands represent a growing appreciation of the risks that climate changes poses to the financial system and a desire to understand the nature and magnitude of those risks. Two of the most comprehensive stress tests have been developed by the Bank of England/Prudential Regulatory Authority and the European Central Bank. Their exams require financial institutions to modify existing stress testing models and create new ones. Third party tool providers have closely observed the expectations of these leading central banks in developing offerings to meet the needs of financial users. Data providers have also been focusing on providing detailed information on counterparties, regions, and industries necessary to generate stress testing outputs.

- **New physical risk data sources and improved granularity**

One of the major challenges tool providers seek to address is converting physical and transition risk data into financial impacts. Doing this effectively demands reasonably granular data that captures elements of financial relevance. Given that many of the original forecasts of climate-related physical risks were developed for scientific purposes, a recent focus of data providers has been on the needs of corporate and financial users. Initiatives such as ClimINVEST are developing open source access to physical risk data as is the EU's Copernicus Climate Change Service (E3CS). Alongside E3CS, through the Linux Foundation, Open Source Climate (OS-Climate) aims to be a clearinghouse for climate data needed by financial actors. In addition to these initiatives, there are also emerging collaborations between tool and data providers to enhance the resolution and coverage of physical hazard data.

Improved physical risk data allows financial institutions to assess their exposures against physical risks in various regions. The proliferation of data also means that tool providers and financial institutions have shown a greater interest in understanding asset-level physical risks, which are highly location dependent. The ability to evaluate asset-level risks is also enhanced by the increasing frequency and detail of corporate climate-related risk disclosures.

- **Growing interest in machine learning, AI, and remote sensing data sources**

Big data has been key to improved climate model projections for many years. Typical simulations of climatological phenomena are highly computationally intensive. As computing power has grown and new statistical techniques have developed, climate risk tools providers are also looking to leverage advanced data collection and analysis techniques. For physical risks, remote sensing technologies can provide early warnings of a hazard or can offer a more detailed picture in previously data-scarce regions. For transition risks, new technologies can detect methane leaks and other sources of emissions to refine estimates of financed emissions.

Machine learning and artificial intelligence have been increasingly used to pour through climate-related datasets and derive new insights. For physical hazards, advanced data analyses have led to the identification of drivers of extreme event severity and the potential for business and supply-chain disruptions. New data sources and AI have also helped tool providers to refine forecasts in real time. An example is Jupiter Intelligence, which has developed a physical risk model up to 2100 that is constantly updated through satellite and sensor data. Also, AI could help to extract firm-level communications of their own climate targets and strategies, which are by some tool providers included in their risk analyses.

- **New transition risk scenarios and a focus on net zero**

Earlier transition risk assessments focused on comparisons between current policy scenarios and Paris-aligned transition scenarios (below 2˚C). However, in the past few years there has been a growing focus on 1.5˚C scenarios and increased nuance in the design of transition pathways.

First, there has been a widespread recognition of the need to incorporate 1.5˚C scenarios into tools. The global focus on 1.5˚C followed the publication of the IPCC's Special Report on 1.5˚C in 2018 that showed significantly greater harms experienced by a 2˚C warmer world than a 1.5˚C one (IPCC, 2018). That report spurred financial actors to call for the development of 1.5˚C scenarios from leading modelers such as the IEA, which obliged with its net-zero 2050 scenario (IEA, 2021). Climate science indicates that the 1.5˚C threshold requires reaching net-zero CO_2 emissions by 2050, which has become a central goal of policymakers and financial institutions alike. Following COP 26, over 90% of the world's governments had made preliminary net-zero commitments, and they were joined by over 450 financial institutions (GFANZ, 2021). The global consensus on the need for net-zero 2050 and the goal of 1.5˚C have made it imperative that tools enable financial institutions to assess their performance under these objectives.

In addition, there has been a growing appreciation that while more ambitious temperature targets can increase transition risks, the nature of the transition itself (orderly vs. disorderly) can have a major impact on the level of transition risk experienced. In UNEP FI's paper Decarbonisation and Disruption, the effects of a disorderly transition were explored for various economic sectors (UNEP FI, 2021). Likewise, the latest NGFS scenarios have developed scenario narratives that explore both orderly and disorderly transitions as well as the implications of delayed action and regional policy differences (NGFS, 2021). These NGFS scenarios provide a more detailed picture of the risks that may result from different transition pathways, and tool providers and financial institutions have been eager to determine the impacts of these new scenarios on financial portfolios.

- **Rising expectations of tool capabilities from FIs**

As more financial institutions use climate risk assessment tools and are faced with growing pressure to disclose and act on their climate risks, tool providers have sought to improve their offerings. Broadly, financial institutions look for tools to be: decision-useful, disclosure-useful, and commitment-useful.

Decision-useful tools enable senior leadership and those in the business to act on the outputs produced by the tool. Such outputs can inform overall climate strategy, improve client engagement, and spur the development of new policies. Decision-useful outputs should be clear and able to answer the questions posed by users.

Disclosure-useful tools are developed to meet regulatory or other external disclosure requirements. They can be used for climate stress testing, TCFD reporting, or other sustainability disclosures. Multiple tool providers have worked to develop approaches that allow a financial user to easily translate the outputs of the tool into commonly used reporting frameworks. In a sense, these tools work backward from the reporting expectations in order to produce outputs that are likely to align to reporting standards.

Commitment-useful tools recognize the large number of financial institutions that have made commitments to green-financing and net zero in recent months. These tools enable appropriate target-setting and can also help financial institutions to monitor progress against specific targets. For commitment-useful tools, the methodology used in the assessment is particularly important as it may need to align with the methodology permitted under specific target-setting protocols.

Tools can serve more than one of these functions and often do.

Recommendations for future tool enhancement

As the trends above suggest, tools are constantly improving as providers look to meet the needs of their financial services clients. However, through the piloting exercise and group discussions, UNEP FI and the participating financial institutions identified several areas for future tool enhancement. These recommendations are geared towards tool providers (both third party and within institutions) in hopes of spurring the further development of approaches and methodologies required by financial institutions. They are grouped into specific areas for ease of reference.

Input data coverage

Although new data sources continue to be developed and many tool providers are working with more data than ever before, financial institutions still identify room for improvement. A common concern for financial users is how appropriate a tool's data is for their portfolio. This can include coverage of different asset classes, economic sectors, and geographic areas. While proxies and extrapolations may be required, there is a strong desire to ensure that their application is both intuitive and transparent. Through the piloting exercise, feedback regarding input data coverage pertained to three areas: physical risk data, transition risk data, and emissions data.

Physical risk data

Regional data coverage

While new sources of data are helping to address gaps in certain regions, much work remains to be done. Pilot participants with holdings in Africa, Southeast Asia, and South America all raised concerns about the degree of granularity offered by climate risk tools. Where data is unavailable, proxies and regional averages are sometimes used. However, there is no replacement for good data, and emerging economies continue to experience data gaps for physical hazards, transition risks, and emissions data.

Physical asset level data

A number of climate stress tests have required financial institutions to conduct counterparty level analyses on potential climate risks. Effective counterparty assessment requires data on the exposures of major assets to physical risks. That in turn demands highly granular data. As noted above, this data is most often lacking in emerging economies, but in some instances even when available only certain hazards are covered.

With a growing interest in asset-level assessments, many tool providers are working to improve their level of coverage and granularity.

Additional physical hazard scenarios

Pilot participants noted that physical risk scenarios typically considered representative concentration pathways (RCPs) associated with IPCC reports. Participants considered the strong mitigation (RCP 2.6) and the no action (RCP 8.5) scenarios to be most relevant in assessing the range of physical risk outcomes. However, within each of the RCPs are a variety of different potential pathways for the development of hazards. These pathways vary based on the underlying climate model used but can demonstrate that even for a given RCP the speed and severity of certain hazards can vary significantly. Participating financial institutions expressed interest in seeing a greater diversity of physical hazard scenarios for given RCPs, something that can be integrated into future tool design.

Transition risk data

Private company transition plans

In late 2021, the TCFD provided new guidance about the importance of disclosing climate transition plans as part of its recommended disclosures (TCFD, 2021). Additionally, certain jurisdictions (such as the UK), have mandated the disclosure of climate transition plans. These plans can provide a wealth of information about a company's preparedness and resiliency during a low-carbon transition. Financial institutions are looking at ways to integrate insights from corporate transition plans into their company-level assessments. Third party tool providers should also consider how this new information can be effectively incorporated into company assessments.

Sectoral assumptions

The transition to a low-carbon economy will affect nearly every sector in unprecedented ways. Assumptions around how different sectors will respond and which industries will be winners and losers of the transition have major implications for tool outputs. When exploring transition risk tools, pilot participants were eager to understand the key sectoral assumptions made by the tools. Participating financial institutions wanted more guidance around sectoral assumptions both to understand their effect on outputs and also to compare them to their own analyses of sector and industry outlooks. Tool providers can offer greater detail on the narratives in their scenarios and the implications of those scenarios for major emitting sectors such as energy, transportation, buildings, and industrials. They can also continue to add nuance to how carbon budgets for these sectors and their associated decarbonisation pathways vary across countries.

Additional transition scenarios

As noted in the trends section, many tool providers have increased the number of transition scenarios available to financial users. The added focus on net-zero pathways and scenarios reflecting current and potential climate policies has been a positive development. However, tool providers can go further in adding nuance to different scenarios, especially for disorderly transition scenarios. While the comparison of an orderly and disorderly transition is useful, a disorderly transition can proceed in many ways. Tool providers can work with economic modelers to consider the implications of different transition pathways on specific sectors and the global economy overall.

Emissions data

Emissions data has become increasingly important for financial institutions to define and track their decarbonisation commitments and to assess the transition risk of their exposures. While initiatives like CDP have done valuable work in collecting and providing self-disclosed data on corporate emissions, coverage is largely limited to public companies. For financial institutions that lend to or invest in small and medium enterprises, a number of assumptions are needed to address reporting gaps. These extrapolation methodologies may have major impacts on a portfolio's financed emissions or its transition risk, and so should be clear, transparent, and aligned with commonly accepted approaches for calculating emissions. Third-party verification of data is also important to validate and improve the quality of self-reported information. Tool providers will need to continue developing methodologies that cover these data gaps in greater detail in order to ensure that outputs generated for alignment and risk assessments are considered credible.

Risk types included

As financial actors and supervisors acknowledge the systemic risk of climate-related developments for financial stability, it has become imperative to gain a comprehensive view of a firm's climate risks. Such a holistic view demands tools that capture potential impacts from a wide range of climate-related phenomena. Pilot participants desired tools to capture the broad set of physical hazards they might be exposed to, common policy-driven transition risks, and emergent literation risks, interactions between risks, and financial system contagion.

Physical risks

Additional hazards

The physical risk tools profiled in the case studies of this report contain a variety of different physical hazards. However, as pilot participants noted, the most prominent hazards may vary significantly by region, and these prominent hazards may require additional detail. An example can be the hazard of flooding, which depending on location may be predominantly driven by coastal inundation (coastal), river overflow (riverine), or rainfall (pluvial) or some combination of these. Some tools already separate hazards into different types, but for those that do not, this additional nuance is welcomed.

Another area of interest involves indirect hazards of climate change. Pilot participants noted that few tools explored topics such as disease burden, water desalinization costs, and biodiversity loss. A full picture of climate risks requires consideration of the range of negative outcomes associated with a warming world. Additional work is needed to determine the financial and economic consequences of some of these more indirect effects of climate change.

Extreme event severities

For physical risks, many tools provide estimates that include both changes in incremental risks and changes in the frequency and severity of extreme events. While the likelihood and nature of extreme events may be moderated by changing baseline conditions (incremental risks), risk managers within financial institutions are highly concerned with the effects of extreme events. However, given different forecasting models there is a large degree of variation in the frequency and severity of these extreme events. Pilot participants sought to consider a larger set of extreme event frequencies and severities in assessing the performance of their portfolios. One way for tool providers to offer this is to show losses under different tail risk events and their associated probabilities (a topic discussed in the methodology points raised below).

Transition risks

Policy risks

During discussions with UNEP FI, pilot participants spoke about their interest in better understanding the implications of various policies on their portfolios. While net-zero commitments have been made by nations around the world, the implementation of this major economic change often remains vague. Different transition scenarios within climate risk tools offer financial institutions the opportunity to consider the effects of various policies and decarbonization strategies. However, among pilot participants, there was a strong recommendation that tool providers include more policy-driven scenarios in their tools and provide clear narratives for how the policies are likely to influence different sectors.

Carbon pricing

While carbon pricing can be considered a policy decision, it also reflects the development of global carbon markets and the use of internal carbon prices by different firms. Pilot participants considered the carbon price one of the clearest ways to evaluate the performance of portfolios and particular counterparties across a transition scenario. Tools that allow users to change the carbon price or compare different carbon prices and their effects were particularly desirable to participants.

Litigation risks

One area of risk rarely, or only indirectly captured by most tools is climate litigation risk. 'Climate litigation risk' in this context refers to the financial risks from any cause of action, regulatory investigation, or any dispute, that has a physical or transition risk catalyst. Customer and counterparty actions that could, for example, give rise to climate litigation include: failures to: mitigate emissions, consider climate change impacts, manage or disclose material climate risks, make accurate representations about climate risks/green credentials, or to comply with regulatory adjacencies.

Climate litigation risks function like other traditional risks in that they can reduce asset values or pose credit risks by creating additional costs that corporates must pay. And whilst it may be challenging to incorporate such risks into tools, the recent growth in litigation in this area means that their consideration is necessary to both fully and adequately assess climate risks.

Additional time horizons

After data granularity and risk coverage, time horizons were frequently brought up by pilot participants as an area for future tool enhancement. Some tools designed for regulatory purposes adhere to the time horizons requested by the supervisory exams, while others align to the time horizons of the publicly available scenarios they take as inputs. These decisions are sensible, but as pilot participants noted in their discussions, financial institutions need to assess climate risks over a variety of time horizons. This can prove challenging given the progressive emergence of physical risks or the time needed to adapt the global economy to a low-carbon operating model. However, greater consideration of short-term shocks can allow financial decision-makers to understand the low-probability high-severity consequences of climate change or the low-carbon transition on today's portfolios. In addition, shorter term risk assessments can be more easily integrated into strategic planning and turned into actionable policies by business lines.

Output application/interpretation

While many providers consider their products as multi-solution tools, pilot participants were eager to better understand the implications and applicability of tool outputs. In order to effectively use the results, participants put a premium on transparency and clarity of assumptions. Relatedly, there was a strong desire to understand the range of uncertainty around different results. Many tools produce a single answer for a portfolio, but according to participants, a range of output values might be as useful if not more so in interpreting the results. Participants also requested additional guidance on how to use tool outputs in reporting and a desire to see illustrative examples to confirm the sensibility of the outputs generated.

Greater transparency

Participants within the UNEP FI pilot program often serve as critical communicators of climate risk insights to the rest of their organization. As a result, these individuals need to understand the outputs and the key assumptions of the tools they are using particularly well. The pilot exercise with tool providers received positive feedback from participants in terms of the transparency and openness shown by the tool providers about their methodologies and outputs. However, that transparency was made possible by direct meetings between the participants and tool providers. It would be valuable for all tool providers to provide accessible documentation that supports a greater understanding of their tools and the associated output among financial users. While this information should not compromise intellectual property, it should enable financial institutions to act as informed consumers of the various tools they may consider using.

Uncertainty around results

All tools based on future projections are subject to uncertainty, a fact widely acknowledged by the pilot participants. More details on the range of that uncertainty in outputs was considered a high priority by program participants. The IPCC itself uses various certainty measures (e.g., highly likely, likely) to connote probabilities of different outcomes in the climate projections it uses. Tool providers could also add more clarity around which results are more likely and which are more highly uncertain. Uncertainty may depend on data considerations, time horizons, and the measures being forecast. However, the inclusion of a form of "error bars" would aid in the communication of tool results and greater confidence in how to act on the information they provide. In addition, users should understand the probabilities associated with different outcomes and where those outcomes fall in a distribution, for example, does an output represent a mean estimate of losses or a 95th percentile? The topic of probabilistic estimates is explored further below.

Clarity in how outputs can be used to meet needs

During the individual tool piloting phase, participants were asked to consider how the tool outputs could be used throughout their organization. Many participants requested that tool providers offered additional guidance for how to interpret results and where the outputs might be most relevant. In the case of regulatory tools, use cases may be clear, but for many outputs, there are a range of potential applications. Tool providers can consider how their outputs might be used and also structure those outputs to fit the needs of these use cases. An example provided by a participant was the challenge in transforming the outputs from the tool into a format that could be incorporated in a TCFD report. Another question regarding tools involves how to effectively use outputs for internal decision-making.

Methodological assumptions

As outputs of climate risk tools are reported in public disclosures, regulatory exams, and internal analyses, methodological considerations around these tools are critical. Through discussions with UNEP FI, the pilot participants identified multiple areas where enhancements in tool methodologies could increase the realism of results. In most of these instances, participants expressed a concern that existing tools and analyses resulted in an underestimate of potential climate risks. The fuller incorporation of different hazards, tipping points, and tail risk events might present an opportunity to capture the potential consequences of climate-related financial impacts more fully.

Additional complexity/realism

Integration of physical and transition risks

As noted previously, some tool providers have begun integrating physical and transition risks into their models. However, even for tools that consider both physical and transition risks, internal consistency may be limited. Rather than applying a single scenario that covers both physical and transition risks, a tool may consider the risks separately and link them based on RCPs or temperatures, meaning that the underlying assumptions between the physical hazards and the transition pathway can come from different models. Beyond just using the same underlying models, tool providers should consider the interaction effects of both risk types on individual assets and portfolios overall. Examples include how coastal real estate may be hit by tropical storms due to climate change and also face higher electricity and rebuilding costs due to the low-carbon transition. On the other hand, a positive synergy might be resiliency measures that also increase energy-efficiency.

Interaction effects between hazards

For physical hazards, interaction effects are critical to understanding the full extent of the climate-related risks. A storm that strikes in a location that has suffered from coastal erosion and sea level rise will be more damaging than its windspeed and flood heights would indicate. There are often correlations between different hazards that also amplify potential damages, such as warmer and drier conditions that make wildfires more likely and severe. While these interaction effects may not be directly modelled by a climate risk tool, tool providers should move away from considering individual hazards in isolation where possible and look for underlying models that consider the relationships between hazards.

Incorporation of tipping points

Climate tipping points have become an area of growing concern due to scientific research indicating that many of them may be activated at even modest levels of warming. Fundamentally, tipping points are non-linearities in a system, which when exceeded change that system from one state to another. They can be physical in nature, such as melting ice sheets, or economic, such as the collapse of confidence in global credit markets in 2008, but regardless of where they manifest, they are critical to gaining an accurate view of climate risks. Few tools explicitly capture tipping points as they relate to physical risks, such as marine ecosystem collapses, or as they relate to transition risks, such as the collapse of coal power in OECD economies. Given that these non-linearities are where outsized climate risks may be experienced, it is imperative that tool providers consider how they can be both integrated into their models and used to inform the outputs generated. These tipping points also demand a paradigm shift for financial institutions from risk-return management to resilience management.

Inclusion of second and third order effects

Climate risk tools often focus on a set of hazards when assessing their financial impact on a portfolio or individual counterparty. These hazards (both physical and transition) are often the direct effects of climate change or of the transition. Examples for physical hazards include damages from flooding or wildfire, examples for transition risks include carbon taxes or rising energy costs. However, many climate-related impacts are not the direct result of the initial event, but rather the secondary and tertiary effects. The case of

Hurricane Katrina is illustrative on this point. While the damage from the storm itself and the attendant flooding were estimated at over $100 BN, the New Orleans economy felt additional shocks. Businesses that remained closed for months or longer lost revenues and customers, the city lost tax revenues, and investments in new projects were repurposed to rebuild the damage. Furthermore, over 100,000 residents who left New Orleans did not return, leading to a smaller city with lower output than before the storm. Assessing the true costs of climate change requires evaluating the long term consequences of different events and policies.

Probabilistic estimates of losses

Many climate risk tools provide specific output values for a given portfolio and timeframe. However, the uncertainties inherent within climate modelling mean that climate risk is a fundamentally probabilistic challenge. Unfortunately, in some cases, users and providers may confuse a scenario with a severity. For physical risks, this may mean considering RCP 8.5 to be the "severe" scenario or for transition risk, it might be considering 1.5˚C to indicate "severe" transition risks. However, each scenario is merely a single potential pathway and the results of a tool are a point estimate of losses or impacts on that pathway.

However, RCP 8.5 may have widely varying implications for different physical hazards. This is easier to see given the proliferation of climate models that are run for RCP 8.5 that may show different levels of flooding, storms, wildfires and other hazards. To look at the most severe outcomes, a probabilistic method should be considered which looks at these different underlying models and considers hazard severity. As such, the 95^{th} percentile of flooding for an RCP 8.5 scenario should be in the top 5% of the worst flooding as indicated by different models. For transition risk, this approach is slightly different, but relies on macroeconomic probabilities of key variables like growth rates and trade balances. It may be more challenging to assign numerical probabilities to different transition scenarios, but certainly for a given 1.5˚C scenario, optimistic, base, and pessimistic cases of economic performance can be considered. The modelling community has explored some of these different futures through the creation of shared-socioeconomic pathways (SSPs).

While these challenges may require the involvement of climate modelers and scenario developers, their implications should be contemplated by thoughtful tool providers. Looking at the tail risks of different scenarios can provide a better view of downside risks that financial institutions must prepare for, and avoid the mistaken assumption that if a portfolio performs well in a certain RCP 8.5 or 1.5˚C scenario than it faces limited climate risk.

Strategic guidance

According to the pilot participants, climate risk tools are already being used to guide decisions. However, in addition to the enhancements noted above regarding coverage, hazards, outputs, and methodologies, participants want tools to provide guidance as well. Specifically, participants are looking for tools that can identify potential climate-related opportunities, improve client engagement, and develop new climate strategies. These desires represent a step forward for many climate risk tools that have been developed to produce a loss estimate or meet a reporting need. The application of forward-looking analytics to opportunities and strategies can allow firms not only to manage their risks but to take advantage and thrive in a changing world.

Opportunity identification

While recent years have seen a large number of tools marketed to help manage climate risk or report on climate alignment, fewer tools appear to focus on the tremendous opportunities presented by climate change through mitigation and adaptation solutions. In the UNEP FI pilot program, many participants indicated awareness of potential climate-related opportunities, but few mentioned that they were using tools to evaluate them. Given the widespread economic shifts that climate change and net zero will bring globally, financial institutions have the opportunity to support the creation of a resilient, just, and sustainable future and profit while doing so. Forecasts from the IEA and NGFS for reaching net zero require trillions in annual funding for the development and deployment of clean technologies. Pilot participants expressed an eagerness to see tools that helped them identify opportunities most suitable to them and determine how best to capitalize on them.

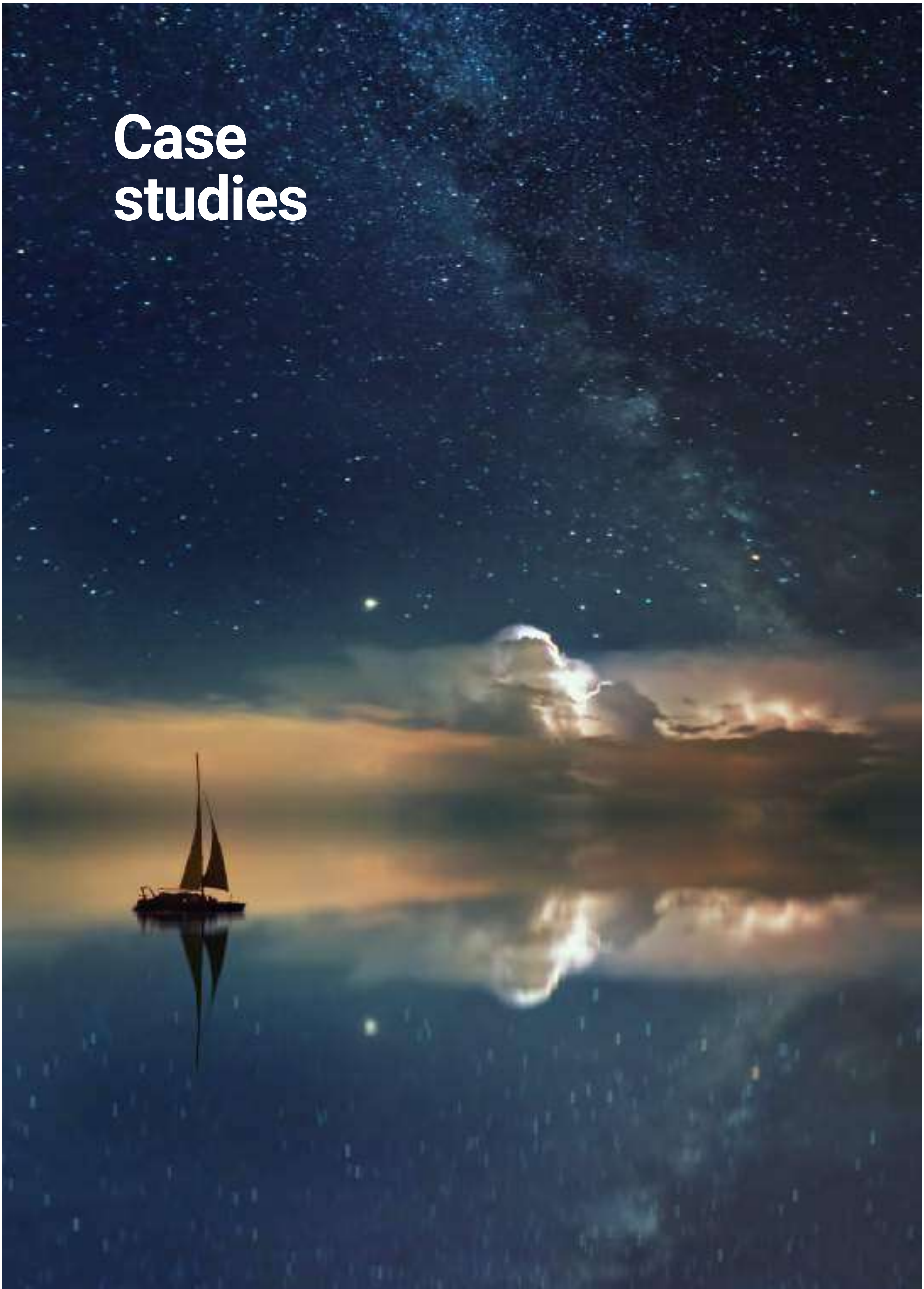
Client engagement

When asked about how they planned to use the outputs of the pilot analyses, participants frequently mentioned client engagement. Information about climate risks and individual counterparties can help financial institutions decide on the relationship the firm would like to have with those counterparties in the future. However, there was a desire for tools to be developed that even more explicitly focused on client engagement, and specifically in helping clients to transition to net zero. A number of participants have made public commitments about supporting client transitions and would welcome the creation of tools that allow them to assess transition plans and more effectively communicate with clients on how they can advance their progress towards net zero.

Strategy-setting

In addition to client engagement, participants also mentioned that pilot outputs could be used in determining climate strategy. Many tools provide outputs that are helpful in developing high-level climate strategies. Yet, for specific businesses, the desire for actionable guidance on climate policies demands more granular outputs. Part of the challenge involves getting the business line familiar with the outputs of climate tools and confident in their usefulness for developing a forward-looking strategy. Beyond that, tools geared towards specific businesses, sectors, or asset classes can provide information that can be integrated into processes such as underwriting and origination.

Case studies



Case study structure

The case study structure was developed in consultation with experts at ETH Zurich and covers the major areas noted below to promote comparability of the tools and the usability of the case studies as a resource for the financial sector. In the case studies that follow, the detail and nature of the criteria below may vary at the discretion of the pilot participant.

Figure 2: Criteria included within case study assessments

Introduction
- Overview of the piloting exercise
- Key findings or conclusions

Process
- The process followed in using the tool, step-by-step
- Main challenges encountered

Data and coverage
- Data needed to conduct the analysis
  - Internal
  - External
- Portfolio coverage
  - What geographies and sectors can the tool assess?
  - What was actually assessed in the demo?
  - Percentage of portfolio, geography, sector, total exposure?
  - Number of counterparties?

Risk factors and scenarios
- Key risk factors explored during the demo (e.g., hazard types)
- Temperature pathway(s) analyzed
- Scenarios used (NGFS, IEA, etc.)

Outputs and insights
- What outputs were generated?
- What learnings came from using the tool?
- What are use cases for this type of analysis or for the full tool?
- Any future plans to extend the analysis or conduct similar analysis internally?

Suggested enhancements for providers
- How easy was the tool to use?
- Are there any modifications or suggestions you have that would enhance your analysis?
- What are areas that you'd like to see the providers explore in the future?

Detail on tool providers and tools

As mentioned in the acknowledgements, UNEP FI and the pilot participants would like to thank the providers for allowing the piloting of their tools. The table below provides a high-level overview of the participating providers and the tools that were piloted.

Provider	Description	Featured tool overview	Risk types covered by tool
Entelligent	Entelligent is a climate risk analytics platform that measures and manages investment exposure to climate risk.	Entelligent has built technology — the first to be patented — that leverages macroeconomic and forward-looking climate-scenario models. This allows Entelligent's platforms to help institutional investors managing equity and corporate bond portfolios to maximize both financial performance and carbon-emissions reductions, while minimizing climate change transition risk.	Transition Risk
ISS-ESG	ISS ESG solutions enable investors to develop and integrate responsible investing policies and practices, engage on responsible investment issues, and monitor portfolio company practices through screening solutions.	ISS ESG provides climate data, analytics, and advisory services to help financial market participants understand, measure, and act on climate-related risks across all asset classes. In addition, ESG solutions cover corporate and country ESG research and ratings enabling its clients to identify material social and environmental risks and opportunities.	Physical & Transition Risk
Moody's Analytics	Moody's Analytics provides financial risk intelligence and analytical tools supporting our clients' growth, efficiency, and risk management objectives. The combination of our unparalleled expertise in risk, expansive information resources, and innovative application of technology helps today's business leaders confidently navigate an evolving marketplace.	Moody's Climate Solution suite offers a complete framework that spans across the overall risk management framework covering climate change analytics across both physical and transition risks, a comprehensive climate scenario analysis framework and stress testing, integration to credit risk modelling and financial metrics and tools to support Climate-related financial disclosures. Note that these studies were conducted pre-acquisition of RMS by Moody's, therefore, can be enriched to bring the breadth and depth of climate-related financial risk analysis that joint firms can today bring.	Physical & Transition Risk

RMS, A Moody's Analytics Company	RMS, a Risk Management Company at the Forefront of Risk Intelligence At RMS, Risk Management Solutions is their name and what they've been building over 30 years: industry-leading risk management solutions for insurers, reinsurers, financial services organizations, and the public sector. Their science, technology, and 300+ catastrophe risk models help (re)insurers and other organizations evaluate and manage the risks of natural and man-made disasters.	RMS has over 200 peril models in nearly 100 countries enabling insurers, reinsurers and other organizations to quantify the potential magnitude and probability of economic loss from catastrophe events.	Physical Risk
Oliver Wyman and S&P Global Market Intelligence	Oliver Wyman is a global leader in management consulting. With offices in 60 cities across 29 countries, Oliver Wyman combines deep industry knowledge with specialized expertise in strategy, operations, risk management, and organization transformation. Oliver Wyman is a business of Marsh McLennan [NYSE: MMC]. S&P Global Market Intelligence is a division of S&P Global (NYSE: SPGI), the world's foremost provider of credit ratings, benchmarks and analytics in the global capital and commodity markets, offering ESG solutions, deep data and insights on critical business factors.	Climate Credit Analytics—S&P Global Market Intelligence and Oliver Wyman developed Climate Credit Analytics, a climate scenario analysis and credit analytics model suite. These tools combine S&P Global Market Intelligence's proprietary data resources and credit analytics capabilities with Oliver Wyman's industry-leading climate scenario and stress-testing expertise. This solution provides a comprehensive, tailored approach to assess credit risk on counterparties, investments, and portfolios under multiple climate scenarios, including those published by the NGFS Phase II framework. Coverage includes more than 1.6 million public and private companies globally.	Transition Risk
TCS	The Climate Service is backed by an Advisory Board including 4 IPCC Nobel Prize winning scientists, and strategic partners including Aon, IBM, the AICPA, and LMI Consulting. Their goal is to help investors, companies and communities to understand their risks from the changing climate, and the opportunities from the transition to a low-carbon economy. Their mission is to embed climate risk data into every decision on the planet, and facilitate the world's transition to a lower carbon economy.	Subscription to the Climanomics® platform enables climate risk reporting and disclosure aligned with the Task Force on Climate-Related Financial Disclosures (TCFD) framework. Subscribers use the outputs to measure and report their transition and physical risks and opportunities in financial terms under different climate scenarios.	Physical & Transition Risk

Willis Towers Watson	At WTW, they provide data-driven, insight-led solutions in the areas of people, risk and capital. Leveraging the global view and local expertise of our colleagues serving 140 countries and markets, we help you sharpen your strategy, enhance organizational resilience, motivate your workforce and maximize performance.	Climate Diagnostic—It can be difficult to conceptualize climate change as a specific risk to your organization—2100 or even 2050 can feel far off, talk of sea levels rising by inches can sound insignificant, and the global effects are broad and complex. This tool shows changes in acute hazards such as extreme wind and flood as well as chronic stress factors like sea level rise and heat stress under multiple combinations of climate scenarios and timelines. It shows how those changes could affect your specific properties. Climate Diagnostic can advance your journey to effective climate risk management. Climate Quantified (CQ) is WTW's suite of models, tools, datasets and services to support organizations to identify, assess, and respond to physical and transition risk—for example through climate stress testing of investment portfolios, assessing compliance with legislative requirements or identifying opportunities to invest in the transition. Combined with learning and knowledge-sharing opportunities, CQ supports implementation of strategic responses to climate change.	Physical Risk
JBA Risk Management	They are JBA Risk Management, otherwise known as The Flood People. They are the one of the global leaders in flood risk science, helping the insurance and property industries, governments and financial institutions to understand and manage global flood risk.	They help the insurance and property industries, governments, and financial institutions understand and manage global flood risk across a wide range of flood sources, including river, surface water and coastal. Our probabilistic (CAT) models and flood maps cover 190+ countries in the World.	Physical Risk
right. based on science	The pioneering˚C data provider: right. based on science GmbH (right.) provides transparency on the climate impact of economic activities—plain & simple in˚C. Their aim is that climate-related decisions are guided by the best available science. Specialized and high-quality data for various key stakeholders: Their software and metrics enable actors from the real economy, finance, and real estate to plot pathways to 1.5°C alignment.	X-Degree Compatibility (XDC) Model—We developed the X-Degree Compatibility (XDC) Model to calculate the climate impact of e.g. companies, buildings, and financial portfolios (private & listed equity, bonds, sovereign bonds). The central question: How much global warming would occur by 2050 if the whole world performed as the entity in question? Results are expressed as tangible degree Celsius values, allowing a direct benchmarking against the Paris Agreement goal of keeping global warming to 1.5°C or, at least, well below 2°C.	Transition Risk

Baringa	Baringa have set out to build the most trusted consulting firm in the world. They team up with their clients to tackle their toughest business challenges. ▪ Their work spans the big picture—vision, strategy, future direction—and the nuts and bolts of the delivery. ▪ They work on challenges like helping clients define their net strategy, deliver complex change, spot the right commercial opportunities, make the move to digital, manage Climate risk, or bring their purpose and sustainability goals to life. They work with everyone from FTSE 100 names to bright new start-ups, in every sector. They have hubs in Europe, the US, Asia and Australia, and they can work all around the world.	Climate advisory We advise clients across financial services, government, regulatory bodies and wider sectors on climate risk and net-zero strategy through; ▪ Leading climate scenario and transition modelling capabilities ▪ Deep sectoral expertise in transition to net zero	Physical and Transition Risk
BlackRock	BlackRock's purpose is to help more and more people experience financial well-being. As a fiduciary to investors and a leading provider of financial technology, they help millions of people build savings that serve them throughout their lives by making investing easier and more affordable.	Aladdin Climate: Central to understanding—and ultimately acting upon—the effects of climate change on investments is a need to quantify the financial impact of climate-related risks. Aladdin Climate was built to quantify climate risks and opportunities in financial terms—bridging climate science, policy scenarios, asset data, and financial models to arrive at climate-adjusted valuations and risk metrics.	Physical and Transition Risk
Pricewater-houseCoopers	PwC's Sustainability practice helps organisations plan, source, deliver, finance and measure the wider impact of products and services. They help to future-proof businesses by making them more resilient, agile and sustainable. They provide guidance on a wide variety of issues, working with clients from the corporate, private equity and public sector. They are specialists in how organisations can spot the risks and harness the opportunities.	PwC's "Climate Excellence" tool for climate scenario analyses supports investors and companies in making their portfolios fit for the risks and opportunities of climate change. This enables them to realize increases in value, adequately manage risks, and set up a long-term sustainability strategy and compliant reporting.	Physical and Transition Risk

Participant:

Sustainable Leaders Capital

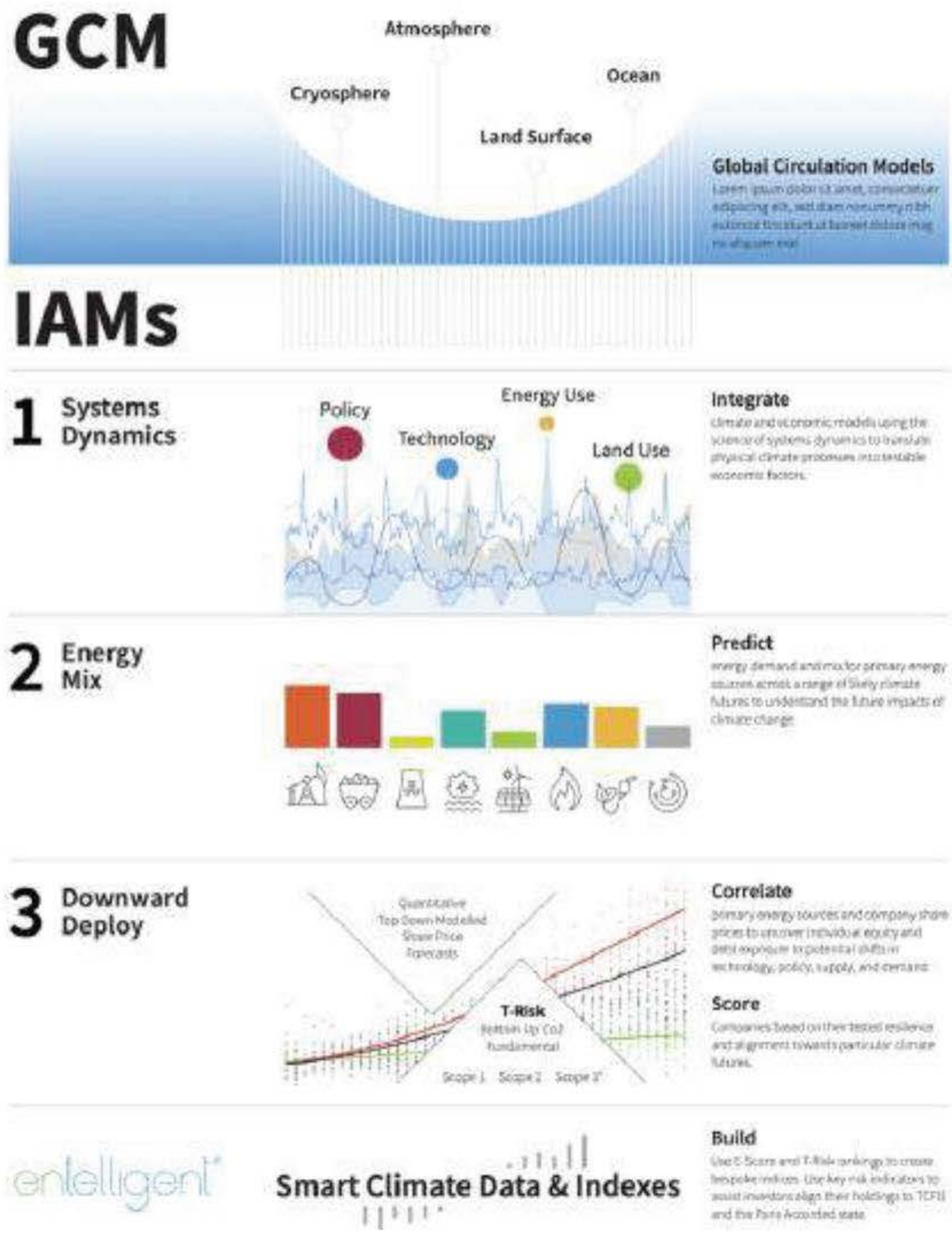
Provider:
Entelligent

Risk types covered by tool:
Transition risk

Introduction

Sustainable Leaders is a private, employee-owned institutional investment boutique offering actively managed thematic and rules-based ESG investment strategies addressing environmental and social themes. We aim to deliver sustainable, first-class investment performance, and to make a material and positive difference for our clients and society.

Entelligent is a data analytics platform that leverages the capital markets to make a positive impact on climate change mitigation and adaptation. Entelligent's climate scenario analysis and climate risk approach—which are patented—use sophisticated climate models and systems dynamics approaches to project scenarios for the future energy mix as the world aligns with the Paris Accord and net-zero commitments. Entelligent's SmartClimate technology scores companies based on climate resiliency, providing data that can underpin stock selection for funds and indexes.



Bringing together the experienced investment team at Sustainable Leaders and the climate science and machine-learning teams at Entelligent, we have built two Paris-Aligned net-zero strategies (U.S. and Global) that are optimized to maximize financial returns and environmental out performance. These case studies demonstrate a breakthrough in terms of enabling investors to better track investments alongside the transition to a low-carbon economy and lower the carbon in their portfolios, therefore reducing climate-related transition risks.

Process

Promethos Capital (now branded Sustainable Leaders for the Entelligent Index and other passive index-tracking, rule-based smart beta strategies) and Entelligent partnered to build two climate change-focused investment strategies: 1) Paris Aligned Net-zero US Large Cap and 2) Paris Aligned Net-zero Global Large Cap. The strategies are designed to build investment portfolios that feature inclusive climate transitions toward Paris goals. The portfolios are optimized to be climate resilient, have neutral representation across sectors and regions relative to the benchmark, and are focused on reducing carbon exposure.

SmartClimate is used by asset and fund managers in a joint product development effort. Sustainable Leaders selects the global index benchmarks, and Sustainable Leaders integrates ESG and mission-oriented strategies with Entelligent's climate science-based transition risk scores[1] to build portfolios that seek to create superior financial performance and environmental outcomes based on TCFD recommended metrics. The steps in the process are summarized below:

- Select global benchmark (Sustainable Leaders)
- Design ESG and mission-based strategies (Sustainable Leaders)
- Select climate scenarios (Sustainable Leaders & Entelligent)
- Project share price returns on the benchmark constituents for the selected scenarios (Entelligent)
- Compute climate risk exposures by estimating share price sensitivity to the range of energy transitions, including energy price and demand (Entelligent)
- Set screening and optimization thresholds for climate resiliency and ESG criteria (Sustainable Leaders & Entelligent)
- Run portfolio strategies and climate optimization (Entelligent)
- Deliver weights/allocations to Sustainable Leaders (Entelligent)
- Build financial products/set trades and provide investable universe to financial leaders (Sustainable Leaders)

Data

For climate modeling and inputs, we use data from MIT's En-ROADS climate and energy simulator. En-ROADs, which incorporates systems dynamics, was first used by Donella Meadows in her Limits to Growth report, published by the Club of Rome.[2] The model uses data from the Internal Energy Agency (IEA), NASA's Goddard Institute for Space Studies (GISS), the Carbon Dioxide Information Analysis Center (CDIAC), the National Climatic Data Center (NCDC), the National Ocean Atmospheric Administration (NOAA), the multisector, multiregional, computable general equilibrium model of the world economy (MIT EPPA). The financial data is from MSCI, S&P and FactSet. The carbon data on Scope-1 and 2 emissions, used to validate findings, is provided by ISS. The model is validated by a third party WSP. The model inputs and outputs are in the confidence

1 More information on Entelligent methodology and score computation is provided here: A demo version of the model is available here: https://en-roads.climateinteractive.org/scenario.html?v=2.7.29

2 A demo version of the model is available here: https://en-roads.climateinteractive.org/scenario.html?v=2.7 29

interval of forecasts from EMF 27 suite, WEO, BP and EIA. The ESG data and company-level exclusions were provided by Sustainable Leaders.

Coverage

The selection universe for the Paris Aligned Net-zero US Large Cap strategy is a U.S. large cap index tracking 500 major companies. The Paris Aligned Net-zero Global Large Cap selects from MSCI world large-cap and mid-cap equity universe.

The data produced (E-scores) is forward-looking, action based and does not hedge on a particular scenario. The model estimates the deviation of share price forecasts two years into the future to estimate climate transition risk. The difference in return forecasts under different climate scenarios is taken as a measure of transition risk. The focus of the methodology is entirely on the climate scenario resilience of share price estimates. Securities with higher area dispersion are more exposed to future policy, technology and energy shocks related to climate change mitigation and adaptation.

There are no bottom-up sustainability factors in our computation. But ISS Scope I and Scope 2 data are used to validate the efficacy of resultant risk-adjusted portfolios. Carbon reductions are an outcome (value-add) of E-score application to portfolio construction for climate-risk minimization, and not inputs to the model. The companies that show more resiliency toward climate and energy shocks tend to be more sustainable compared to their peers in the same sector and region. The process of score computation is fully standardized. It is same for BP, Walmart or Tesla.

The database is updated every quarter to make sure the latest data, price movements and corporate actions are captured. The unit of output is area estimates of dispersion. More specifically, the raw units are a two-year summation of absolute deviation over expected returns under a max and min carbon scenario.

Risk Sources & Scenarios

The sources of risks are climate transitions such as carbon tax, electrification, changes in energy efficiency, technical breakthroughs and other socio economic and energy factors. Each of these factors contributes to a shift in the supply, demand and price of energy. This approach considers climate transition risk and chronic physical risk factors such as temperature rise, atmospheric concentrations and sea-level rise. The visuals and scenario outputs are provided in more detail below.

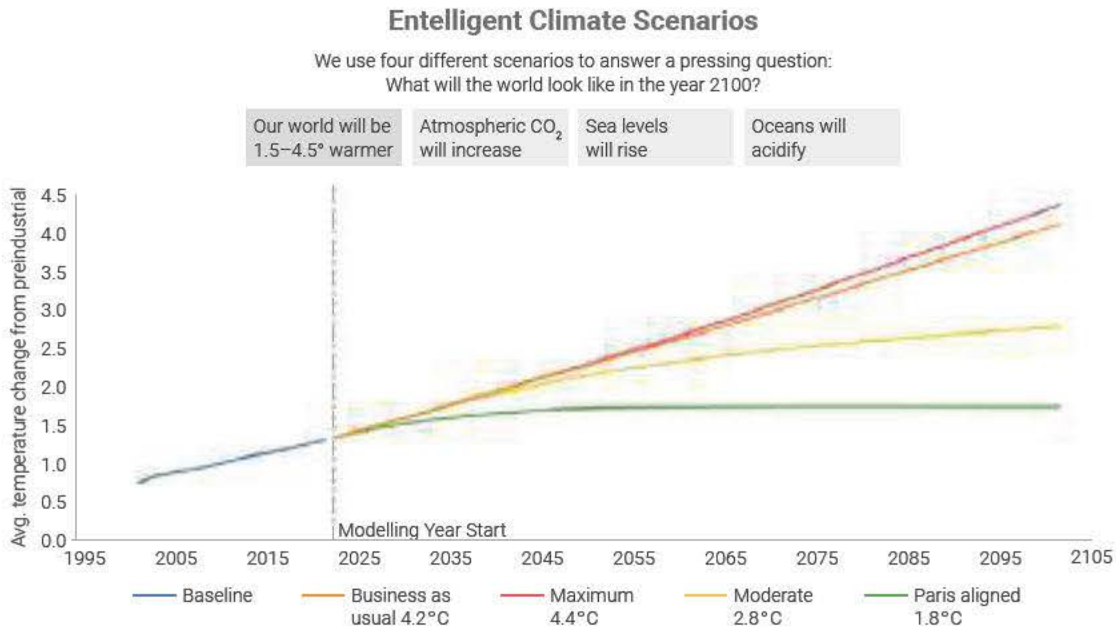


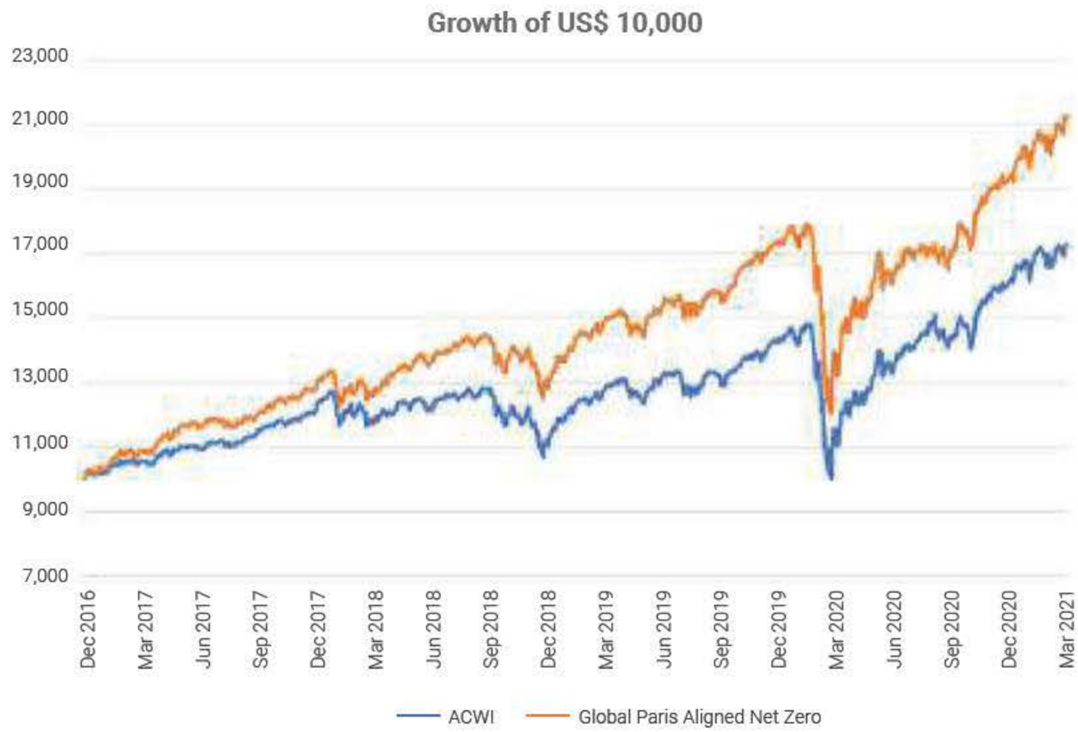
Table 1: E-Score Dataset: Default Min & Max Scenario Settings- Environmental & Energy Impact (2100)

Time of Departure 2018			
BAU		**Min Scenario**	**Max Scenario**
Global population in billions	11.18	11.18	11.18
Global GDP per capita	59,473.60	59,473.60	66,671.30
Average total final energy intensity of GDP	1.52	0.62	1.41
Carbon intensity of final energy	105.01	34.82	103.94
CO_2 emissions from energy	106.03	14.48	109.25
Total Final Energy Demand	1009.65	415.86	1051.06
Atmospheric concentration CO_2	893.84	536.62	948.51
Equivalent CO_2	904.404	627.95	957.69
Temperature change from preindustrial	4.24586	2.86	4.45
Fuel price of oil per barrel	181.77	233.89	201.02
Market price of electricity in KWh	0.11	0.16	0.15
Sea level rise (from 2000)	1282.81	1054.27	1305.48
Delta pH levels (from 2000)	-0.32	-0.12	-0.25

Output

Entelligent's SmartClimate platform minimizes portfolio exposure to climate transition risk subject to diversification principles such as min/max holding size, regional exposure, sector allocation and constituent turnover.

This strategy yields U.S. and global equity portfolios with decreased exposure to climate change risk and greater opportunity for resilient business activities. Hypothetical financial and environmental performance over a four-year backtest for the global portfolio is presented below.



The chart above shows the performance of the Global Paris Aligned Net-zero index versus an all-cap world index. The goal of the index, comprised of about 300 companies in 23 developed markets and 27 emerging markets, is to reallocate capital toward a low-carbon and climate-resilient economy. Index components are developed by screening out certain weapons, tobacco, coal and fossil fuel companies. Additionally, companies that are non-compliant with international ESG standards such as the United Nations Global Compact Principles are removed. The companies included are projected to have the greatest potential for both environmental and valuation impact.

The tables below show comparative environmental out-performance of the index based on TCFD-recommended metrics. Entelligent projects the Sustainability Leaders can achieve an 80% improvement on carbon intensity, a 400% increase in revenues per tons of carbon invested and a 257% improvement in carbon footprint.

Carbon Impact Results	Portfolio	Benchmark	% Better
Carbon intensity	119	597	80%
Carbon revenue/ton	8,373	1,675	400%
Carbon growth percentage	-3.4%	-3.1%	10%
Average carbon footprint	13.6	35.0	257%
Total carbon emissions/MM	15.5	26.7	172%
Exposure carbon related assets/MM	1.7	13.6	800%
Exposure carbon related assets/%	1%	6%	600%

Annualized return	1 Yr	3 Yr	Inception
Global Paris Aligned Net Zero	54.7%	18.7%	19.4%
ACWI	50.9%	13.4%	13.7%
+/- Benchmark	3.8%	5.3%	5.7%

Global Paris Aligned Net-Zero Characteristics		
Benchmark	MSCI ACWI	
Position Size	5% Maximum	
Holdings	200	
Sector	+/-3%	
Region	+/-3%	
Top 10 Holdings	43%	
Market Cap	Large	
Tracking Error	4.63%	
Beta	0.96	
Style	Core	
E-Score	4.95	5.0

Insights gained

It is possible to maximize financial returns and environmental performance via a climate transition strategy. Science-based strategies (such as this) are both effective and scalable. The strategies outlined above demonstrate that, when science meets business, we can find opportunities that are win-win for both investors and the environment.

Working with Entelligent, Sustainable Leaders streamlines the TCFD six-step process for applying scenario analysis to climate-related risks and opportunities and into investment decision-making processes:

Governance	**Risk Management**
▪ Board oversight of climate-related risks and opportunities ▪ Management's role in assessing and managing climate-related risks and opportunities	▪ Organisation's processes for identifying and assessing climate-related risks ▪ Organisation's processes for managing climate-related risks ▪ Integration of the above processes into overall risk management structure
Strategy	**Metrics and Targets**
▪ Climate-related risks and opportunities over the short, medium and long term ▪ Climate-related risks and opportunities on the organisation's businesses, strategy, and financial planning ▪ Resilience of the organisation's strategy, considering various climate-related scenarios, including a 2°C or lower scenario	▪ Metrics used by the organisation to assess climate-related risks and opportunities in line with its strategy and risk management process ▪ Scope 1, 2, and Scope 3 greenhouse gas emissions, and related risks ▪ Targets used to manage climate-related risks and opportunities and performance against targets

i. Sustainable Leaders' board and management have been directly involved in the definition and adoption of climate-related risks and opportunity KPIs for investment decision and monitoring. This aligns with the Step 1 governance of TCFD recommendations.

ii. Entelligent's approach helped Sustainable Leaders' board and management learn how to determine the present-value of the medium- to long-term material impacts of climate change—technology, policy and market shocks—to near-term outlooks. This involves setting up processes and functions for risk management, per TCFD Step 2.

iii. Through a series of climate scenarios (from Paris alignment to 4+ hot world) relevant to Sustainable Leaders investment strategies, selecting climate scenarios and investment benchmarks are very close to TCFD's Step 3 recommendation.

iv. The computed climate risk exposure (Step 4) establishes the important of setting up screening and optimization thresholds to ensure long-term financial and environmental performance in line with Sustainable Leaders' fiduciary duty.

This case study helped us identify key processes and KPIs that should be communicated to relevant parties to ensure full transparency and accountability. Establishing climate targets, metrics and quarterly measuring standards ensure portfolios remain aligned with Paris goals. This aligns with the final TCFD recommended metrics and targets.

TCFD states that this exercise can be a useful additional factor in determining how to prioritize risk management activities and where to consider making additional allocations.[3]

Usability

Sustainable Leaders and Entelligent Paris Aligned Indices are available to asset managers and asset owners to capitalize their financial and sustainability goals. These applications are highly customizable and can be integrated to multiple investment visions, missions, themes and philosophies. We understand the diversity in investment practices, and we want to use the power of diversity and inclusion to build Paris and net-zero aligned climate solutions.

Suggested enhancements for the tool providers

Sustainable Leaders suggests Entelligent include bottom-up data such as carbon emissions, biodiversity, water and physical risk packaged with the existing top-down transition risk approach. That way, the analysis will be more complete and persuasive. The development of a 360-degree view on climate risk and opportunity, which may require collaborating across multiple climate scoring systems, would be beneficial. Entelligent uses Scope 1 and Scope 2 emissions data in the validation of its E-Scores. The next iteration of its scoring methodology, known as T-risk, will add Scope 1 and Scope 2 emissions as inputs into the ranking.

3 https://www.tcfdhub.org/scenario-analysis/

Participant:

TD Asset Management

Provider:
ISS ESG

Risk types covered by tool:
Physical and transition risk

Introduction

TD Asset Management Inc. (TDAM, a wholly-owned subsidiary of The Toronto-Dominion Bank) considers climate change a systemic risk affecting economies, companies, and investors. Our approach to climate change is aligned with our overall philosophy of integrating all sources of risk and return in our investment processes.

As an investment manager of diversified asset classes, we consider climate change as an important area of research to fulfill our fiduciary responsibility on behalf of our clients. We actively engage with companies as well as our partners, and leverage our asset ownership positions to encourage improvements in company disclosures on climate-related risks and opportunities facing their businesses. In addition, we participate in numerous industry collaborations including Climate Action 100+, Carbon Disclosure Project, and the United Nations Environment Programme Finance Initiative (UNEP FI) TCFD investor pilots, with the first two furthering our company engagement efforts, and the latter developing a better understanding of climate-related investment risks. Our approach continues to evolve to help position our portfolios to capitalize on investment opportunities arising from an accelerated transition to a low carbon economy and manage undue climate-related physical and transition risks.

As part of the UNEP FI landscape review module, TD Asset Management Inc. was tasked to evaluate a third-party tool used to measure the climate risks of an investment portfolio. We were matched with Institutional Shareholder Services (ISS) ESG (Climate Solutions), a source of corporate governance and responsible investment solutions. We were provided with login credentials (usernames and passwords) to access ISS' proprietary DataDesk platform (the "platform") as well as a brief tour and walk through of the platform to ensure that we would be able to maximize our 4-week trial period.

For our analysis, we turned our attention to the portfolio analysis section of the platform which let us generate a PDF report emphasising the key climate risk exposures of the portfolio. Notably, all data used to create the report could be conveniently downloaded as a CSV file for added flexibility and further examination.

Data and Coverage

For this exercise, we uploaded the holdings (as of December 31, 2020) of a long-only global equity portfolio benchmarked to the MSCI All Country World Index. The portfolio held 195 securities from over 30 countries across both developed and emerging markets, and leaned toward mid-sized, dividend-paying and low volatility securities from defensive sectors such as Utilities and Consumer Staples.

Uploading the portfolio to the platform was straightforward. We simply had to provide the platform with a CSV file comprising the following information: portfolio name, client identifier type (e.g., ISIN), client identifier (i.e., the ISIN values), modeling currency (in our case, CAD) and weight in percentage. Every security of the portfolio was successfully mapped onto the platform. Moreover, all dual-class shares and ADRs were correctly mapped to their underlying issuers.

The platform contained data for 99.83% of the portfolio (by weight), or 194 out of the 195 securities. It is worth noting that all missing data, as with that of the non-covered security, was suitably labelled as either "not applicable", "not collected" or "not disclosed", to avoid confusion with available but zero or null-valued data points.

Risk Sources and Scenarios

ISS ESG's offering can be split into four categories: emission analysis, climate scenario alignment analysis, transition risk analysis and physical risk analysis.

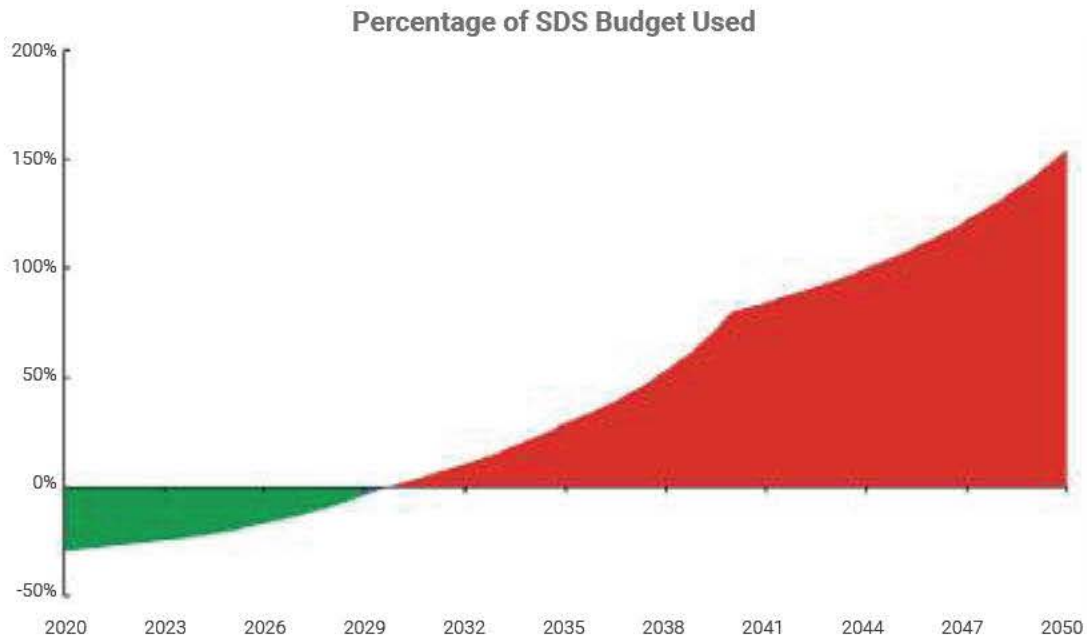
The first category, emission analysis, comprises common carbon metrics, where applicable aligned with the TCFD Recommendations and the PCAF Global Standard, such as the share of disclosing holdings, carbon emissions (including scope 3 emissions) and carbon intensity. An interesting feature of the platform is the emissions "trust" rating. This metric estimates the extent to which we can trust a company's reported carbon emissions numbers. For instance, emissions that have been externally audited would be rated higher than emissions that have only been estimated. The second category, climate scenario alignment analysis, compares current and future portfolio greenhouse gas emissions with the carbon budgets from the International Energy Agency (IEA) Sustainable Development Scenario (SDS), Stated Policies Scenario (STEPS) and Announced Pledges Scenario (APS). The third category, transition risk analysis, focuses on green energy generation and fossil fuel reserves (i.e., oil, gas and coal). The fourth and last category, physical risk analysis, gauges the impact of the six most costly physical climate change risks such as floods, droughts or storms on the current and future overall value of the portfolio.

Outputs and Insights

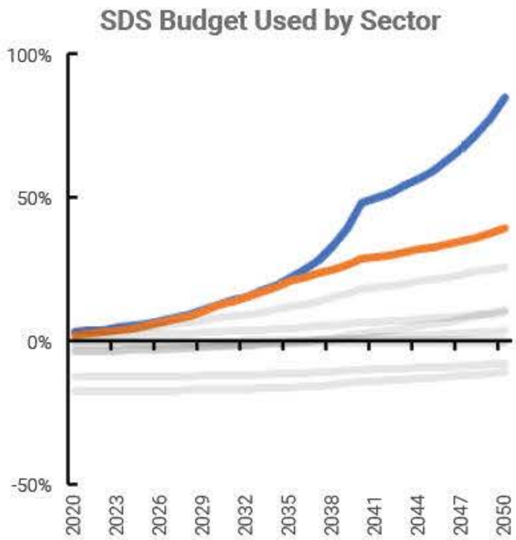
For the sake of brevity, we chose to focus solely on the last three categories, namely climate scenario alignment analysis, transition risk analysis and physical risk analysis, and only on the data that we deemed most interesting to us, as specified below.

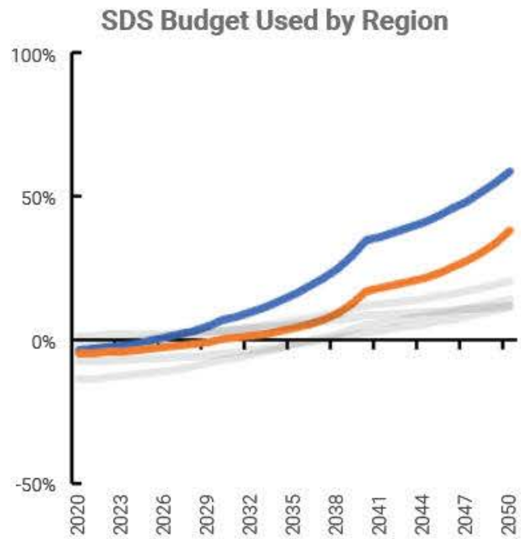
Climate Scenario Alignment Analysis

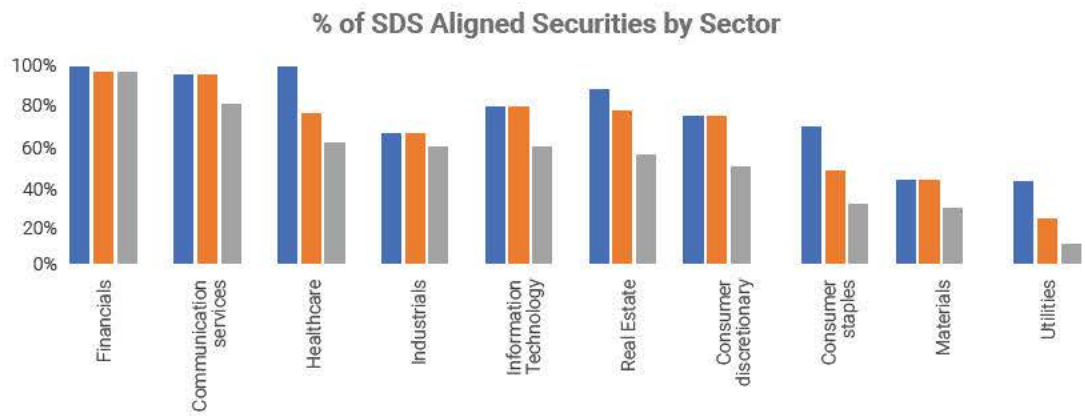
For the climate scenario alignment analysis, we concentrated on the IEA's Sustainable Development Scenario (SDS) pathway as it boasted the most comprehensive and intuitive data. The SDS charts a GHG emission pathway in line with the Paris Agreement of holding warming to well below 2˚C by the end of the century. The following chart plots the portfolio's emission pathway as a percentage of its SDS budget. As it stands, the portfolio is misaligned with the SDS scenario by 2050 and is on course to exceed its SDS budget by 2030. By 2050, it is expected to overshoot its SDS budget by nearly 150%, corresponding with a potential temperature increase of nearly 2˚C by 2050.



The PDF report generated by the platform highlights the key sectors contributing to the misalignment of the portfolio. Having the data readily available outside of the platform allowed us to perform additional analysis on the portfolio. For example, we could easily single out the sectors, regions or even securities which used most of the SDS budget of the portfolio. Namely, we found that most of the SDS budget is used by securities in the utilities sector. In particular, we found that a small portion of the portfolio, representing roughly half a dozen securities, was responsible for using most of allocated SDS portfolio budget.





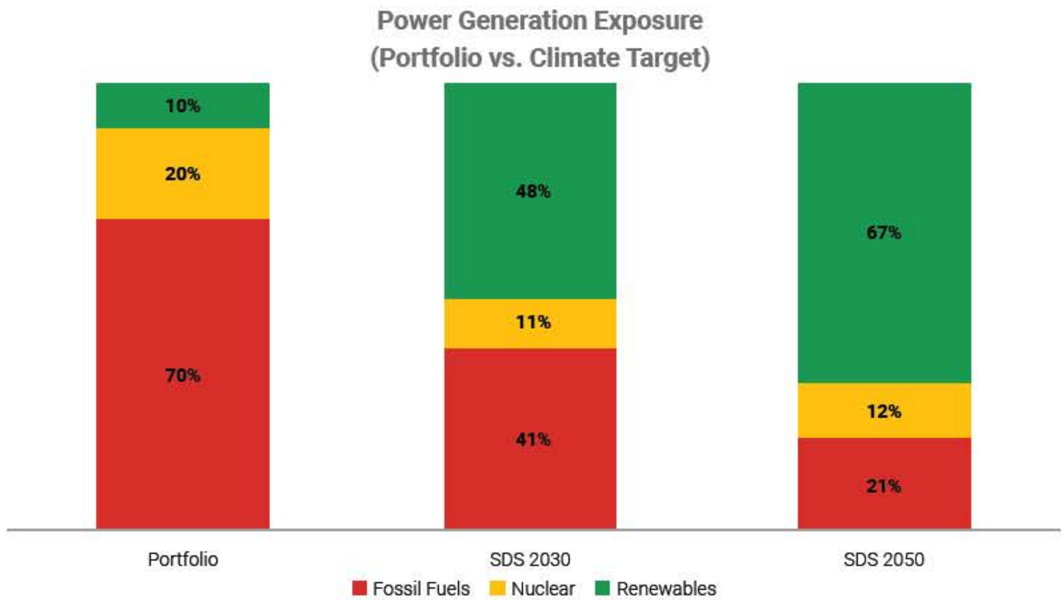


This information is important because it alerts us to the fact that the portfolio could be more closely aligned with the SDS pathway with only minimal changes to the portfolio's holdings. This information also reveals which sectors and/or securities we should target our carbon risk reduction efforts on.

Transition Risk Analysis

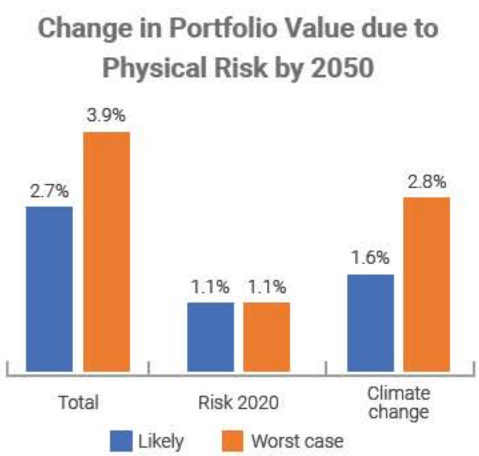
The transition risk analysis module of the platform emphasizes both power generation (demand side) and fossil fuel reserves (supply side) as key to transitioning to a greener, decarbonized economy. The rationale is that exposure to "brown" (i.e., non-renewable) electricity generation or fossil fuel reserves may eventually lead to higher reputational risks, policy and/or regulatory risks as well as stranded asset risks.

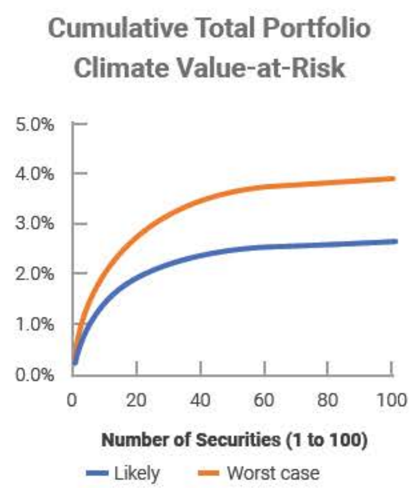
The portfolio used in this exercise holds no energy companies and therefore has minimal exposure to fossil fuel reserves. However, it is strongly exposed to traditional utilities companies, and consequently, to "brown" electricity generation. The graph below compares the energy generation mix of the portfolio against the SDS target mix for 2030 and 2050.



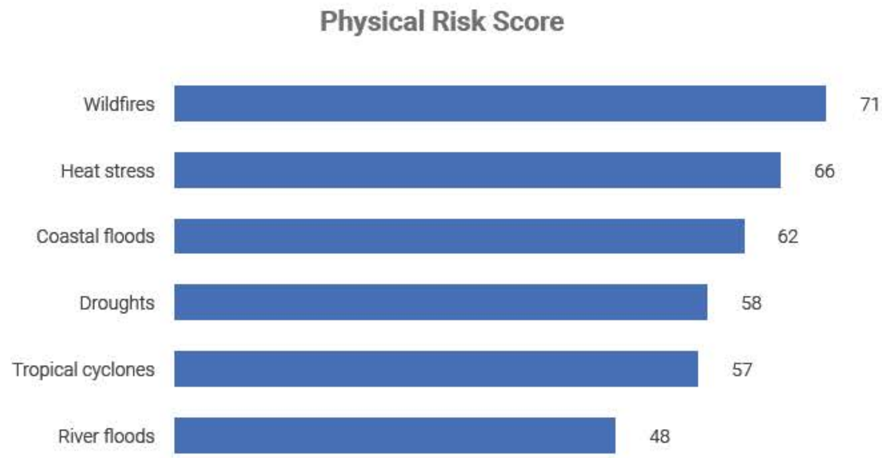
Physical Risk Analysis

The platform's physical risk analysis measures the potential financial impact of the six most costly natural climate hazards such as floods, droughts or wildfires on the value of the portfolio. The first metric used to assess physical risk is a portfolio-level climate value-at-risk. The chart below on the left highlights the potential impact on overall portfolio value in 2050 based on 2020 risk levels (Risk 2020) and hazards due to climate change (Climate Change) for two climate warming scenarios of the Intergovernmental Panel on Climate Change (IPCC) (most likely and worst-case scenarios), while the chart below on the right highlights the cumulative portfolio value-at-risk for the first 100 riskiest securities (based on climate value-at-risk). A striking observation from these two charts is that nearly 80% of the climate value-at-risk of the portfolio can be attributed to just 30 securities.





The other metric used to quantify physical risk is a physical risk score. This physical risk score is impacted by the projected change in financial risk due to individual hazards in a likely warming scenario. A low (high) score implies a large (small) projected increase in physical risks. The figure below charts the weighted-average physical risk score for the six main natural hazards.



It should be noted that physical risk scores were unavailable for close to a quarter of the securities in the portfolio, most of which were in the utilities sector, since the underlying asset-level data base is still being scaled up.

Uses Cases

The platform offers a broad and deep look into potential climate risks, encompassing emissions analysis, alignment analysis, transition risk analysis and physical risk analysis. This information can be used in security selection, to get a better understanding of the climate risks faced by companies under consideration, as well as for portfolio construction, to lower or cap the portfolio's overall exposure to climate related risks. It can also be a useful tool for reporting purposes.

Conclusion and Suggestions

The platform was approachable, and the web interface was intuitive which made navigation straightforward. The platform included a data dictionary carefully describing the various data series which helped along with our exploration of the data at hand. Having the ability to download the data in spreadsheet-form was also extremely useful to further our understanding of the data and expand our analysis beyond the bounds of the platform. We did encounter minor online formatting issues and glitches that may have been due to browser compatibility. For example, highlighting a data column would occasionally display the wrong data definition. However, none of these issues prevented us from successfully using the platform.

In a future iteration of the platform, it would be interesting to see more ambitious climate alignment scenarios, such as such as net-zero emissions by 2050 (NZE2050). According to ISS ESG, this scenario is already on their product roadmap and should be available on the platform by the end of 2021. Lastly, many well-know indices and benchmarks are available in the screener portfolio of the platform, but without weights. Therefore, they cannot be use for portfolio benchmarking in the portfolio analysis section of the platform. ISS ESG acknowledged this limitation and advised that it will be discussed internally as to whether weighted indices will be included on the platform going forward.

Author:
Jean-Francois Fortin, Vice-President, TD Asset Management Inc.

Participant:

DNB Asset Management

Provider:
ISS ESG

Risk types covered by tool:
Physical and transition risk

Introduction

As part of this UNEP FI-TCFD pilot project, DNB Asset Management (DNB AM) selected ISS ESG to conduct a trial of the ESG Carbon and Climate Impact solutions tool. The tool is intended to help investors to understand, measure, and act on climate-related risks across all asset classes by providing detailed analyses of Scope 1, 2 and 3 emissions, transition and physical risks, and climate scenario analysis. The trial was conducted on 10 of DNB AM's equity portfolios, all of which implement the DNB Standard for Responsible Investments. This is our investment policy which is intended to ensure that DNB does not contribute to the infringement of human or labour rights, corruption, serious environmental harm or other actions that could be regarded as unethical. It shall also ensure that assessments of risks and opportunities related to ESG (Environment, Social and Governance) factors are integrated in the investment management process. Several of the funds implement additional exclusion criteria, others have an additional sectoral focus, including those which focus on selecting companies providing solutions to climate and environmental issues faced throughout the world.

The tool contains the following components:

Data	Portfolio Analytics	Ratings
▪ Carbon and Climate Data ▪ Potential Avoided Emissions Data	▪ Carbon Footprint Report ▪ Climate Impact Report	▪ Carbon Risk Rating ▪ Fund Rating

While the trial provided access to all components of the ISS' solution, we chose to focus on the Portfolio Climate Impact Report and the accompanying dataset to explore physical and transition risks, as well as the Climate Scenario Alignment across the selected DNB equity portfolios used in the trial.

Sectoral and geographical coverage

The tool allows for the assessment of both transitional risk and physical risk for the uploaded portfolios—with the production of a range of outputs in a single report. As part of the transitional risk assessment, the tool considers fossil fuel reserves and renewable energy assets contained within the portfolio. As part of the physical risk assessment, the tool provides an assessment of the potential financial implications of a range of climate hazards on the portfolio value. The analysis uses the median impact of the ensemble of models forced with the RCP 4.5 and RCP 8.5 scenarios. The RCP 4.5 is a "middle of the road" emission scenario (likely) while the RCP 8.5 is a high emission scenario (worst-case). The analysis is done for baseline year 2050 (median of 2025 through 2075). Several metrics are provided to offer insights on the physical risk exposure of individual issuers and the portfolio, namely Financial Risk metrics, Value at Risk, a Physical Risk Score and a Physical Risk Management Score.

Given we are based in Norway, as are many of our customers, we chose to analyze a number of our Norwegian and Nordic funds, to understand the potential transitional and physical risks faced. We also chose to assess several our fund products which focus on selecting companies providing solutions to climate and environmental issues faced throughout the world. These funds assessed include both actively and passively managed funds. Coverage of data for the funds assessed ranged between 76–100% of constituents.

Assessment process

The tool was straightforward to use, and available through the ISS DataDesk platform. After logging in, the following steps were undertaken to conduct the assessment:

1. Upload fund holdings into platform. For each of the holdings, the tool required information regarding the holding identifier, weight, and values of the holding.
2. Ran 'Climate impact assessment' for the funds in question.
3. Reviewed PDF report and the excel file of data factors produced by the tool.
4. Also possible to assess the results in the online tool using the DataDesk screening function to deep dive into issuer level analysis of companies. This provided greater detail regarding the companies' commitments and performance relative to targets under different scenarios.

It was possible to undertake analysis using equity, fixed income or mixed portfolios, however for the purpose of the case study we only assessed equity portfolios.

Outputs and potential use case

As part of the Portfolio Climate Impact report, two outputs of the data are produced:

Climate Impact Assessment Report

This is intended to provide users with a straightforward overview of the information produced by the tool. The report includes a range of analyses and metrics across carbon emissions, transition risk, and physical risk (by risk type, sector, and company)—a few select elements of the report are outlined below. Broadly the report provides an overall assessment of the potential performance of the fund with regards to climate, while also highlighting companies most at risk—this information could be fed into a company engagement process, and feature as part of investment decision making.

Alignment analysis

The report includes an analysis of the funds' alignment with the IEA Sustainable Development Scenario (SDS), Stated Policies Scenario (STEPS) and the Announced Pledges Scenario (APS), based on current and projected future emissions. Comparison is indicated as the percentage of assigned budget used by the portfolio and benchmark, as well as an indication in which year the fund will, based on the modelling, exceed the SDS budget along with the corresponding potential temperature increase associated with the fund (see table in graphic below). The results from this analysis across the funds assessed were within our expectations. For the example in the graphic below, given the focus of that fund on climate and environmental solutions, we would expect to see the fund not exceeding the SDS budget in 2040 or 2050. We anticipate that as more companies within the fund begin to set science-based emission reduction targets and begin to reduce emissions in line with these targets, that the budget overshoot will be lessened. At the same time, our experience with other approaches is that for companies providing products and services which lead to emission reductions, these reductions can be difficult to quantify and as a result are not sufficiently captured. This could also be a consideration here.

Portfolio and Benchmark Comparison to SDS Budget (Red=Overshoot)

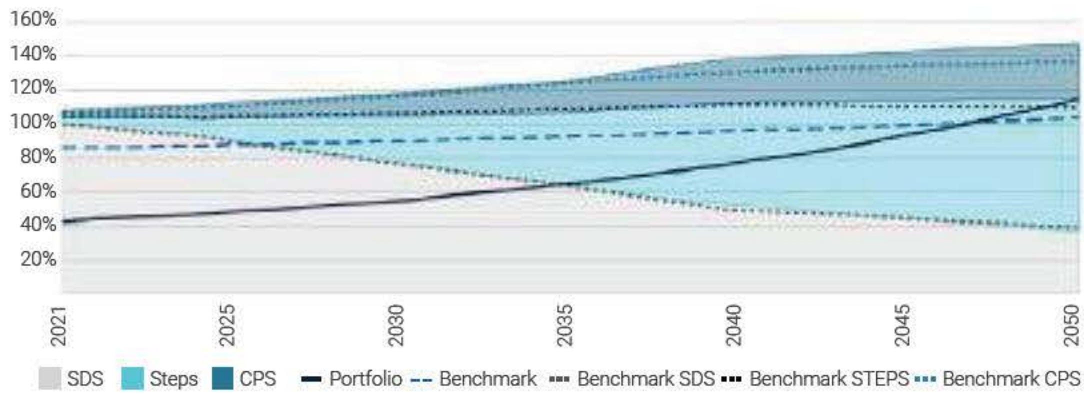
	2021	2030	2040	2050
Portfo io	-57.45%	-31.36%	-45.70%	+213.91%
Benchmark	-14.41%	+15.05%	+92.74%	+166.23%

2036 The portfolio exceeds ts SDS budget in 2036

2.7°C The portfolio is associated w th a potential temperature increase of 2.7°C by 2050.

As part of this assessment, there is also a visualization of the Portfolio emissions pathway compared with the carbon budgets of the selected climate scenarios, this could be utilized as part of regular assessment of funds' holdings and climate related risks (both physical and transitional). This visual (and the underlying data) may prove useful with fund clients interested in the understanding the alignment/misalignment of their funds with different climate scenarios—and may be particularly relevant for fund managers with public commitments for net-zero or other science-based emission reduction targets. The assessment of the alignment could also be a KPI of interest to management/board, as it may provide an indication regarding the potential direction of travel for specific funds, different classes of funds, or all holdings. For the example below, the assessed fund in its current state is misaligned with the SDS scenario in 2050, while the fund's benchmark is also misaligned.

Portfolio Emission Pathway vs. Climate Scenarios Budget



Climate Targets Assessment

To reach the global climate goal set out by the Paris Agreement—to limit global warming to well below 2, preferably to 1.5 degrees Celsius—companies are widely being called upon to set public GHG emission reduction targets to ensure they are part of the solution. These targets should be public to ensure transparency and accountability of the companies' actions. A challenge faced as an investor when assessing companies' emission reduction targets relates to the comparability of and quality of the targets set. As we continue to focus on how companies position themselves and manage climate related risks, having insight into the targets being set is important.

The Climate Targets Assessment provides a fund level overview on the targets companies within the fund are setting. The targets are placed in 5 categories: Approved SBT (Science-based target), Committed SBT, Ambitious Target, Non-Ambitious Target, and No Target—the chart below is then produced based on the weights of companies in the fund and can be compared with the benchmark (see below). This information is also available on the company level as part of the data file. As with the above analysis, the assessment of the targets could be a KPI of interest to management/board and may be particularly relevant for fund managers monitoring emission reduction targets of companies within their funds. This will likely be of increasing importance with increasing commitments to net zero, as well as from increasing disclosure requirements in the European Union including the Sustainable Finance Disclosure Regulation (SFDR).

Physical Climate Risk Analysis

The assessment of the physical climate risk is comprised of four elements, providing insight into the physical risks the fund is potentially exposed to, as well as an assessment into how the company is managing these risks. One output is included below, with the left chart providing a quantification of the value at risk by sector (under the RCP4.5 scenario), with Information Technology contributing 48% of the risk. The chart on the right provides a breakdown of the strength of the physical risk management approaches of companies within the fund. We found these charts used together provides a clear overview of where the potential risks exist within the selected fund from a sectoral perspective, while also indicating the portion of companies in the fund managing these risks.

Underlying data via excel, API, FTP or data desk.

The underlying data for the companies included in the analysis is provided for the companies in the portfolio. The company specific data can be analyzed in the excel spreadsheet or on ISS' Data Desk, and it is also possible for the data to be delivered by API or FTP.

The data output allows direct integration into internal databases for further internal integration into the active ownership and investment processes, particularly when comparing companies to peers and the fund relative to the benchmark. Access to granular data provides the opportunity to deep dive into the potential performance of the companies under different scenarios. The metrics indicating a company's percentage of the carbon budget utilized under three climate scenarios presents an opportunity to assess a company's emissions trajectory and assess scenario alignment at a given point in time. The scenarios included are the Sustainable Development Scenario (SDS), the Stated Policy Scenario (STEPS), and the Announced Pledges Scenario (APS). When combined with other data points regarding targets provides a picture of a company's commitment to decarbonization, and the likelihood of achieving this. This could also be utilized as part of TCFD reporting regarding climate scenario analysis.

Overview and Future plans for tool

The opportunity to demo the tool provided some new and useful insights into the potential climate risk and impact of the selected funds. The tool was straightforward to use and produced the desired reports and data files without issue. The results from the analysis were broadly in line with our expectations. We observed for the funds where we place a greater emphasis on climate and the environment, were associated with temperature increases closer to 1.5 degrees and also lower potential exposure to physical risks, while funds with greater exposure to sectors or geographies with high emitting companies or sectors, were associated with higher temperatures.

The assessment of the carbon reduction targets for the companies in the fund and categorization of targets into SBT-committed/approved, and ambitious and non-ambitious targets, is greatly welcomed. This aspect of the analysis presented some unexpected results particularly when compared to benchmarks, namely that some funds were without. With the increasing focus on net zero both for companies and for investors, insights like this can help to provide focus for engagement and impact the selection decisions.

We provided feedback on suggested enhancements to the company directly, and ISS flagged several future developments expected in late 2021/early 2022. Including:

- Introduction of metrics related to the IEA's NZE2050 scenario as part of the development of their net-zero product. This will utilise the ISS climate data, as well as ISS' voting and engagement services.
- A transition Value at Risk will be launched which will reflect carbon pricing and sector growth risks.
- Update its current estimation approach on Scope 3 data and add reported and quality checked Scope 3 data to the existing dataset.
- Provide derived data in excel file for further use by asset managers in integration of the data in internal systems.
- Continued expansion of physical risk assessment, increasing the number of risks covered.

Participant:

TD Bank

Provider:
Moody's Analytics

Risk types covered by tool:
Physical and transition risk

Introduction

TD Bank Group (the "Bank") and Moody's Analytics worked together in a pilot project in March 2021 to explore an approach to quantifying climate change impacts on actual Bank borrowers and exposures held by the Bank. Moody's Analytics used its internally developed tools to evaluate the climate-related risks for a sample of the Bank's publicly traded Commercial & Industrial (C&I) and U.S. Commercial Real Estate (CRE) obligors under three representative Network for Greening the Financial System[4] (NGFS) scenarios.

Overall, the Moody's Analytics models provided meaningful insights into how the Bank could approach incorporating climate risk into its credit assessments. It also highlighted the significant challenges associated with trying to quantify the impacts of a multi-dimensional scenario over a long-time horizon, including sensitivity to assumptions and model validation challenges. TD feels confident it can use the information from the pilot project to help the Bank move forward on its climate risk quantification and management journey.

Process and Data

The initial base for all scenario analysis for both the C&I and CRE models was a set of Moody's Analytics' proprietary macroeconomic scenarios that align with the NGFS scenarios. These scenarios reflect many of the chronic physical and transition risk impacts with variables including productivity metrics, energy demand, commodity, and carbon prices, as well as classic macroeconomic measures like government spending, employment by industry, incomes, and output.

C&I Credit Analysis

The C&I analysis estimated the individual and combined impacts of physical and transition risk on each individual borrower's propensity to default. Both physical and transition risks were estimated using Integrated Assessment Models (IAMs), which predict economic and climate outcomes for the underlying scenarios. For transition risk, the IAM was augmented to incorporate an oligopoly-based model of firm competition

4 A global group of 90 (as of April 2021) central banks and supervisors helping the financial sector address the risks of climate change and support the transition to a resilient economy: https://www.ngfs.net/en/page-sommaire/governance.

and price setting. These were then extrapolated into equity, asset volatility and liability impacts, customized by individual firm's carbon emission intensity and energy emission intensity to determine a Climate-adjusted Expected Default Frequency (EDF) and associated change to Borrower Risk Ratings (compared to the non-climate-adjusted model).

The model automatically sources the required data from either public source (i.e., corporate financials) or proprietary databases (i.e., firm-level physical climate risk scores[5] and total carbon emissions). Where the required degree of granularity is not available, including for private entities[6], proxies can be used. For TD's sample of 13 firms, one firm lacked a firm-specific physical climate risk score and a sovereign average was automatically used as a proxy. Similarly, two firms lacked carbon emissions data and industry averages were used.

CRE Credit Analysis

The CRE Climate-adjusted EDF model also sources proprietary physical climate risk data automatically, at very precise spatial granularity, focusing only on wildfire and flooding impacts for the TD CRE footprint. Those physical risk impacts are calibrated to historical losses for similar building types and locations. The remaining inputs are typical of any CRE credit model, principally including loan origination and maturity dates, loan rate and outstanding balance, property type, address, value, and net operating income.

Coverage

The intent of the pilot was to improve TD's understanding of the capabilities of Moody's Analytics climate risk models, as opposed to a sampling analysis of TD's entire credit portfolio.

The 13 public firm C&I borrowers evaluated in this pilot represented a very small fraction of TD's customers, but the sampled firms did span eight industries with headquarters in two countries (U.S. and Australia). The CRE sample of 55 properties represented less than 10% of the value of TD's global CRE portfolio, although they spanned 12 metropolitan areas in the U.S., five property types[7], and had varying loan maturities, including some exceeding 10 years.

At the time of the pilot, the C&I Climate-adjusted EDF model accommodated only public firms, which could be located anywhere in the world, subject to the availability of appropriate macroeconomic scenarios. Climate-adjusted scenarios were then available only for the U.S., Canada, UK, and Western Europe.

5 These scores include acute and chronic physicals risks (wildfire, cyclone, inland flooding, heat stress, water stress, sea level rise) to all corporate facilities and operations, as well as to the firm's supply chain and markets.

6 Functionality also supports the inclusion user-supplied firm characteristics in order to enhance the analytical output for non-public entities.

7 Multifamily, Office, Retail, Industrial and Hotel.

The climate risk impact data used by the CRE Climate-adjusted EDF model are translations of specific physical risk (e.g., inland flooding) scores for each Metropolitan Statistical Area, and climate transition risk macroeconomic scenarios. When the pilot project was undertaken, coverage was limited to the U.S. data coverage for both the CRE and C&I EDF modeling approaches has since expanded significantly.[8]

Risk sources and scenarios

This pilot project examined the impact of climate risk on the EDFs of a sample of C&I borrowers and CRE loans. The key sources of risk included acute physical climate risks (wildfire, cyclone, flooding), chronic climate risks (sea level rise, heat stress and water stress), and transition risks stemming from political, economic, and technological drivers, with firm sensitivities driven by industrial subsector and current carbon emissions. For TD's specific CRE portfolio, only wildfire and inland flooding were considered since none of the properties were subject to cyclone risk.

The physical risk quantifications were provided by Moody's ESG Solutions, and reflect future potential temperatures based on Representative Concentration Pathway (RCP) 8.5. Transition risks were introduced through a consistent set of local macroeconomic scenarios that were fully aligned with the NGFS definitions of Orderly, Disorderly, and Hot House World scenarios.

While a great many parameters in these models can be specified or manipulated, this pilot project focused more on the differences within the loans and borrowers, and across the three primary NGFS scenarios.

Output

Both models produce term structures of EDFs, with annual granularity extending forward 10 years for the CRE loans and 30 years for the C&I borrowers. One such EDF term structure is produced for every loan or borrower, for each of the three NGFS scenarios. In addition, EDF term structures are also provided showing the pre-climate adjustment EDFs, and a "worst case" EDF (based on the 95th percentile highest temperature pathway). Expected loss figures are also produced for the CRE loans, where outstanding balances are available.

One summary view of the climate risk impacts is the overall change in implied ratings at a future point in time, and an example of this is shown in Exhibit 1 for TD's C&I portfolio. The physical climate risks to all these obligors produced implied rating deteriorations, while the transition impacts produced both risks and opportunities for various obligors. In only one case was the upside (transition) risks greater than the physical risk impacts, resulting in an overall projected implied rating improvement.

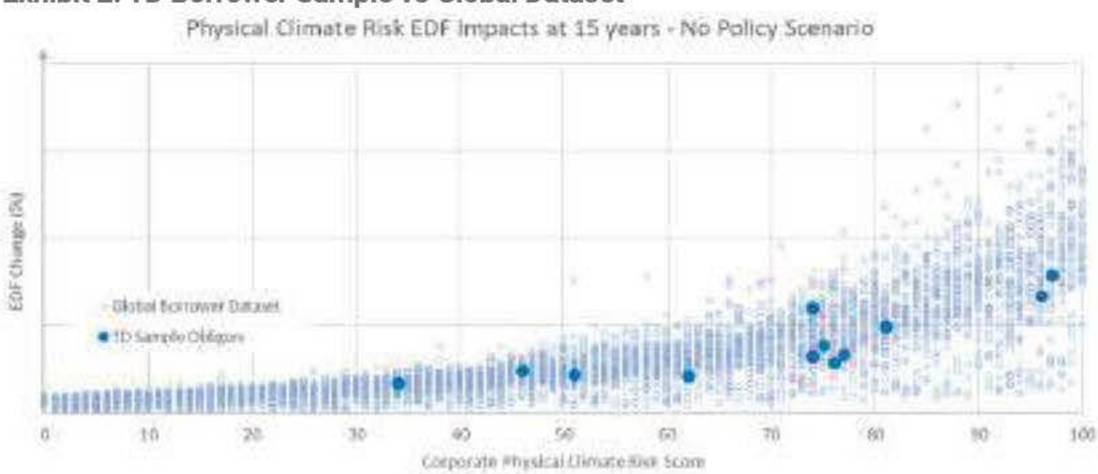
8 As of September 2021, physical climate risks scores and macroeconomic scenarios were available globally, and CRE translations were available for US, Canada, the UK and Western Europe. The C&I model coverage had also expanded to include private firms, globally.

Exhibit 1: Change in 10 Year Annualized EDF-Implied Rating for C&I Sample Set

Risk	Scenario	2 Notch Improvement	1 Notch Improvement	No Change	1 Notch Deterioration	2 Notch Deterioration	3+ Notch Deterioration
Combined	Early Policy		8%	23%	38%	15%	15%
	Late Policy			8%	54%	31%	8%
	No Policy			23%	46%	15%	15%
Physical	Early Policy				85%	15%	
	Late Policy				69%	31%	
	No Policy				77%	23%	
Transition	Early Policy		8%	54%	23%	8%	8%
	Late Policy		8%	77%	8%		8%
	No Policy	8%	15%	54%	8%		15%

While all the output is provided as digital flat files, a variety of automated sorting, filtering, aggregating and mapping functions were also used to better understand the C&I exposures. In addition, physical risk output can be compared to a much larger universe of borrowers to provide some perspective and relative sense of impact, as shown below in Exhibit 2.

Exhibit 2: TD Borrower Sample vs Global Dataset[9]



9 The graph plots TD's sample of 13 public firm C&I borrowers against the global dataset; only 12 points are shown in the graph due to an overlap of two of the TD Sample Obligors.

Insights gained

The relatively small fraction of TD's total portfolio that was analysed precludes drawing any conclusions about aggregate impacts to the Bank, but it did highlight the range of scenarios and parameters available, and the outputs and metrics that might be useful in the future. TD has made several observations about its exposure to various borrowers and loans during this pilot project, including:

- Many of the credit risk impacts, under all scenarios, were relatively small for both the CRE and C&I books, but some EDFs were projected to increase dramatically even looking forward only 7–10 years. This may indicate both the difficulty of using a top-down evaluation approach, and the opportunity to pinpoint individual loans and borrowers that have much higher exposures to climate risk.
- Where credit deterioration was projected for CRE loans, it was almost exclusively due to acute physical risks. In contrast, the impacts to the C&I portfolio being more mixed, with physical risk deteriorating credit quality somewhat broadly but transition risk causing significant EDF erosion for a subset of borrowers.
- In some cases, borrowers were projected to benefit from the anticipated economic transition, driving credit quality improvement. While this was broadly a function of the industry sector, it was also observed for firms whose earnings were derived from several industrial sub-sectors, highlighting the value of detailed earnings attributions. The clear articulation of winners and losers within industries and regions show the potential advantages of a more fulsome credit analysis, incorporating climate risk.
- The transition risk impacts become evident at the date of a policy announcement, driven by the resolution of the uncertainty in investor expectations. For some borrowers those dates markedly increased or decreased creditworthiness which pointed to the potential value of exploring alternative policy development timelines or expectations.
- More broadly, these insights may be useful in the future for portfolio risk analysis and stress testing, as well as individual borrower credit underwriting and loan structuring.

Usability

As TD continues to strategically build capabilities in climate risk analysis, understanding the nature, content and detail of the analytical results will be critical in developing that roadmap. This pilot provided good transparency into the current methodology and process and was a foundational step in the Bank's journey.

This pilot revealed that the differences across loans could be sufficiently large, at some date in the future, to warrant further attention, review or action. Quantification of such risks is growing increasingly important for several use cases, including pricing reviews, portfolio allocation, the potential for stress tests and disclosure requirements at some point. The Moody's Analytics models sourced the required data automatically, and were thus straightforward in terms of execution, though a more fulsome integration into existing credit applications has not yet been explored. Model outputs provided the detail necessary to "drill-down" and explore the drivers of individual results.

Ultimately TD's climate risk management process could provide key metrics for the executive team, and further enable the Bank to examine and guide the loan portfolios relative to the Bank's risk appetite. A key function of usability will be considerations regarding how to establish validation techniques beyond traditional credit risk models, noting TD has historically validated credit risk models against past performance metrics that may not be appropriate given the forward-looking nature of the analysis.

Suggested enhancements

Given the nascent nature of the industry, both Moody's Analytics and TD have identified areas to continue to enhance both the capabilities and the usability of the models.

Capability Considerations

- Expansion of CRE Physical Risk Model and translation data to global geographies, to fully cover the Bank's CRE portfolio.
- Inclusion of forecasted forward-looking physical frequency and damage assessments. The CRE model uses hypothetical scenarios at the user's discretion, however including expected changes would provide a meaningful baseline scenario.
- More granularity in key industries or data availability for private firms. Lending to publicly traded entities is a small subset of TD's overall commercial lending exposures; additional granularity is required (e.g., sub-industry emissions averages) to more meaningfully differentiate across borrowers within a given industry.
- Better flexibility regarding input scenarios. The fundamental basis of the Moody's Analytics' models is the NGSF scenarios and IAMs; the ability to alter assumptions would be useful, primarily to better isolate the impacts of individual assumptions.

Usability Considerations

- Model "validation" guidance—recognizing that traditional approaches to validating this credit model may not be effective, additional detail regarding how we can assess the appropriateness of the model is necessary to be comfortable the Bank is not introducing significant model risk.
- Integration with other internal or third-party platforms to minimize duplication of work efforts by credit analysts.
- TD worked directly with Moody's Analytics to generate the outputs, therefore there was limited ability to assess the user interface. However, further data exploration tools would be useful, including the ability to view portfolio wide metrics and impacts.
- Further documentation and training materials, recognizing that this would need to be used by individuals at the Bank that are not heavily involved in ESG or climate risk matters.

Participant:

A European Bank

Provider:
Moody's Analytics

Risk types covered by tool:
Physical and transition risk

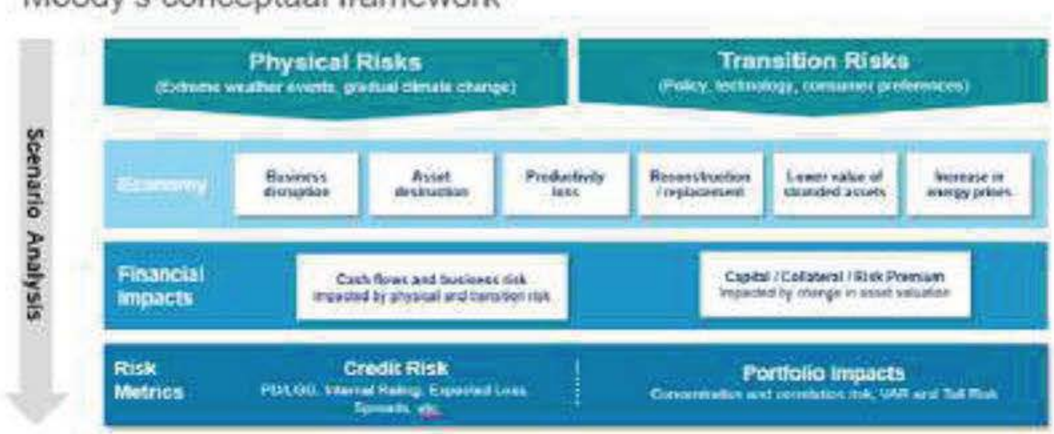
Introduction

Banks can be impacted by climate change in different business lines, overlapping opportunities and risks. Our Group is a global commercial financial institution with positions in Europe and South America. Our engagement in this pilot aimed at investigating leading practices on tools covering the physical and transition impacts of climate risk applied to some of our portfolios. This pilot provided us with a comprehensive view into how Moody's tool could be used to assess physical and transition risks and opportunities.

Process

Moody's tool offers a complete framework that spans across the overall risk management framework covering climate data analytics across both physical and transition risks, climate scenario analysis and stress testing, integration to credit risk modelling, and financial metrics and tools to support Climate-related financial disclosures.

Moody's conceptual framework



Moody's structural approach combined with ESG, transition risk, physical risk and macroeconomic analysis allows to:

1. define appropriate climate scenarios
2. link the climate scenarios to the climate risk impact channels
3. translate risk into financial and economic scenarios
4. estimate the climate adjusted risk metrics.

It can also leverage reference climate scenarios (such as the NGFS) as well as support the bank's vision based on the level of desired complexity, granularity in scenario analysis through its tailored approach.

Data inputs/Coverage

Moody's pilot analysis started with the assessment of a representative portfolio of our Group:

1. Retail & Wholesale Real estate Collaterals in several geographies in Europe and South American countries: location specification
2. Corporate (listed) in Spain and Mexico: ISINs were sufficient to perform the complete climate credit risk analysis on the entities.
3. Fixed Income & Equities Global (listed): ISINs were sufficient to perform the complete climate credit risk analysis on the entities.
4. SME (Spain) and Corporate (private firms): Moody's assessed physical risk exposure based on location-specific inputs through its Climate on Demand real asset application. Bank also provided sector-level (granular NACE classification), baseline rating (PD) to analyse the climate adjusted credit risk metrics and financial analysis.

In summary, 6.870 ISINs of more than 3,000 listed entities were analysed in the sample. Moody's also conducted a full analysis on climate physical risks across 1 million collaterals in Spain, and in two South American geographies.

Risk factors and scenarios

The methodology assesses policy, market upstream, market downstream and technology risks associated with climate transition scenarios and includes physical risk exposure scores for listed entities with detailed analytics for six climate hazards (extreme rainfall and inland flooding, heat stress, water stress, hurricanes & typhoons, sea-level rise and wildfires) as well as an overall score and benchmark measures of supply chain risk and market risk.

The physical risk methodology leverages highly granular raw climate data from global climate models and applies them to a broad range of asset classes for listed companies, private equity, real estate, sovereigns, and sub-sovereigns.

On transition risk, Moody's provides emission profiles and energy transition risk scores for counterparties. The score provides an opinion on the quality of the company's management of risks and opportunities related to the transition to a low carbon economy and its capacity to reduce its future carbon footprint. These risks and opportunities are specific to each sector and the company's operations.

Moody's collects issuer's emissions data following the GHG protocol for all scopes. When emissions data is not publicly disclosed, Moody's estimates Scope 1 and Scope 2 emissions using its own proprietary models.

At the firm level, physical and transition risks are modelled by linking the climate scenarios to the key drivers of a Merton style structural model framework. Thus, each firm's

Earnings and Asset Values are considered to be affected by each scenario through information obtained by carbon footprint and transition risk assessment, as well as by the physical risk exposure scores.

Scenarios

Moody's tool can support Climate Change Scenario Analysis in line with reference practices, including and not limited to:

- **Orderly**/Immediate 2C with CDR (Carbon Dioxide Removal), Emission peak year as 2025, net-zero-year 2050 CO_2 only
- **Disorderly/**Delayed 2°C with limited CDR, Emission peak year as 2030, net-zero year 2060 CO_2 only
- **Hot House**/No additional policy, Emissions continue to rise till 2100
- **Alternative scenarios** on physical risk via 1.5°C (with 66% probability)—NGFS Immediate 1.5 with CDR, IPCC RCP2.6, 4.5, 6 and 8.5.

In addition, physical risk scenarios can be provided by either **directly specifying a path of global expected economic damage from physical risk or specifying an emissions path from an IAM or other assumptions.**

Moody's is committed to updating reference scenarios (like NGFS) in its solutions as they become available.

Time horizons: 30-year time horizon considered whilst there is full flexibility to change it, such as nearer-term or longer-term to 2100.

Outputs and Insights

The analysis results were provided at firm/asset level (output for the retail portfolio is based on mortgage collateral location and SME production site location) and the bottom-up methodology captures firm/asset specific factors to differentiate across sectors, countries, specific location of facilities/supply chains/market context and emission profiles (Scope 1+2 and forward-looking) of counterparties. The same methodology is applied for the SME and private firm universe, depending on the data inputs provided.

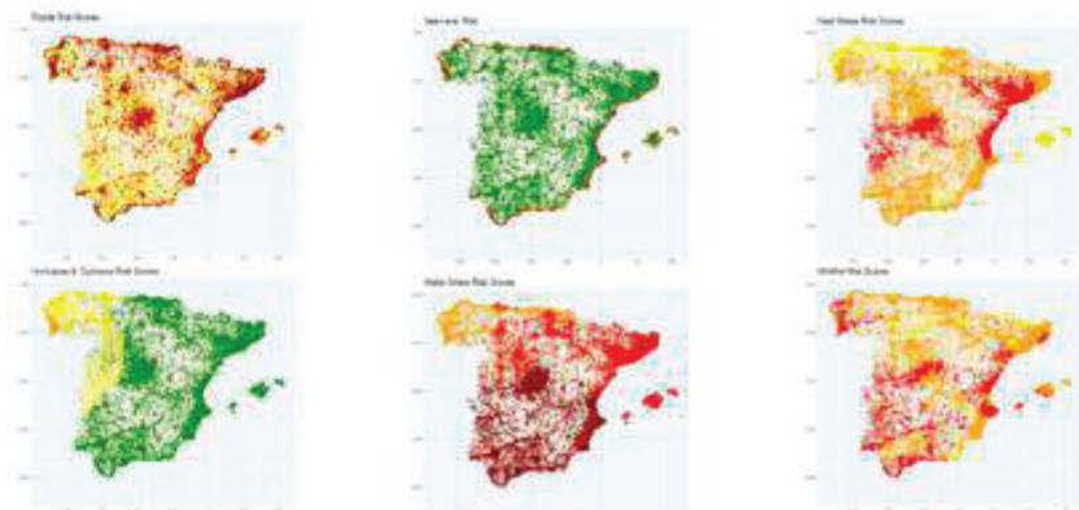
A short summary of outputs that were provided for the bank Fixed Income, Corporate & Private Firm portfolios, where possible:

- Probability of Default (EDFTM)—Expected Default Frequency- change (due to climate risk), Probability of Default (climate risk-adjusted)
- Credit Rating change (due to climate risk), Credit Rating (climate risk-adjusted)
- EBITDA change (due to climate risk) where Moody's use Free Cash Flow to the Firm as a measure of earnings, EBITDA (climate risk-adjusted)
- Expected value (e.g. mean estimate—high probability, estimated impact)
- Extreme value (e.g. tail estimates—low probability, high impact)

Moody's provided a set of climate risk assessments for physical risk and transition risk and trial access to its Climate on Demand application for real assets where our Group was able to analyse at granularity the physical risk exposure against key hazards. In addition, Moody's also conducted a full analysis on climate physical risks across more than 1 million collaterals in Spain, and some thousands in South American geographies during the pilot and provided results.

Insights:

Collaterals (retail & wholesale): 2040 physical risks results based on the RCP 8.5 scenario for 1 million collaterals in Spain by climate hazard:



A similar analysis was conducted in some South American countries (where the largest mortgage exposure is concentrated). The climate hazards exposure differs in each region. For example, hurricane and typhoon risk is not relevant in Spain, but it is significant in some countries of South America.

Suggested enhancements for the provider

Overall, our Group was satisfied with Moody's tool and Moody's team. The demo was effective at demonstrating the climate risk analysis capabilities of Moody's tool for several asset types. The tool is easy to understand, and the methodology document and overview provided were very helpful.

We have developed a wish list of enhancements related to data, scenarios and methodology that could be advisable:

- The physical risk scoring model is limited to the 2040 time-period and the RCP8.5 scenario. It would be useful to be able to compare results with the baseline and other time periods, as well as other IPCC warming scenarios in the long term.
- While there are some sensitivity/mitigating factors implemented for some types of assets, there is room for improvements to be able to customize other adjustment factors in the physical risk scoring.
  - The methodology used for the assessment of wildfire risk by Moody's tool is very much designed for large rural areas (low resolution 25x25 km), extrapolating the

most common type of vegetation to all the area, and does not take into account other factors such as urban infrastructure and vulnerability by sector. These limitations should be taken into account when assessing the results (which could be overestimated in some cases).
    - Sensitivity factors based on the asset types or industry activity of the asset (such as collaterals) or clients (such as corporates or SMEs) are not taken into account, aside from some sensitivity adjustments based on activity for real assets. It does not consider the resilience/sensitivity of clients based on their production activity (not only sector), supply chain characteristics, and initiatives aimed at mitigating physical risks.
- Regarding how transition and physical risk impact the risk parameters such as PD and LGD for the mortgage portfolio, there was a limitation of local historical data in certain geographies. In addition to the NGFS scenarios and existing methodologies, extensive preparation is needed to develop tailored models for each geography (such as the ones created for the USA and UK). This effort was left out of the scope of this pilot.

In general, we also believe transparency when accessing internal parameterisation and scoring rules should be a priority for future developments, for Moody's tool and for any other platform.

Due to time constraints, our Group did not access the broader suite of Moody's solutions, and there are some aspects of the tool that couldn't be tested, such as the Moody's ESG Score predictor which expands climate profiling coverage to the uncovered universe, e.g. SME credit, on-demand scoring to address further any geocoding issues (transforming postal addresses to coordinates), the outcome visualization within the tool (heatmaps, geographical distributions, PD impacts, etc), or the potential data connection required to connect internal financial data with the results.

Note that these studies were conducted pre-acquisition of RMS by Moody's Analytics, which expands the depth and breadth of physical risk capabilities (direct/indirect risk (cost) factors, scenario sets and time spans and impact analysis across broader asset classes) that joint firms can today provide.

Participant:

Intesa Sanpaolo

Provider:
Risk Management Solutions, Inc. (RMS)

Risk types covered by tool:
Physical risk

Introduction

As part of the UNEP-FI TCFD pilot program, Intesa Sanpaolo selected Risk Management Solutions, Inc. (RMS®) as the supplier to participate in the case study.

The RMS climate condititoned catastrophe risk models were used in order to quantify the flood risk related to a small sample of the Intesa Sanpaolo Italian mortgage portfolio.[10] In particular, the RMS climate change Europe Inland Flood HD Models were used in this case study considering the Region interested and the type of risk.

The results of the analysis show losses at sample portfolio level comparing today's risk to 2040 using RCP 6.0 and RCP 8.5 scenarios and related province level estimates.[11]

Differences in the "climate-adjusted" Probability of Default (PD) and Loss Given Default (LGD) are also provided with different return period losses.

Flood risk methodological framework

The RMS modelling framework consists of five key modules, which are detailed below:

- **Stochastic:** the stochastic module contains thousands of simulated events for a given peril. For example, the Europe Inland Flood HD Models' stochastic event set stem from a continuous simulation of precipitation and all subsequent hydrological processes over a period of 50,000 years. These events have been created to represent the full range of possible flood extents and severities, both from pluvial and fluvial flooding, that can impact Europe;

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10 The RMS methodology is commonly used by governments, financial institutions and their corporate clients to manage their exposure to extreme events and has over 200 peril models in nearly 100 countries enabling organizations to quantify the potential magnitude and probability of economic loss from catastrophe events (from earthquakes and hurricanes to flood and wildfire). A combination of science, technology, engineering knowledge, and statistical data is used to simulate the impacts of natural and man-made perils in terms of damage and loss.

11 Province level coincides with the NUTS 3 classification (Nomenclature of statistical territorial units of the EU).

- **Hazard:** the hazard module determines the flood extent and severity for each event in the stochastic set. It simulates each precipitation event and determines how these are translated into flooding in space and time considering all relevant processes, such as topography, hydrology, built-up areas, antecedent conditions, to just name a few. Flood hazard is expressed by the extent and flood depths of each flood event;
- **Exposure:** exposure is information about the assets at risk in a given study area. This information is captured in an exposure database. The exposure database contains information on the type, location, value and additional characteristics of each property asset. During the modeling process, the locations of exposed assets are overlaid with the hazard footprint of each stochastic event to determine the severity of the hazard each asset is subjected to;
- **Vulnerability:** vulnerability is the relationship between hazard (e.g. flood height) and damage (e.g. 30% of a building structure damaged). The vulnerability of an asset is dependent on its physical attributes, and can vary by peril (e.g., flood, extreme winds). The models store vulnerability information for thousands of asset types in the form of vulnerability curves, which link hazard values to damages;
- **Financial:** the hazard experienced at an asset location is linked to damage to that asset in the vulnerability module. The financial loss from this damage is then calculated (for each stochastic event and for each asset) using the financial module. Losses are then aggregated across all assets included in the analysis, taking into account any applicable protections (physical or financial) which may be in place or under consideration.

It follows that catastrophe models can be used to deliver insights into how frequently a location is to be impacted by different hazard levels. For example, they can be used to determine how frequently a given location can be expected to be impacted by flooding in excess of 6ft, or other thresholds of interest. These insights can then be used to inform decisions such as top elevations for new seawalls, or road elevation standards for new infrastructure developments.

When used in combination with the exposure, vulnerability and financial module, the model can additionally assess the frequency and severity of the economic impact caused by a specific peril, such as flooding.

This impact is quantified by subjecting the location, its associated vulnerability and financial value of exposed assets to the corresponding hazard severity for each simulated event. This economic impact analysis is particularly useful to objectively compare levels of potential loss to financial assets at different levels of likelihood.[12]

12 As mentioned, the RMS Europe Inland Flood HD Climate Change Models were utilized to quantify the impacts of climate change under different potential future states. This climate change model framework allows a selection between four different Representative Concentration Pathways (RCPs), as defined by the IPCC (https://www.ipcc.ch/), at five-year intervals until the year 2100 to understand the physical risk of climate change in the portfolio.

Data and coverage

The case study was made on a limited sample of the Intesa Sanpaolo mortgage portfolio in Italian locations with the aim to estimate the related flood risk.

A sample consisting of 1,200 positions within the Intesa Sanpaolo mortgage portfolio (0.27% of the mortgage portfolio) was selected for this case study. The total value of the collateral to which these positions refer, is equal to a total of € 680 Mn (0.15% of the collateralized portfolio) and 85 out of 110 Italian provinces (NUTS 3 level classification) are represented. The key information of the sample is represented below.

Risk drivers' composition of the selected sample (sorted by Probability of Defaults)

Positions sorted by PDs	Average PD	Average LGD
PD <= 0.1%	0.04%	4.98%
0.1% < PD <= 0.5%	0.24%	10.50%
0.5% < PD <= 1%	0.68%	10.56%
1% < PD <= 3%	1.75%	10.67%
PD > 3%	6.25%	12.86%

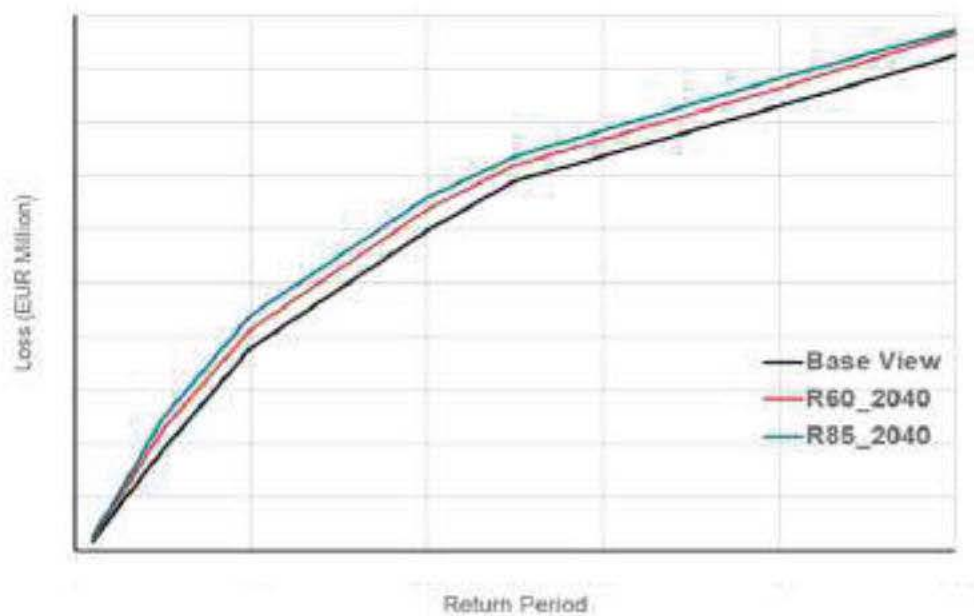
Italian provinces included in the sample (in red)

Risk factors, scenarios and outputs

The RMS model was applied to both the RCP 6.0 and the RCP 8.5 scenarios, considering 2040 as the reference year for the projections. The application of the model resulted in the definition of a haircut on the value of the collateral with a proportional increase in the expected LGD. The graphs and tables below show the effect of the model assumptions in relation to an inertial baseline view and two commonly used climate projections (RCP 6.0 and RCP 8.5) considered in terms of impact on:

1. the probability curves related to the gross value loss caused by the event damages and in relation to different return periods;
2. the average return period annual losses, reported in percentage changes with respect to the baseline view, in the most important Italian provinces.

Portfolio Probability Curves (Sample Portfolio Gross Losses)



Average Return Period Annual Losses (most populated Provinces)

Province	Average Annual Loss (% vs Baseline) Change R85_2040
Rome	**Over 50%**
Milan	**Under 20%**
Naples	**Over 50%**
Turin	**Under 20%**

Based on the analysis, Intesa Sanpaolo calculated the impact on Loss Given Default (LGD) and the effect on the Probability of Default (PD) was deduced by exploiting the relationship between PDs and LGDs (following the approach proposed by J. Frye and M. Jacobs Jr., 2012 [1]).

The underlying general premise behind the Frye-Jacobs model is that LGD is an increasing function of default rate, and consequently of the PD, which essentially means that if the default rate increases, the LGD also increases approximately in a similar proportion and vice versa.

Once all steps were performed, the LGDs and PDs implied in the different stress scenarios were estimated for all counterparties of the given sample. The following table summarizes the results taking into account the initial risk drivers' composition of the borrowers, in terms of PDs, and a return period equals to 1 on 500 years losses (for 2040 under RCP 8.5) as a worst scenario. The impacts on PDs and LGDs are substantial and vary from 4% to 39% with respect to the initial values.

Main impacts of scenarios analysis on the mortgage sample selected (sorted by Probability of Defaults)

Positions sorted by PDs	Initial Average PD	Stressed PD	Initial Average LGD	Stressed LGD	Stressed PD (x-times)	Stressed LGD (x-times)
PD <= 0.1%	0.04%	0.05%	4.98%	5.63%	1.19x	1.13x
0.1% < PD <= 0.5%	0.24%	0.30%	10.50%	14.64%	1.23x	1.39x
0.5% < PD <= 1%	0.68%	0.85%	10.56%	12.22%	1.25x	1.16x
1% < PD <= 3%	1.75%	1.92%	10.67%	11.54%	1.09x	1.08x
PD > 3%	6.25%	6.53%	12.86%	14.09%	1.04x	1.10x

Final considerations and suggested enhancements

Regarding the relationship between climate scenarios and credit methodologies, it is certainly true that this tool represents a useful opportunity for understanding the impact of flood risk (especially after the recent ECB Guide on climate and environmental risks, 2020 [2]).

Nevertheless, there is a potential for further enhancements for assessing the risks related to the mortgage portfolio.[13] Below some key points and general considerations:

1. a sample of the mortgage portfolio deemed sufficiently significant in terms of territorial diffusion, collateral values, duration of the loan to provide an acceptable output for the application of the model was chosen. The results appear to be quite satisfactory, despite the need to verify their consistency by expanding the scope of application;

13 RMS is working on methodologies to integrate damage and loss output from RMS cat models with Moody's credit models

2. although collateral properties are identified by the physical address of the building, it has not always been easy to bring them back to NUT 3 level;

3. the choice of the correct time horizon for the risk models used should be consistent with the long term strategies of the institution and in line with the reallocation portfolio decisions;

4. in this preliminary phase, the most direct way to define a correlation between the results of the model and the credit parameters was to evaluate the impact in terms of LGD and, through the relationship between PD and LGD (Frye-Jacobs approach), obtain an impact also in terms of PD. Although the results showed a good level of rationality, further refinements should be developed;

5. this case study primarily focused on acute physical risk from climate change. The analysis should be enhanced by considering other issues such as the energy efficiency certificates (EPC) that characterize every single collateral and the related impact on PD, the possible macroeconomic effects deriving from an indirect effect of a natural catastrophe (e.g., the unemployment rate) and the possible mitigation effects deriving from the presence of specific insurance policies at each counterparty level.

The proposed approach should therefore be considered as an attempt to assess the potential impact on the mortgage portfolios of the flood risk in Italy from the point of view of the financial system, to be refined time by time with the new methodologies and enrichment of data that will gradually become available.

References

[1] J. Frye, M. Jacobs Jr., Credit loss and systematic loss given default, The Journal of Credit Risk Vol 8, 1–32, Spring 2012

[2] European Central Bank, Guide on climate-related and environmental risks—Supervisory expectations relating to risk management and disclosure, November 2020

Participant:

Banorte Financial Group

Provider:
Risk Management Solutions (RMS)

Risk types covered by tool:
Physical Risk

Introduction

Banorte is participating in the third phase of the TCFD-UNEP FI 2021 program for banks, in which we involved various business areas (including risk, credit, specialized areas, sustainability, insurance, and innovation) in developing capabilities to identify, manage, and disclose climate-related risks and opportunities. To better understand and assess climate and physical risks to our portfolios, Banorte began by focusing on our loan portfolio. This was an introductory study to establish a baseline view of risk. The intent of the study was to explore using RMS models to better understand Banorte's exposure to climate and environmental risks. RMS models have the ability to show the baseline risk and climate change risk from hurricane, and as a next step, we will explore opportunities to examine future climate change risk against our baseline. We chose RMS™ from amongst several suppliers to participate in a demo that focused on the physical risk of real assets from our clients across all territories in which Banorte has provided a credit.

RMS is a very well-known provider of physical risk evaluation solutions. The company has performed several assessments for the insurance and reinsurance industry in Mexico. In fact, one of the reasons we chose RMS is because the company has been evaluating our region for more than 20 years. The RMS demo focused on sectors such as metal and mineral processing, business services, agriculture, and manufacturing of cement, lime, and plaster. The demo covered our Commercial Bank Loan book, which represents 10% of our portfolio.

Because we did not have the exact location and detailed characteristics of the facilities and assets included in the exercise, we gave RMS only the ZIP code, city, and state as an approximation to the location, the asset amount, and the sector. RMS performed its analysis based on this data.

Process

RMS consulting ran all of the model and communicated to us how their model would work. Once we had agreed on the data that RMS required to run the Banorte portfolio, we worked internally to team up with different areas of our loan department.

Our loan department and our insurance subsidiary helped us find the information we needed. We realized that our insurance subsidiary had the exact location of the clients we chose for the analysis, because all loans must be protected by an insurance policy. This significantly expedited data collection. The greatest challenge we had been facing was related to overcoming internal legal requirements so that we could share information with providers' and customers' exact geolocation.

Data and coverage

During the analysis, RMS requested data from our clients to load into their platform. Our clients provided this data via a spreadsheet that shared their sector, location, and total assets. To increase the granularity of the analysis, our clients also provided their ZIP codes.

Table 1: Data showed by RMS using their platform.

Top 10 locations by Asset Value					
Loc num	**State**	**City**	**Postode**	**Occupancy**	**TIV**
57842	Guanajuato	El Liano	36390	Metal & Minerals processing	2,587,000,000
57853	Jalisco	Marina Vallarta	48335	Business Services	2,504,000,000
57844	Distrito Federal	Polanco II Sección	11530	Metal & Minerals processing	2,177,000,000
57846	Distrito Federal	Moctezuma Segunda Sección	15530	Business Services	1,697,000,000
57835	Tamaulipas	Roma	89350	Metal & Minerals processing	1,371,000,000
57856	Quintana Roo	Tulum	77760	Agricu ture	1,230,000,000
57840	Sinaloa	Bachigualato	80130	Agricu ture	1,060,000,000
57855	Nuevo León	Pedregal de Escobedo	66061	Agricu ture	700,000,000
57847	Distrito Federal	Sector Naval	2080	Business Services	631,000,000
57839	Puebla	Guadalupe	74126	Metal & Minerals processing	509,000,000

Table 2: Example of information provided on Banorte's behalf.

State & Sector	Zip Code	Total Assets USD*
Baja California Sur		
Hotels and similar accommodation	23403	140
Nuevo Laredo		
Hospital activities	87120	302
Manufacture of cement, lime and plaster	89350	1371
Mining and quarrying n.e.c.	89606	12
Rental and operating of own or leased real estate	89000	64
Waste collection	87080	303

	RMS
Internal	1. Sector 2. Location 3. Total assets

Because Banorte only has operations in Mexico, our assessment focused on specific locations within the country. We shared data of 25 clients representing 10 percent of our portfolio and have commercial activities in the following sectors:

1. Hotels and similar accommodation
2. Hospital activities
3. Cement manufacturing
4. Lime and plaster
5. Mining and quarrying.
6. Rental and operation of own or leased real estate
7. Waste collection
8. Growing of perennial crops
9. Structural metal manufacturing
10. Motor vehicle manufacturing
11. Electric motor manufacturing
12. Generators
13. Electricity distribution and control
14. Monetary intermediation
15. Office administrative and support
16. Real estate activities on a fee or contract basis
17. Architecture and engineering
18. Office administrative and support
19. Meat processing and preserving.

Number of companies: 25
Total: $1.6 billions

Coverage Mexican territory

Risk factors and scenarios

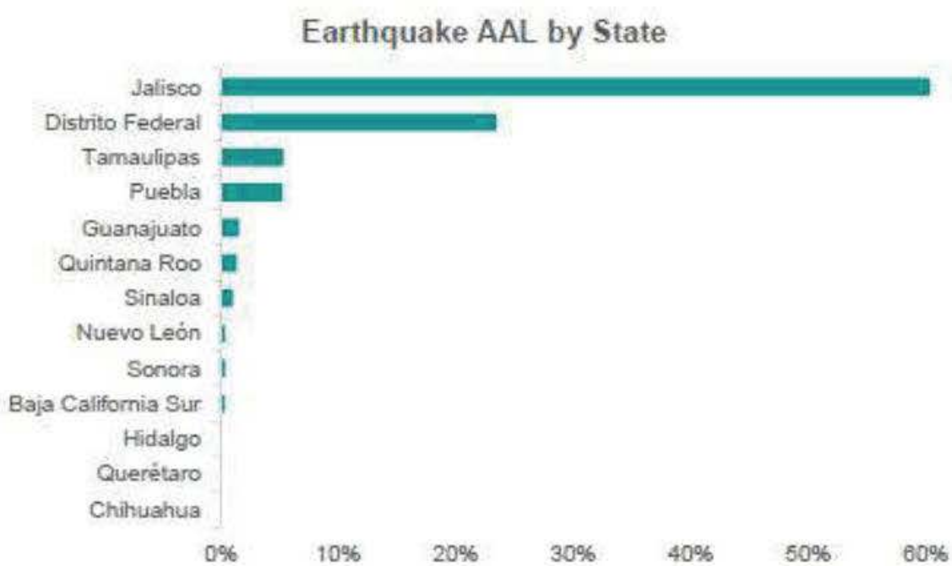
RMS provided us with an analysis that focused on physical hazards such as windstorms and earthquakes. This analysis used the following assumptions:

- Asset value is building only.
- Construction class, year built, and number of stories: unknown (based on inventory database in the model).
- RMS has construction assumptions included in their model data.
- Temperature pathway(s) analyzed: none. It was an exercise with current climate conditions.
- Scenarios used (NGFS, IEA, etc.)
  Because this was an exercise with current climate conditions, the scenarios were based on three situations:

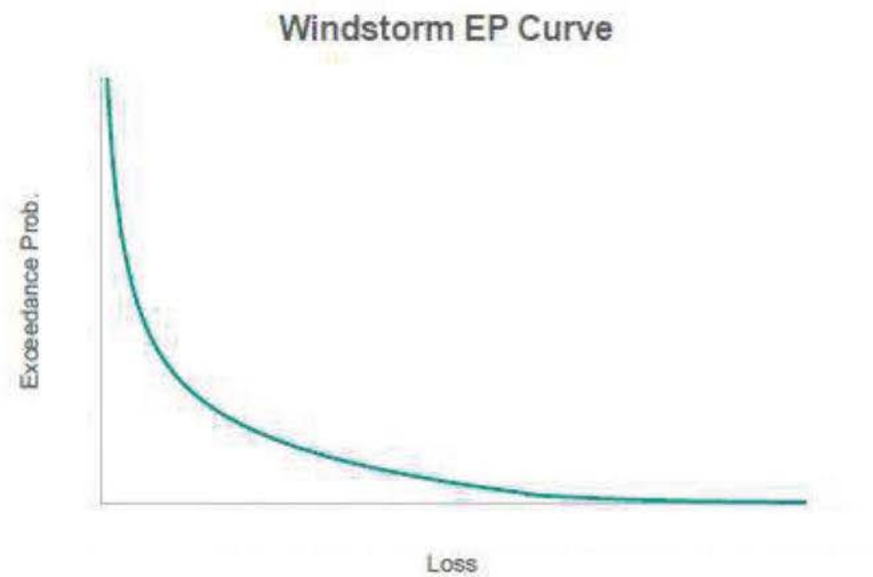
  1. Baseline current physical building risks (what is used today for insurance)
     - Earthquake and windstorm
     - 25 locations

Earthquake results:

Loss By Geography



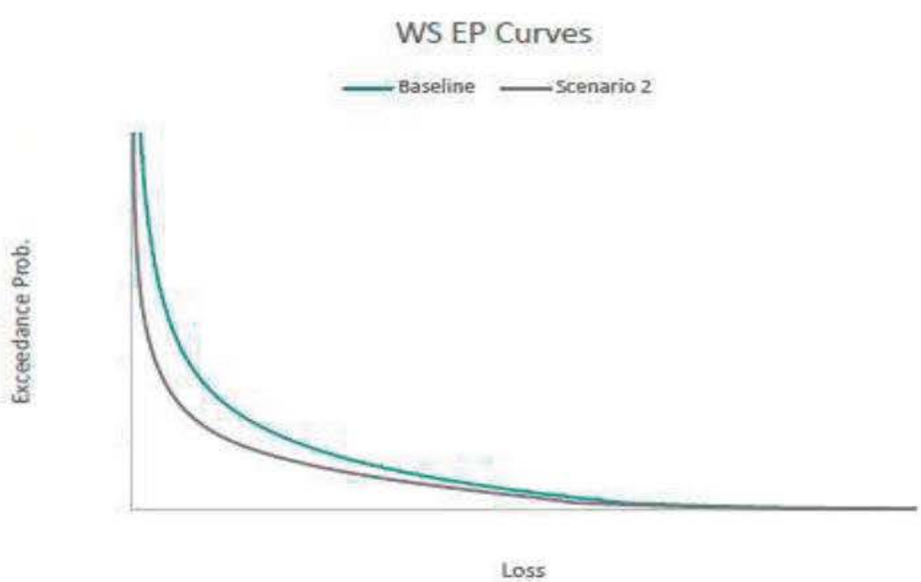
Windstorm



2. Borrow equity captures exposed risk to bank
   - Made assumption to show how one could model LTV
   - Used a 10% LTV assumption
   - Shows loss amounts after 10% borrower equity is considered

Results:

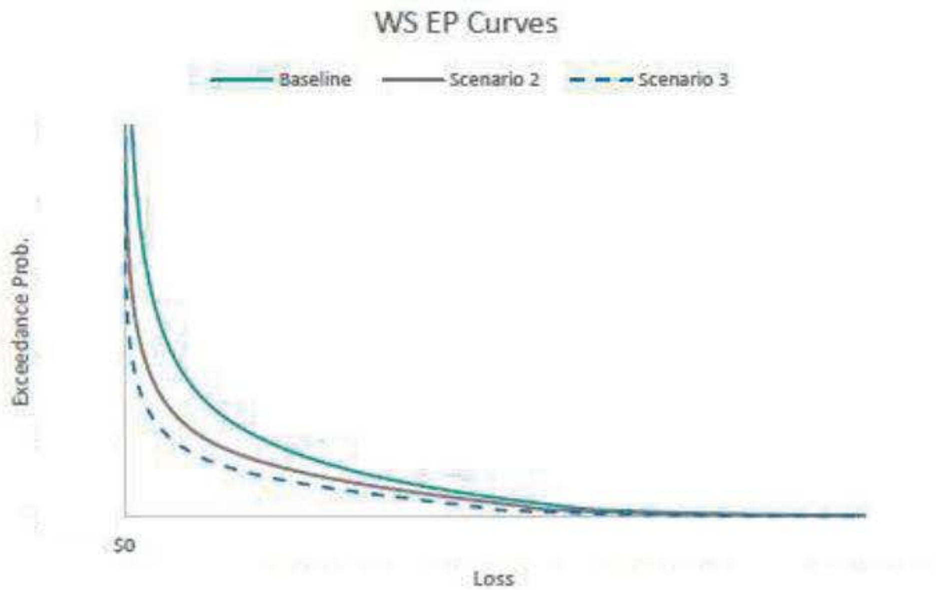
Windstorm



3. Insurance modeling projects losses after insurance is applied
   - Assumed that insurance limit is 10% of each property value
   - Modeled net losses to bank after borrower equity and insurance is considered

Results:

Windstorm



Summary of Windstorm Exceedance Probability Loss Results with % Scenario Change

Exceedance Probability	Return Period	Baseline	Scenario 2	Scenario 3
0.00%	50,000	$2bn+	-6.70%	-14.59%
0.01%	10,000	$2bn+	-6.12%	-14.60%
0.02%	5,000	$1.5bn-$1,99bn	-6.75%	-16.07%
0.10%	1,000	$1,000-$1.49bn	-9.90%	-20.39%
0.20%	500	$1bn-$1.49bn	-10.26%	-22.55%
0.40%	250	$500M-$999M	-17.22%	-35.85%
0.50%	200	$500M-$999M	-21.64%	-42.98%
1%	100	$200M-$499M	-41.35%	-65.88%
2%	50	$0-$199M	-59.59%	-84.25%
4%	25	$0-$199M	-84.89%	-98.13%

The outputs generated form RMS included Loss Outputs on each scenario they provided and the following metrics:

EP (Exceedance Probability): Probability that the single largest event loss in a year will exceed a loss threshold.

Return Period: Refers to a point on a loss curve (for example, an occurrence exceedance probability or aggregate exceedance probability curve) that describes the likelihood of exceeding a loss threshold from the single largest event (OEP) or the aggregation of one or more events (AEP). It is defined as the inverse of the annual exceedance probability. For example, a return period of 100 years corresponds to an annual exceedance probability of 1.

AAL (Average Annual Loss): Sometimes called Pure Premium or Burn Cost, AAL is the expected value of the modeled loss distribution. It is the average loss one would expect to see in a year. The actual annual losses will fluctuate around the AAL in any given year. AAL does not include expenses, non-modeled loss, profit, or risk load.

RMS can assess physical risk under actual conditions. They are working on a model to incorporate climate change to simulate future possible conditions. It would be possible to run climate change views for hurricane risk using any of the above scenario perspectives (specifically Hurricane).

- We believe that using this type of analysis helps us to assess physical risk under actual conditions.
- RMS displays clients graphically, exposing the distribution of assets by geolocation, exposure, and sector.
- Within the results of the model, RMS shows which states of our republic have the greatest risk of loss for hurricane and earthquake.
- Results could be displayed per client to see how different scenarios affect them individually.

Suggested enhancements for providers

- **How easy was the tool to use?**

  It was easy to gather the information for the exercise because RMS told us we could use an approximation of the geolocation. They only needed three indicators: sector, location (ZIP code), and total assets.

- **Do you have any modifications or suggestions that would enhance your analysis?**

  Because we did not provide details of the assets evaluated by RMS, they used some assumptions to perform the analysis:

  Asset value is building only construction class, year built, and number of stories: unknown (based on inventory database in the model)

  RMS includes construction assumptions in their model data.

  For the reasons already explained, having more details of the assets we gave RMS would have resulted in a more refined analysis.

- **What are the areas you would like to see the providers explore in the future?**

  This study did not include running RMS climate change catastrophe models. In the next phase, RMS will have the opportunity to demonstrate the capabilities of their climate change catastrophe models with detailed exposure data as part of the analysis. It would be important to see the recent capabilities they have developed around climate change. This new feature was just being finished at the time we needed to get the results to comply with the TCFD deadlines. We would like to explore it and we agreed on a demo because the new feature assesses:

- Mexico Windstorm baseline vs. RMS climate change views.
- RMS climate change views based on four RCP scenarios (2.6, 4.5, 6.0, 8.5) and/or a 2o C increase.
- Loss estimates from 5 to 80 years forward (in 5-year increments). Example output shows 2030 and 2050.

RMS is a trademarks of Risk Management Solutions, Inc.

Participant:

BMO Financial Group

Provider:
Oliver Wyman/S&P Global Market Intellgence

Risk types covered by tool:
Transition Risk

Introduction

As part of the Landscape Review exercise, BMO Financial Group worked with Oliver Wyman and S&P Global Market Intelligence to demo Climate Credit Analytics, a climate scenario analysis and credit analytics model suite. Climate Credit Analytics is a turnkey solution that enables bottom-up analysis of five high carbon-emitting sectors (oil and gas, metals and mining, power generation, airlines and automotive) as well as a generalized approach for all other sectors. For the purposes of the demo, the Bank focused on the metals and mining sector.

The scenario analysis tool is used to assess the credit risks associated with the transition to a low carbon economy. Climate Credit Analytics assesses the credit rating impact of climate scenarios on a counterparty or portfolio level by calculating climate adjusted financial statements. The tool leverages S&P Global Market Intelligence's data resources, including financial and industry-specific data, credit scoring methodologies and Trucost environmental data. This is combined with Oliver Wyman's climate scenario and stress-testing expertise.

Process

Climate Credit Analytics can be accessed through two interfaces: an Excel version or an Application Programming Interface (API) version.

To generate results through Climate Credit Analytics, the user follows a few simple steps:

- Search or upload portfolio companies in Climate Credit Analytics
  - Tool automatically populates required financial and environmental data
- Select scenarios to run and interval period of results (either at 5-year intervals or annually)
- Select the S&P Global rating model that will be used to re-rate the companies
  - Internal rating model can also be used
- Adjust or override model parameters, if desired
  - The parameters available to adjust range from financial parameters (e.g. level of dividends paid, leverage ratio) to sector-specific parameters and scenario variables

- Run the model
  - Results presented in two ways:
    - Single entity view: focuses on a single company, showing the evolution of the financial statements and the rating and probability of default changes
    - Batch view: gives the full financial statement and rating results for all counterparties selected to run in the model to allow for further portfolio analysis internally by the user

The model translates climate scenario and sector-specific supply and demand elasticities and market dynamics into drivers of financial performance to provide financial statement forecast, impact on credit score and probability of default. Core metals and mining assumptions include:

- **Price:** as demand for coal decreases prices will likely fall, while other minerals see an increase in price as the scenario emissions costs are passed through to consumers
- **Volume:** demand for coal falls in the transition while demand for energy transition minerals increases with electrification/ EV adoption. Other minerals grow with the economy
- **Unit cost:** mining production costs increase due to the carbon price and emissions intensity of production for each mineral
- **Capital expenditure:** coal capex is expected to decrease along with demand as high cost mines close, while increasing for other minerals to meet rising production levels

Based on this information, the model calculates scenario adjusted financial statements (e.g., income statement, balance sheet and cash flow statement). It then links the scenario-adjusted financial statements to S&P's credit rating model to calculate scenario-adjusted credit scores, or ratings. The user can also link the scenario-adjusted financials to internal risk rating models.

Data

A sample of North American and European publicly traded metals and mining counterparties was assessed. The data required for the analysis is included in the Climate Credit Analytics tool. Climate Credit Analytics covers 1.6 million public and private companies across all geographies. If a company is not included in the S&P Global dataset, the user can upload the required data via the API.

Climate Credit Analytics segments metals and mining production into three categories: fossil fuel minerals, energy transition minerals and other minerals and models the impact related to demand and emissions. Fossil fuel minerals include thermal/steam coals used for electricity generation and metallurgical coal used in steel making. Energy transition minerals are critical to electrical vehicle battery production and include lithium, cobalt, nickel, manganese and copper. Other minerals include iron, silver, uranium, aluminium, zinc, gold, molybdenum, diamonds, lead, platinum/PGM and titanium.

Risk factors and scenarios

Climate Credit Analytics enables analysis of climate transition reference scenarios published by the Network for Greening the Financial System (NGFS). NGFS scenarios extend to 2050 and are loaded in the model. These scenarios cover temperature pathways ranging from 1.5°C to 3°C+ and have over 1700 sector specific and macro variables, e.g., GDP. Credit risk can also be analysed under a global carbon tax scheme that is enacted over a three-year period (e.g., 2020–2022). Users also have the option to run customized scenarios.

The key transition risk factors explored in the demo were technology and carbon pricing. The following NGFS transition scenarios were assessed:

- Immediate 2°C with carbon dioxide removal (CDR) technologies
- Immediate 1.5°C with limited CDR. Limited CDR scenarios require larger reductions in fossil fuel use as CDR technology cannot be relied on

Outputs and insights

Climate Credit Analytics generates full scenario-adjusted financial statements (Income Statement, Balance Sheet, Cash Flow Statement) at a counterparty level on an annual basis. The model also generates climate adjusted credit ratings and probabilities of default using an embedded rating model from S&P Global. Counterparty level outputs can then be aggregated at a portfolio level.

Immediate 2°C, with CDR

- Diversified miners are expected to maintain profitability as losses in coal are offset by growth in other minerals, e.g., energy transition and other minerals
- As the demand for transition minerals increases, profitability should grow for companies with no coal production
- The average rating impact for the sample of counterparties was limited. This is attributed to nature of the companies included in the sample

Immediate 1.5°C, limited CDR

- Diversified miners are expected to maintain profitability due to growth of non-coal minerals provided they have sufficient profit margins
- Margins expected to shrink for companies with no coal production as growth in volume of transition and other minerals is counteracted by increased unit costs of emissions for mining these minerals, however they should remain profitable provided they have sufficient starting margins
- The average rating impact for the sample of counterparties was limited. This is attributed to nature of the companies included in the sample

The following illustrates how counterparty ratings can change under a transition scenario. Note the results depicted do not reflect demo results.

Demo results are consistent with what we would expect, namely that diversified companies are better positioned to navigate transition risk. The ratings impact is aligned with exploratory analysis that we have conducted internally on the same sample of counterparties. Climate Credit Analytics outputs can inform discussions on transition risk implications.

Climate Credit Analytics is user friendly and easy to navigate and results are generated quickly. It automatically populates the necessary input data for analysis which saves significant time and effort in sourcing data. The integration of NGFS and carbon scenarios in the model and the ability to customize scenario parameters further contributes to the ease of use.

Participant:

Desjardins Group

Provider:
The Climate Service (TCS)

Risk types covered by tool:
Physical and transition risk

Introduction

As part of the UNEP FI TCFD pilot programme, Desjardins selected The Climate Service (TCS) as one of its preferred potential suppliers to participate in a demo. The Climanomics® platform of TCS provides screening-level climate risk analysis and enables users to identify physical and transition risks across their portfolio of real assets. Desjardins provided a sample of 50 real assets from different sectors (residential, industrial, and corporate) to upload into the platform and interpret results. The platform models absolute climate risk ($M) and relative climate risk (%), reported as percent of asset value. Overall, the sample provided by Desjardins faces the highest physical risk from fluvial flooding and the highest transition risk from carbon pricing in the 2030s, in both RCP 4.5 and 8.5 scenarios. This fact remains true to 2100 with most physical risks and transition risks increasing over time. At the asset level, most impacted assets are those with high emissions, as a result of carbon pricing over time in both scenarios. Renewable energy assets have the lowest total risk in both scenarios. The platform also offers a high- level analysis of the opportunities related to climate change; however, our focus for this first assessment was on climate risks.

Process

The Climanomics® platform is accessible by creating a user profile in climanomics.com. Once the user has logged into the platform, the user will be given an option to access the Real Assets or the Listed Equities platform. Our demo was focused on the Real Assets platform, with data provided in an Excel file (see Data and coverage section) and TCS conducting the upload. Note that regular users can directly upload data through files or an Application Programming Interface (API).

Once the user has entered the platform, a view of the aggregated portfolio risk is seen with the option to drill down to the asset level. All assets have been geolocated and are visible on a map. Risk factors analyzed are listed to the left of the screen with the calculated absolute risk and relative risk, with toggles to provide values for both RCP 4.5 and 8.5 at decadal intervals (from 2020s to 2090s). The relative risk is shown in green if it is below 10% risk, yellow if it is between 11% and 15% and in red if it is above 16% to facilitate materiality analysis. The ranges for this colour coding can be modified upon request to the TCS team.

For a given asset, a deeper analysis is provided for each risk, with a chart showing the evolution of the hazard (e.g. temperature increase per decade compared to baseline) and the associated impact function (e.g. production loss per additional degree of daily max temp). The user has the option to navigate from the risk tab to the opportunities tab which has a very similar format. The platform also has a quick access to the methodology document.

Our main challenge with the platform during this demo is external to TCS and completely related to our institution's strict IT security processes. While we were able to create a profile in the Climanomics® platform website, we were not able to access the real assets platform for several weeks. This issue is completely external to TCS but other financial institutions with strict security processes may face similar issues when engaging potential suppliers of climate risk tools. Even though the data provided for this demo had already been assessed as nonconfidential, accessing the platform from Desjardins's environment required a thorough IT security analysis. The TCS team was very supportive during this process, and they even developed a findings document that enabled us to visualize and better understand the results.

Data and coverage

To conduct this analysis, Desjardins provided a list of 50 portfolio assets, along with name, value in USD millions, reported/estimated GHG emissions, and location (address or latitude and longitude). All asset data was provided by Desjardins (this included internal data and data collected from data suppliers and desktop research.) No additional data was required to conduct the physical and transition risk analysis with the Climanomics® platform software platform.

In terms of portfolio coverage, Desjardins has US$289 billion in total assets and our list of 50 assets used in this demo represents less than 1% of our investments or loan books. Our sample included assets primarily in Canada but also in the United States, Europe, Australia and Asia (see figure below) with a variety of sectors represented including, agriculture, renewable energy, fossil fuels, manufacturing, retail, corporate and residential real estate.

Figure 1: Locations of the 50 real assets analyzed in this demo with color coding representing relative climate risk

Risk factors and scenarios

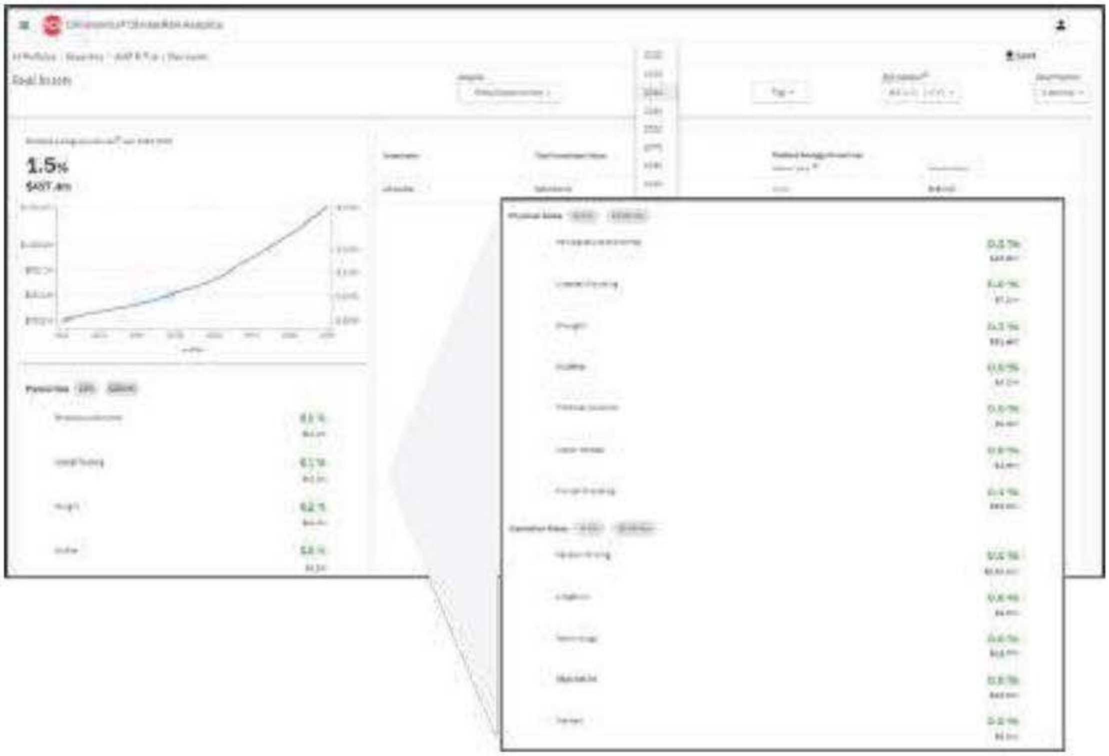
The Climanomics® platform conducts physical and transition risk hazard modelling. The risk hazards included in the assessment are shown in the table below:

Table 1. Physical and Transition hazards in the Climanomics® platform

Physical hazards	Transition hazards
Temperature	Carbon pricing
Drought	Litigation
Wildfire	Reputational damage
Coastal flooding	New technology
Fluvial basin flooding	Markets
Tropical cyclones	
Water stress	

The platform currently reports risks for 10-year increments and the user can view the modelled average annual loss (MAAL), that is the sum of expected financial losses resulting from climate change for the designated period by selecting the desired decade in the drop-down menu (see figure below). A dropdown menu is available to select the desired RCP scenario (8.5 or 4.5). The resulting MAAL in absolute and percentage terms will be shown per risk, with aggregated values for physical and transition risks overall.

Figure 2: Climanomics® dashboard view and modeled average annual loss breakdown



The Climanomics® platform includes scenarios based on the Representative Concentration Pathways (RCPs) from the International Panel on Climate Change (IPCC). Two scenarios are currently included in the platform: RCP 8.5 and 4.5; other scenarios (RCP 2.6 and RCP 6.0) are currently being integrated to the platform and are scheduled to be available by the end of September 2021. According to the Climanomics® platform methodology document, the RCP 8.5 scenario constitutes the high emissions scenario with an assumption that no major global efforts are made to limit emissions resulting in a global mean surface temperature that will be in the range of 4.2 to 5.4°C. On the other hand, the RCP 4.5 constitutes the lower emissions scenario by implying coordinated action to limit emissions and achieve a global temperature warming limit of about 2°C; the estimated mean surface temperature used for this scenario is 1.7 to 3.2°C.

Shared Socioeconomic Pathways (SSP) are integrated in the platform to model carbon pricing. For the RCP 8.5 scenario, the Climanomics® platform uses scenario SSP3-60. SSP3 scenarios assume high challenges to both adaptation and mitigation at different degrees. The price is available at the regional level, for 5 regions: OECD, REF, ASIA, MAF and LAM.[14] The SSP3-60 scenario shows carbon prices starting at $8/tonne CO_2e in 2010 and increasing to $82/tonne CO_2e by 2100. On the other hand, for the RCP4.5 scenario, the Climanomics® platform uses scenario SSP3-45 with prices starting at $8/tonne CO_2e in 2010 and increasing to $440/tonne CO_2e by 2100. Among other sources,

14 Organisation for Economic Co-operation and Development and EU member states and candidates (OECD), Reforming Economies of Eastern Europe (REF), Asian countries with the exception of the Middle East, Japan and Former Soviet Union states (ASIA), Middle East and Africa (MAF) and Latin America and the Caribbean (LAM)

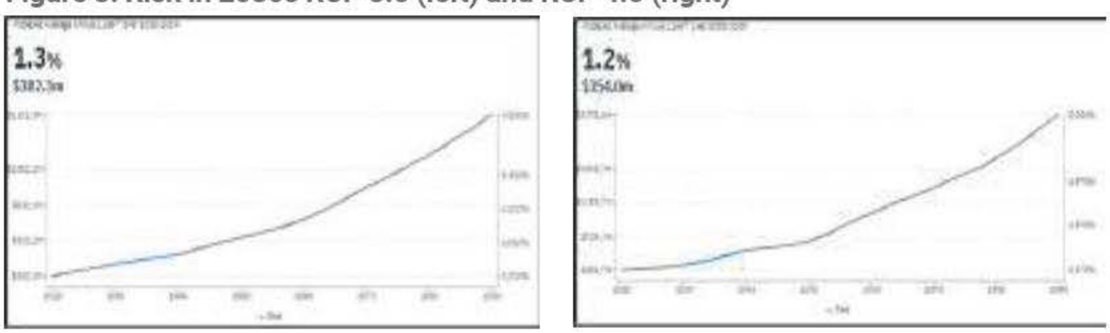
these scenarios are available at the SSP Database from the International Institute for Applied Systems Analysis (IIASA). The platform calculates carbon pricing risk for each asset depending on their location and the GHG emissions data entered.

Outputs and insights

The Climanomics® platform generates an aggregated portfolio result and an asset-level result. Overall, the highest physical risks faced by Desjardins based on the sample data provided is fluvial flooding and the highest transition risk is carbon pricing. Both top risks increase over time at different degrees for both RCP scenarios. The high-level results from the asset sample uploaded for this demo can be found in the table below for the 2030s 10-year window.

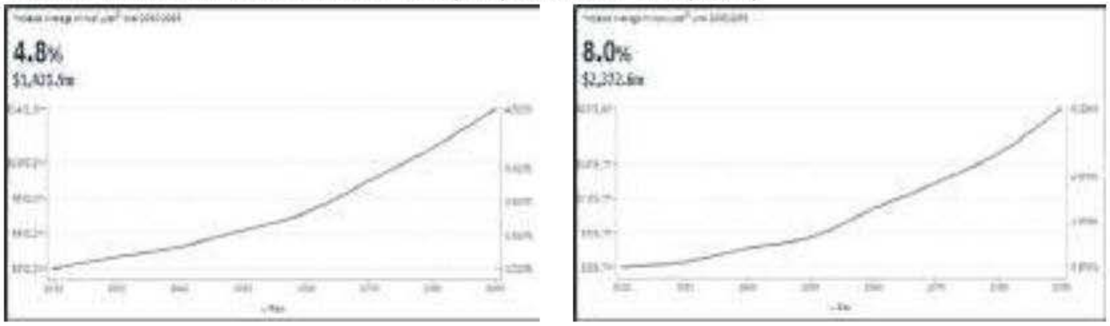
Priority	RCP 8.5 "High emissions"	RCP 4.5 "Low emissions"
Top	▪ The highest physical risk overall is faced from fluvial flooding and the highest transition risk is faced from carbon pricing in the 2030s. ▪ Two natural gas-fired power plants face the highest total risk in the 2030s.	▪ The highest physical risk overall is faced from fluvial flooding and the highest transition risk is faced from carbon pricing in the 2030s. ▪ Two natural gas-fired power plants face the highest total risk in the 2030s.
Medium	▪ Drought poses the second highest physical risk, while Technology poses the second highest transition risk in the 2030s	▪ Drought poses the second highest physical risk, while Technology poses the second highest transition risk in the 2030s.
Low	▪ Wind farm 1 has the lowest total risk in the 2030s.	▪ Wind farm 2 has the lowest total risk in the 2030s.

Figure 3: Risk in 2030s RCP 8.5 (left) and RCP 4.5 (right)



In 2030, the RCP 8.5 scenario shows a slightly higher overall risk than RCP 4.5 primarily because of higher physical risk with MAAL at $190.3m (0.6%) compared to $143.8 (0.5%). On the other hand, the RCP 8.5 scenario shows a slightly lower transition risk than RCP 4.5 with $192.0m (0.6%) compared to $210.2m (0.7%); this difference is due to higher carbon pricing projected in RCP 4.5, despite slightly higher reputation and litigation risk for Desjardins in this decade with RCP 8.5. This trend continues to the 2090s, with physical risks being higher in RCP 8.5 and transition risks higher in RCP 4.5. As shown in the figure below, the incremental risk of carbon pricing in RCP 4.5 surpasses the risk of physical risks in RCP 8.5, resulting in an 8% MAAL compared to a 4.8% in the 2090s.

Figure 4: Risk in 2090s at RCP 8.5 (left) and RCP 4.5 (right)



The results of this demo and the lessons learned are aligned with our current climate change risks analysis perspectives. We are using this experience to learn about the methodologies available and decide how to best conduct this type of quantitative analysis for different sets of assets, faster and at a larger scale than our capabilities allow. The outputs generated by the Climanomics® platform and other similar platforms might inform decision-making for longer term investments and financing in multiple sectors. The results further validate our net-zero strategy and the need to expand our nascent climate change adaptation analysis. We will also showcase internally a comparative view of carbon-intensive assets versus ones with low emissions to continue to build awareness on transition risk. As part of our climate action plan, we have identified carbon intensive sectors for which we are engaging with our clients to support their transition to low carbon scenarios. The outcomes and ease of use of this tool can support discussions with clients in these sectors who have not already quantified their potential transition risk.

Asset-level outlook for a dairy farm and a solar farm in the 2050s

Dairy Farm: Located about 1.5 hours northeast from Montreal at an elevation 110 meters and close to a river, the dairy farm will face a modeled average annual loss (MAAL) of 6.7% to 8.5%, for RCP 4.5 and RCP 8.5, respectively. The highest risks faced are from temperature extremes, followed to a lesser degree by fluvial flooding and drought at both the RCP 4.5 and RCP 8.5 scenarios. The largest difference among the two is temperature extremes representing a 5.7% MAAL in RCP 8.5 and 3.9% MAAL in RCP 4.5. Regarding transition risks, at this point, with the emissions estimated for the farm, there are no significant risks. However, if actual emissions are higher than estimated, or if carbon prices are higher, transition risks may become significant.

Solar Farm: Located between the cities of Toronto and Montreal at an elevation of 140 meters, this solar farm will face a MAAL of 0.6% to 1.8% for RCP 4.5 and RCP 8.5, respectively. Most of the risk faced will be from fluvial flooding in both RCP 4.5 and RCP 8.5 scenarios. Transition risks are very close to zero, primarily because estimated emissions are zero. Overall, and when compared with other assets, the solar farm faces very low risk. To put things into perspective, for the same time period, a natural gas-fired power plant in Canada in our sample asset list will face a MAAL of 32.2% and 64.6% for RCP 8.5 and RCP 4.5, respectively. This very high risk is almost entirely dependent on the high amount of emissions generated by the asset and the projected carbon pricing.

Suggested enhancements for providers

The demo was effective at demonstrating the climate risk analysis capabilities of the Climanomics® platform for several asset types. The tool is easy to understand, and the methodology document and overview provided were very helpful. The data entry function is user-friendly as well as the navigation throughout the platform. For physical risks, the methodology is perceived as robust by our team with a good coverage of hazards. The two RCP scenarios included are good options to test assumptions. Transition risk analysis is more complicated to conduct and utilize as there are multiple variables to consider and scenario data is limited. Out of the five hazards, carbon pricing is the only hazard linked to a shared data scenario (SSP3) with a key limitation being that SSPs are done at the regional level, as explained above in Risk factors and scenarios. Upon discussion with the TCS team, we were informed that carbon pricing can be modified to include more granular projections for which data is available, upon request from the user. It would certainly be an enhancement for this and other platforms to provide carbon pricing projections at the national/sub-national level. The other transition hazards, including litigation, reputational damage, new technology and markets are calculated with a high-level approach that will be refined as data and granular approaches become available. Automating a granular transition risk analysis seems to be a key challenge for this type of tools currently and in the near future.

Overall, Desjardins was satisfied with the Climanomics® platform and the TCS team. Since this is an evolving science, we will continuously explore the methodologies and data used to improve the accuracy of the projections.

Lastly, we have developed a wish list of enhancements that could be good additions to the Climanomics® platform or to other similar climate risk analysis platforms:

- A variable to incorporate remaining asset life (years) per asset or update the projected portfolio every 10–20 years
- A variable to incorporate projected emissions reduction per asset or asset type
- A variable to incorporate planned adaptation measures impacting the vulnerability per asset or asset type
- A benchmarking view on how the risk level is distributed for similar assets modelled (e.g. risk curve, or x% of similar assets in the same region or worldwide more/less exposed). This benchmarking capability is in development by TCS.
- Heatmaps to indicate where some risks (physical and transition) are higher for each asset type. This capability is in development by TCS.
- Guidance and practical examples on how to best incorporate results into existing risk analysis models in the financial sector
- A qualitative description explaining the resulting MAAL per hazard at the asset level. For instance, an automatic text box that could answer the question “why is this particular farm more exposed to flooding and drought than this other farm”?

Participant:

TD Asset Management

Provider:
The Climate Service (TCS)

Risk types covered by tool:
Physical risk

Introduction

TD Asset Management Inc. (TDAM, a wholly-owned subsidiary of The Toronto-Dominion Bank) considers climate change a systemic risk affecting economies, companies, and investors. Our approach to climate change is aligned with our overall philosophy of integrating all sources of risk and return in our investment processes.

As an investment manager of diversified asset classes, we consider climate change as an important area of research to fulfill our fiduciary responsibility on behalf of our clients. We actively engage with companies as well as our partners, and leverage our asset ownership positions to encourage improvements in company disclosures on climate-related risks and opportunities facing their businesses. In addition, we participate in numerous industry collaborations including Climate Action 100+, Carbon Disclosure Project, and the UNEP FI TCFD investor pilots, with the first two furthering our company engagement efforts, and the latter developing a better understanding of climate-related investment risks. Our approach continues to evolve to help position our portfolios to capitalize on investment opportunities arising from an accelerated transition to a low carbon economy and manage undue climate-related physical and transition risks.

About TDAM's Global Real Estate Strategy

TDAM's Global Real Estate Strategy was seeded in 2019. The strategy is invested in over 800 properties in 140+ cities throughout the United States, Europe, and the Asia-Pacific. This provides broad diversification globally by regions, property type, and risk strategy (core, value-add and opportunistic). The strategy focuses on developed metropolitan areas and urban, transit-linked, office, multi-unit residential, retail, and logistics/distribution-oriented industrial assets. The comprehensive diversified exposure of a global non-listed real estate portfolio can add significant diversification benefits to multi-asset class portfolios.

These risks and opportunities are present within all our portfolios, but are especially notable within non-listed real estate investments. Physical buildings play an integral role in climate change since properties not only contribute to, but are impacted by, their environment and their communities. However, the commercial real estate industry is at the beginning of its journey to measure and adapt to the full financial and operational impacts of climate change. Governments and tenants, increasingly concerned about physical property's contributions to climate change, are likely to mandate changes. And these changes are happening concurrently with an increase in the acute and chronic physical risks that threaten buildings. As a result, building owners are likely to be presented with additional costs, risks, and opportunities.

Part and parcel of deeply understanding risks residing in the portfolios we manage, we first seek to understand the tools and methodologies available, and then increase awareness around the strengths and potential gaps in such evaluations. As part of our efforts, members of TDAM's Investment Risk team participated in the UNEP FI Landscape Review module to gain insight into climate-related physical asset risks for a portion of our Global Real Estate Fund. We were paired with The Climate Service (TCS), who provided an estimate of the financial impacts of the physical risks due to climate change for a sample of assets from the fund's non-listed indirect Asia-Pacific Real Estate investments. Risk was estimated as an annual loss, for each decade from the 2020s to the 2090s, across two climate scenarios.

Overall, the results of the analysis were insightful and enabled the naming and quantification of vulnerabilities at the asset, metro, and region level, encouraging further locale-specific research and conversations with our investment teams and fund managers. The trial also highlighted a handful of potential improvements which could enhance the accuracy and applicability of the results.

Process Overview

After being paired with TCS, we met with them to review scope and data requirements, and subsequently populated an excel-based template with internally sourced asset data. After some processing time, we were provided logins to their web-based platform (Climanomics®) and met with TCS to review the results. We performed an exploration of the results within their platform as well as loaded the raw data into an internal database, performing our own portfolio-level analysis. We then reported our findings to internal stakeholders.

Data and Coverage

TCS requested market value, emissions, property type, and location information for each asset participating in the trial. For location, we submitted latitude and longitude, but they would have also accepted a street address, from which a latitude and longitude could be derived. Elevation was also a required input and was calculated automatically by the Climanomics® platform.

We were able to source all data internally, except for emissions data. For emissions data, we sourced it from the GRESB platform, within which some of our managers make information available to us as investors. However, mapping the data from GRESB to internal data was an arduous process. Property types also required translation from internal types to TCS sub-types.

The number of assets we could include in the trial was limited. Because of this, we narrowed our focus to the Asia-Pacific region of our Global Real Estate Fund. Within that region we selected 75 assets from the 200+ available. They spanned the industrial, office, hotel, multi-unit residential, and retail property types. In order to achieve coverage across metros and property types, we selected at least one asset per metro and type. In the event there were multiple that met these criteria, we selected based on value and/or if there was something else of interest, like having high intensity greenhouse gas emissions, being close to sea level, or having a large weight in the region. This selection method enabled us to achieve 100% coverage on 13 out of the 24 Asia-Pacific metros to which our fund is exposed, and over 70% of the value of the Asia-Pacific region of the portfolio.

Risks factors and scenarios

At a high-level, TCS covered global transition risks, physical risks, and opportunities for physical assets such as real estate, energy and power generation infrastructure, transportation, and agriculture. More specifically, the risks and opportunities covered included:

- **Physical risks:** extreme temperature, drought, wildfire, water stress, coastal flooding, fluvial basin flooding, and tropical cyclones
- **Transition risks:** carbon pricing, litigation, reputational damage, new technology, and markets
- **Opportunities:** resource efficiency, energy source, products and services, markets and resilience

We opted to focus exclusively on physical risks since we were participating in a parallel UNEP FI module focused on transition risks.

At the time of the trial, TCS supported two Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathways (RCP) scenarios: RCP 8.5 “High Emissions” and RCP 4.5 “Low Emissions”. The RCP 8.5 scenario assumes that there will be no major global effort to limit greenhouse gas emissions and the RCP 4.5 scenario implies a coordinated action to limit greenhouse gas emissions such that global warming is limited to approximately 2°C. TCS plans to add two additional climate scenarios, RCP 2.6 and RCP 6.0, by the end of September 2021.

Outputs and insights

The principal output of TCS’s platform was *Modeled Average Annual Loss,* represented in two forms: a quantitative dollar amount (in millions, USD) and an annual loss presented as a percent of total asset value. Both measures were estimated for each decade, up-to and including the 2090s, for both the RCP 4.5 and RCP 8.5 scenarios. Values were available via the web-based Climanomics® platform as well as a machine-readable format.

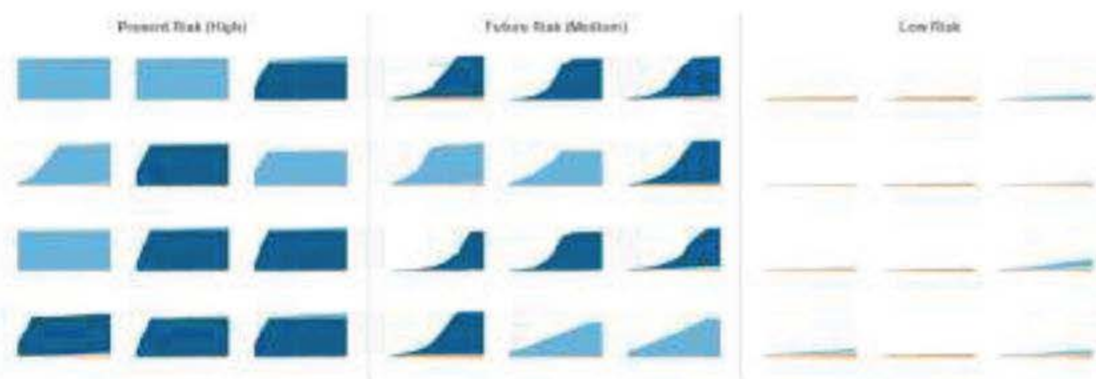
Internal analysis of the results revealed multiple insights. First, at an aggregate level, the primary contributors to physical risk within the assets were coastal and riverine flooding, as can be seen in Figure 2. Combined, these two risks comprised 86% of all physical risks.

Figure 2: All-time cumulative physical risks for all trial assets, RCP 8.5

Source TDAM, TCS

Second, by classifying the assets by their cumulative risks, we observed that there were significant physical risk exposures as early as the current decade. This is readily apparent in the assets' physical risk "fingerprints" seen in Figure 3. In these low-resolution plots, time is along the horizontal axis and percentage risk is represented on the vertical axis. The Present Risk (High) class sees exposures commencing in the current decade whereas in the Future Risk (Medium) class, they commence mid-century. The majority of the assets were classified as Low Risk where the physical risks are low throughout the century.

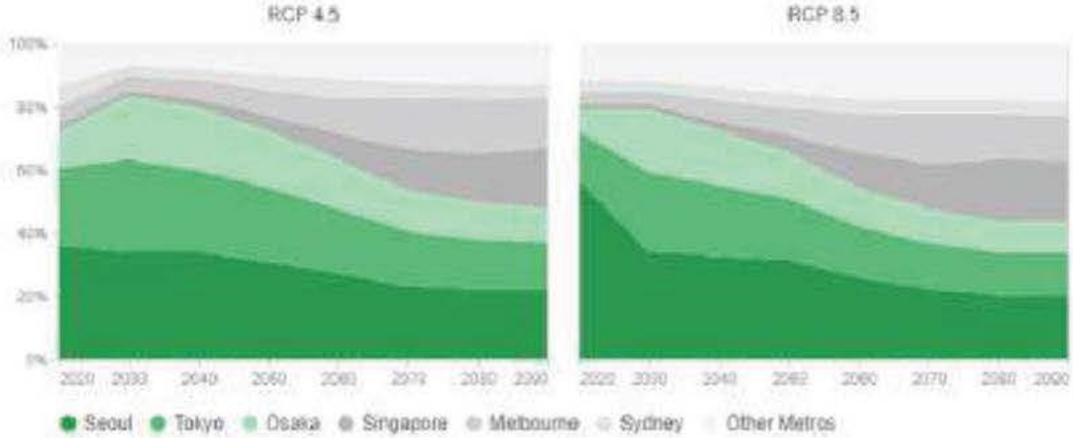
Figure 3: Sample of trial asset physical risk fingerprints, by risk class, RCP 8.5



Source TDAM, TCS

The third insight we gained was with respect to location. By aggregating the individual assets' risks by metro, we were able to see which metropolitan areas were the most vulnerable—specifically, Seoul, Tokyo and Osaka, as shown below in Figure 4.

Figure 4: Metropolitan area contribution to risk in Asia-Pacific



Source TDAM, TCS

Being presented with these three insights led us to ask questions of, and seek additional information about each metro:

- What geographic and topological features were driving the risks in each metro?
- What adaptations measures are currently in place or being planned?
- Are local governments adapting to the expected increases in frequency and intensity of events? If so, how?

Seeking answers to these questions is instructive in the sense that it is these factors that ought to be considered in our investment decisions.

Lastly, we calculated a region-level risk measure. Because the trial was limited to only 75 of 200+ assets in the region, it was necessary to extrapolate values for the portion of the portfolio that was not included in the trial. To accomplish this, we calculated the average risk for each metro and then applied that average to each out-of-trial asset before weighting the assets by their investment exposure. This method was not particularly sophisticated, but it served as a good-enough first order approximation. Having a region-level measure enabled us to contextualize its magnitude by contrasting it against the region's cash dividend yield. This demonstrated that impacts due to climate change have the potential to be material to the fund's long-run income return.

Use cases

Within the investment decision making and management processes, information like that which TCS provided can be useful at two levels.

First, it can be useful at the asset level. Knowing how an asset is physically vulnerable focuses our attention by moving our understanding from the nebulous "physical risks" to the specific, like "riverine flooding". This knowledge underpins productive conversations about asset-specific adaptations and resilience.

Still at the asset level, we see it also being of utility during due diligence when acquiring an asset. Knowing the specific risks makes it possible to at least speculate about the costs of potential adaptation measures and what impact the costs of physical risks might have on a potential asset's long-run investment returns. While the *Modeled Average Annual Loss* cannot be used directly in a discounted cash flow projection since it does not account for municipal/building adaptations or insurance, it provides at least a starting point from which we can perform sensitivity analysis.

Second, information can be useful at a metropolitan level or "locale". Commercial real estate assets are typically located in major metropolitan centers, which means that most assets within that locale are subject to similar physical risks, driven by the geography and topology. For example, both Tokyo and Osaka are coastal, situated on alluvial floodplains, and are thus enduringly vulnerable to coastal and riverine flooding. Knowing this directs our focus on civic planning and governance issues related to local adaptations and resilience measures.

Although we did not explore them, additional uses could include stress testing as well as meeting disclosure obligations.

Tool Approachability

TCS offered both a web-based platform as well as a Microsoft Excel data-download of all risk estimates for each asset, for each decade, and for each scenario. The website was clear, simple to use, and enabled basic analysis and identification of individual asset vulnerabilities. Information could be viewed at a variety of levels of detail, including at the asset or portfolio levels. If tags were provided with the data, they could be further viewed along those user-defined dimensions. In addition, their web-based platform embeds methodology details alongside the measures, which enabled interpretation of the results.

However, the amount of time we spent within the web platform was limited since we have internal analytics capabilities and gravitated towards performing our analysis using them. Importantly, TCS enabled this not only by contractually allowing it, but by providing a methodology document and then arranging to meet with us to review it within the context of their platform. Having this understanding made it possible for us to independently validate how we were using their data by proving we could calculate aggregate values as they appeared in their website.

Throughout the duration of the trial, TCS was notably transparent with respect to their modeling methodology. This transparency enabled us to tune and interpret the results of the modeling with greater understanding and confidence.

Suggested Enhancements

Over the course of the trial, a handful of potential enhancements within the platform emerged. We reviewed and discussed each of these with TCS. They acknowledged the limitations and indicated that improvements were either already in progress, or on their product roadmap:

1. Support for the RCP 2.6 scenario

With the policymakers around the world advancing commitments and changes necessary to meet the objectives of the Paris Agreement, insights from the RCP 2.6 scenario, which is a low physical risk/high transition risk scenario, would complement the other scenarios already supported. TCS plans to incorporate two additional scenarios, RCP 2.6 and RCP 6.0, by the end of September 2021.

2. Tropical cyclone risk in the Northwest Pacific basin

Although tropical cyclone risk was covered in the Atlantic Basin (eastern North and Central American coasts), it was not yet covered in the highly active Northwest Pacific basin (Japan, China, South Korea, Singapore, etc.) where our in-trial assets were located. TCS plans to extend the tropical cyclone model to the Pacific basin by the end of September 2021.

3. Flash flooding risk

TCS had coverage for both riverine and coastal flooding, but not for flash (a.k.a. pluvial or inland) flooding due to extreme precipitation. The assets we submitted for the trial were in the Asia-Pacific region where flash flooding is a substantial risk.

4. 10km threshold for coastal flood risk

At the time of the trial, TCS's coastal flooding model had a 10km cut-off from the coastline where any asset beyond that point was assigned a risk of zero. Some of the assets submitted for the trial were in Tokyo and Osaka. These are coastal metropolitan areas situated on alluvial floodplains, meaning most of the territory is near, at, or below sea-level. These factors combined to create some curious results, such as having two assets at opposite ends of the same street, one with a very high coastal flooding risk, and the other with no coastal flooding risk at all—because it was just beyond the 10km threshold. TCS has an enhanced coastal flood model in development which will remove this limitation and be released later in 2021.

5. Coastal and riverine flooding risk-ceiling

Within TCS's model, both coastal and riverine flooding risks are measured as the probability that a 1-in-100 year flood event occurs within a given year. However, the model stops calculating additional impacts once the annual probability of such an event reaches 100% (certainty). That is, the risk impacts have a ceiling, as can be seen in Figure 5.

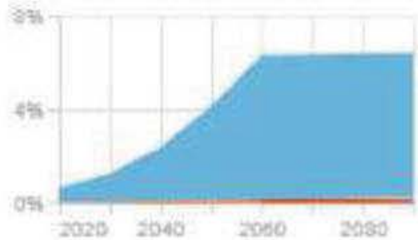


Figure 5: Example of flooding risk ceiling

Source TDAM, TCS

6. Quantification of uncertainty

TCS's primary measure, the *Modeled Average Annual Loss*, is currently only available as a point estimate. They have plans to make the distribution of potential outcomes available to end-users.

7. "Missing data"—when no data value is available

The data exported from the platform was in a standard format except for when a risk was not available for an asset. For example, in the case of tropical cyclones, which were not yet covered in the region of the trial assets, the risk was assigned a value of zero. This resulted in ambiguities where a value of zero could be due to the risk actually being zero, or because the risk was not available. The only way to tell these apart was to review the asset manually within the web-based platform, where a note and explanation could be seen.

Conclusion

Participating in the UNEP FI Landscape Review module was a valuable experience that allowed us to identify assets at highest risk, begin to pinpoint the causes of that risk, and advance a conversation about how to mitigate those risk causes. Our participation in the module has also provided us an opportunity to raise awareness within both TDAM and the commercial real estate industry on the importance of understanding, measuring and mitigating climate risks. We look forward to continuing to build on the progress achieved over the past several months and collaborating with our internal and external partners to advance the conversation on the impacts of climate change.

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Participant:

Folketrygdfondet (FTF)

Provider:
Willis Towers Watson (WTW) and JBA Risk Management

Risk types covered by tool:
Physical risk

Introduction

In this piloting exercise, we focused on various physical climate risks and assessing how these affect a selected portfolio of Fixed Income real estate investments. We chose to analyze a portfolio of real estate companies with a primarily Nordic scope. The analysis was done in two steps; 1. analyzing how various climate hazards evolve from the present-day to future time periods in specific property locations under different temperature scenarios, and 2. Assessing how the key climate hazard identified in step 1, affects property value and business interruption, the latter reflected as loss of rental income and relocation expenses.

The piloting exercise enabled us to look at the evolution over time of climate hazards that can impact real estate. In the two temperature scenarios, we find that extreme precipitation and flooding are two key hazards that emerge and can cause disruption of business activity as well as loss of market value. The findings make clear what the key climate hazards are in the Nordic region, and thus provides guidance on what measures real estate companies should focus on to mitigate the negative effects of these climate hazards.

Process

The piloting exercise consisted of a two-step approach. First, we looked more high-level at various hazards for the real estate investments in our Fixed Income portfolio. The second step entailed a more detailed focus on one real estate company and the impact of the most important hazard expressed in financial terms.

In the first step, we used the Climate Diagnostic tool from Willis Towers Watson (WTW), to pilot a physical climate stress test for the portfolio sample, with diagnostics and ranking of climate hazards. In the second step, we used probabilistic catastrophe/flood models from JBA and analysis provided by WTW.

The Climate Diagnostic tool was applied to the real estate portfolio, and the geographic coverage was primarily the Nordic region, and some additional locations. The exercise included a wide range of cities. The climate variables evaluated were fire, heat stress, heavy precipitation, and river flood for the present-day and the 2050s under two temperature scenarios.

In the second step, to quantify property damage and business interruption in financial terms for the deep dive analysis of one real estate company, JBA's flood models for Scandinavia were used. The objective was to quantify the expected physical climate losses from asset damage and business interruption due to flooding. The models simulated thousands of events to quantify the range of physical damage and business interruption losses which the company's properties could experience, under present-day conditions and future climate scenarios.

Data and coverage

For the piloting exercise, we used publicly reported company data on property locations, market values, occupancy classes, and average rental values. WTW used their own database for the Climate Diagnostic modeling, based on locations for each property. The JBA probabilistic modelling used data based on four elements: exposure, hazard, vulnerability, and financial information.

The Climate Diagnostic tool can cover a wide range of sectors and is global in coverage. For this piloting exercise, the portfolio selection was narrowed down, due to the challenges of data collection and accessibility for our portfolio. Web scraping software was used by WTW to identify property locations for each real estate company, for input into Climate Diagnostic.

For the JBA probabilistic modelling, one company was selected for a deep dive analysis of flooding, which Climate Diagnostic had demonstrated is the key hazard for the locations of the company's investments. The modelling looked at property damage and business interruption due to flooding and quantified the impact in financial terms. Property damage assumes losses related to the reconstruction costs, including costs for material and labor. Tax values were used as a proxy for market value as real estate companies don't report market values per property, but rather they report value on an aggregated level. Since tax values are not an ideal representation for actual market losses, we chose to focus on business interruption as a metric and expression of climate risk. The input for business interruption estimates were calculated by WTW from the total area of each property multiplied by the average rental value (SEK/sq.m) for different regions and occupancy classes. For business interruption, the residential losses are estimated costs for relocation expenses, while for commercial assets the model estimates possible loss of earnings and downtime.

Both tools (Climate Diagnostic and JBA's flood model) can be applied to a range of sectors and geographic locations. The selected real estate portfolio for this exercise totaled 14 companies, constituting approximately 2,9% of the total FTF Fixed Income portfolio.

Risk factors and scenarios

The climate variables included in the first part of the pilot (Climate Diagnostic) were fire, heat stress, heavy precipitation, and river flood. Climate Diagnostic covers a broader range of variables, but not all were relevant for the portfolio selection. JBA's flood model covered scenarios related to flooding. The following climate scenarios for 2050s were assessed:

- 2°C (Representative Concentration Pathway, RCP 4.5)
- 4.5°C (RCP 8.5)

Outputs and insights

In the first step, the Climate Diagnostic tool measured climate hazards for investment locations in the present and future scenarios. The hazards were ranked 0–5 in terms of severity of their impact.

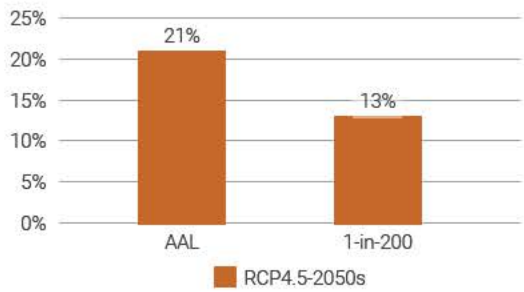
In Norway, the primary hazards from the present-day to the 2050s under the two scenarios, were heavy precipitation (which can lead to surface water flooding) and river flood. We saw increased heavy precipitation in Bergen, Sandvika and Baerum under both scenarios, and the latter two also had increased risk of flood under the RCP 8.5 scenario. There was a modest increase in fire hazard under the RCP 8.5 for areas such as Larvik. The figure below shows the climate hazards in Norway for the 2050s, ranked by importance.

In Sweden, flood is the primary hazard at present, and remains high under future climate scenarios. There is modest increase in heat stress under RCP 8.5 for cities such as Malmo.

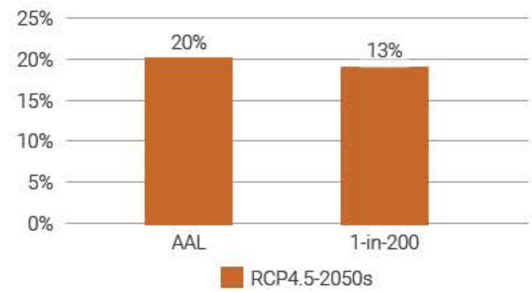
In Finland, the predominant hazard is river flood in Turku. There were no major changes in climate hazard factors by the 2050s, but modest increases in fire hazard and heavy precipitation were identified in selected cities.

In step two, JBA's probabilistic flood modelling was used on one company to analyze in detail and quantify expected physical climate losses in financial terms as asset damage and business interruption. The model provided annual average losses (AAL) and 1-in-200-year return period losses. The figure below shows the percentage change in property damage as market value loss, and business interruption as relocation expenses and earnings loss, in an RCP 4.5 2050s scenario compared to the present day.

Property damage: AAL and 1-in-200RP % increase by 200s, RCP4., compared to current



Business interruption: AAL and 1-in-200RP % increase by 2050s, RCP4.5, compared to current



We found this pilot to be an important tool for understanding climate risk and how these risks play out in different scenarios. The models used have provided us with a starting point for looking more closely at the connection between climate risk and financial risk.

The exercise has also identified a main challenge as it relates to the lack of granularity of reported company data. For the real estate sector in the Nordic region, most reporting on property values is done on an aggregated level. Therefore, we don't have correct values for each property, and so we used tax values as a proxy instead. The output of the models does therefore not reflect actual property value loss in monetary terms but does however more clearly reflect change in loss in percentage terms. In general, we recognize that lack of granular portfolio data remains the main obstacle to properly evaluating the financial impacts of climate change on our portfolio.

The tools presented in this case study, were quite complex, but our understanding of the tools was facilitated by the thorough presentations given by the team at WTW. The modelling was done by WTW and JBA, so our time was spent more on understanding the tools themselves and the output generated for this pilot. A challenge due to time constriction for the pilot is that it did not allow for much time for us to test the tools for ourselves. We are therefore not familiar with the full extent of the tools and its coverage and scope. The portfolio selection was narrowed down to balance the extensive data collection and analysis required against the limited scope and time at our disposal for this pilot. For this reason, we were not able to test the entire portfolio, however, the selected portfolio gave a good representation of the possibilities of the tools tested.

The pilot has connected us with industry experts, and insightful discussions have given us a better understanding of the impact of climate risks on real estate and key climate hazards in the Nordic region. This pilot is a good starting point for gaining a better understanding of climate risks and the negative financial impact it can cause. As such, this pilot has been a valuable learning experience.

Participant:

Manulife Investment Management

Provider:
Willis Towers Watson (WTW)

Risk types covered by tool:
Transition risk

Introduction

Global decarbonization efforts are underway, with a long journey ahead for both investors and issuers. Developing tools that can assist in providing clarity around the impact of decarbonization pathways is critically important, as transition risk has been shown to carry a high likelihood of negatively, or in few cases positively, affecting companies' financial statements.

This is the second UNEP FI pilot project in which Manulife Investment Management has participated. As part of the pilot, we participated in a climate tool demonstration using WillisTowersWatson's (WTW) climate transition analytics tool.

Steps taken by Manulife Investment Management for this case study

- Provided a list of global large-cap stocks across multiple industries; some are held in existing portfolios and some are not
- Analyzed an abbreviated compilation of output
- Held discussions with WTW to review the original output, take a deeper dive into the methodology, run trade simulation impacts, and review revised output

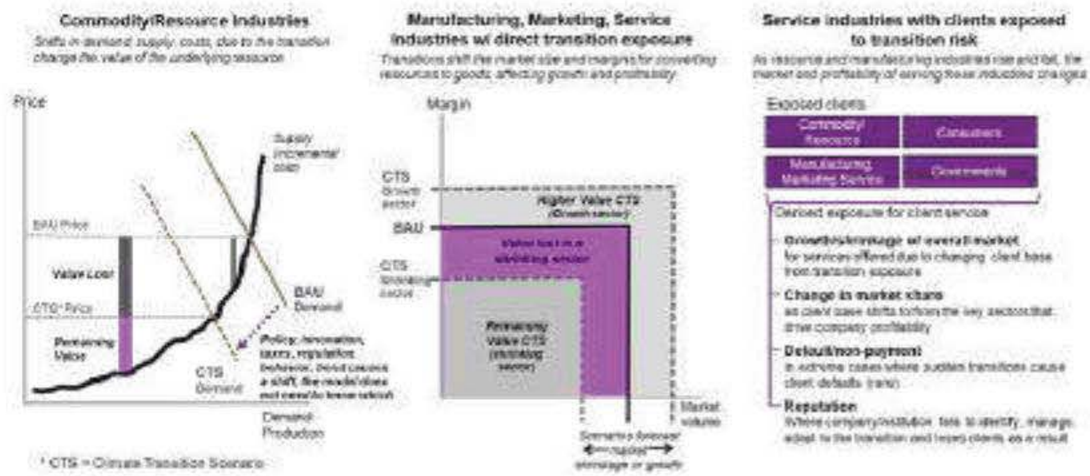
Objective of the tool

WTW's climate transition analytics tool is designed to help portfolio managers understand the explicit and unintended risks of the climate transition in an investment portfolio. It elevates the risk awareness at a company, industry, and sector level, which in turn enables the portfolio manager to create a more climate resilient portfolio through more risk-aware security substitution and/or hedging activities. The tool allows for sensitivity analysis based on the factors of security weight and selection. Consequently, a portfolio manager can model and change the portfolio, and thereby avoid unintentionally betting against the high likelihood of the global decarbonization.

Understanding the methodology

A core functionality of the tool is its methodology to measure the climate transition value-at-risk (climate VaR) of publicly listed companies (6,000 primary listings from 45 countries). Climate VaR represents the difference between the discounted free cash flow (DCF) valuation of the business under "current market expectations" (aka Business as Usual or BAU) and a climate transition scenario (CTS) consistent with a well below 2 degrees outcome (WB2C). The approach taken to estimate a company's climate VaR depends mostly on its industry, as illustrated in Figure 1, which shows how commodity-focused companies are modelled through a fundamental analysis of their underlying commodities and valuation impact to the applicable resource(s). Companies outside the resources space with direct exposure in carbon intensive businesses are modelled by business segment, assessing the potential shrinkage of the market driven by less carbon intensive alternatives.

Figure 1



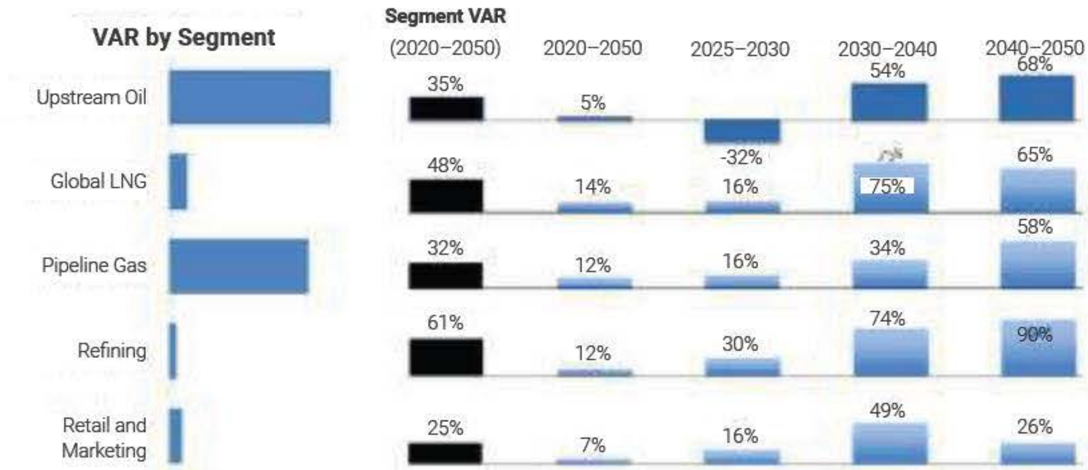
Source: WillisTowersWatson, 2021.

The resulting dataset of (debt and equity) climate VaRs is exploited by the tool in multiple ways, notably to:

1. Construct and periodically rebalance proprietary climate transition indices (CTIs)
2. Create and manage hedging investment solutions (e.g., partial clones of CTIs)
3. Improve a portfolio's resilience to climate transition risks

As previously mentioned, total decarbonization of emissions is the long-term goal, but it's important to appreciate the market and financial impacts will not be linear. The severity, as well as the growth opportunities, will become greater over time by orders of magnitude. Figure 2 below provides the climate VaR for the energy sector across industries as well as the segmentation of the impact by time periods. The quantification of climate VaR can be particularly helpful to investors as they try to assess current valuation within specific time horizons.

Figure 2:



Source: WillisTowersWatson, 2021. Not derived from Manulife Investment Management test portfolio.

Data, coverage, and output

The tool covers over 6,000 primary listings: 2,400 in North America, 1,200 in Europe, 600 in Japan, and the remaining geographically spread out across multiple countries, including Australia and emerging markets.

At the individual security level, the output from the tool consists of 4 sections:

1. A **climate transition risk** tab, which reports:
   - Debt and equity climate VaR for a given transition scenario
   - Underlying CTCs (whenever applicable)
   - Market index vs. climate transition index weights
2. A **signals** tab, which covers:
   - Fundamental attractiveness (fitness, value, momentum) and controversy levels
   - Global macro profile and sensitivities
   - Miscellaneous information (business description, brokers' view, peer group, etc.)
3. A **signal timeline** tab, which provides a visual representation of the above over time
4. Another side tab, which offers a perspective from the point of view of the investor taking the other side of one's trade (e.g., bull/bear arguments, top institutional buyers/sellers).

Portfolio-level output

At a portfolio level, the tool offers insight into historical performance and return attribution on the one hand, and prospective risk/return on the other, with two notable features:

- **"Mitigate" function**: The tool singles out the largest detractors from the portfolio's climate VaR, suggests investment candidates to rotate into, and simulates the impact of the resulting turnover on the portfolio's fundamental and climate characteristics

- **"Tracking error impact"**: which helps visualize turnover-tracking error trade-offs and run portfolio optimizations that minimize downside tracking error relative to a CTI under set constraints (mandate, turnover, minimum trade, etc.).

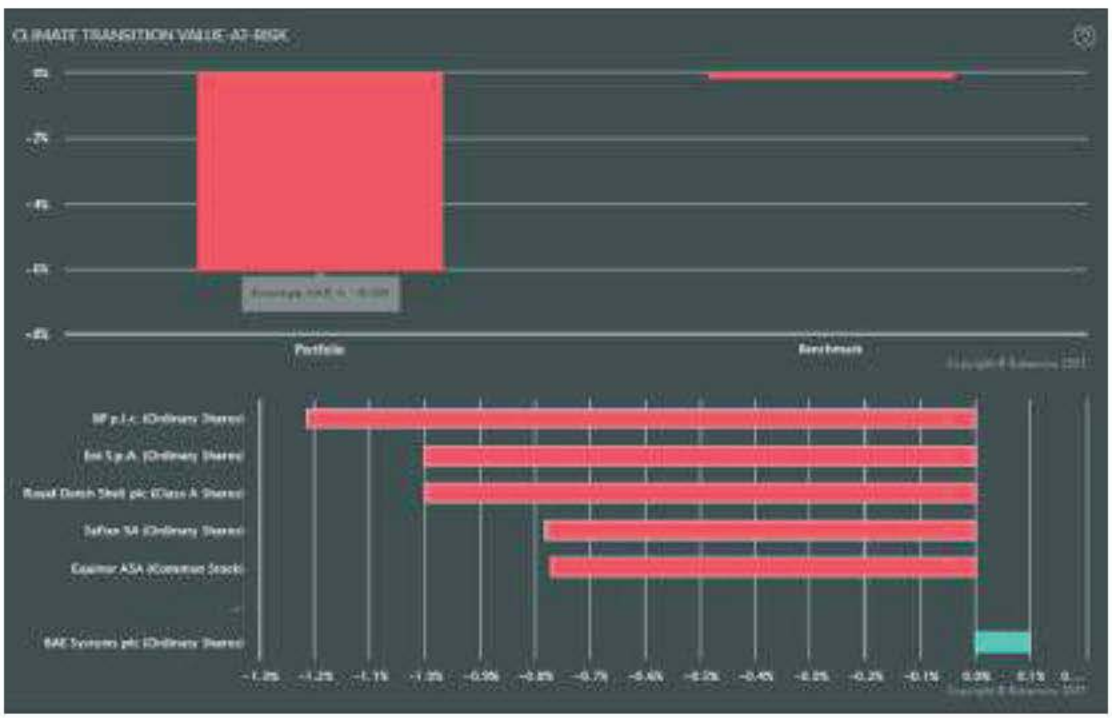
Market-level output

At a market level, the tool provides proprietary signals aimed at complementing the bottom-up, forward-looking security/portfolio analytics described above. This consists of a top-down "nowcast" of expectations priced in by financial markets, which informs asset allocation and factor exposure decisions.

Portfolio management viewpoints[15]

For the model portfolio we provided, the WTW climate transition analytics tool calculated the average transition climate VaR to be higher than that of the (Europe CTI) benchmark, with an average of -6% for the portfolio (Figure 3). In the bottom chart, BP PLC and Eni S.p.a. contribute the greatest climate exposure. In addition, of the top five contributors, four of them are in the energy industry.

Figure 3



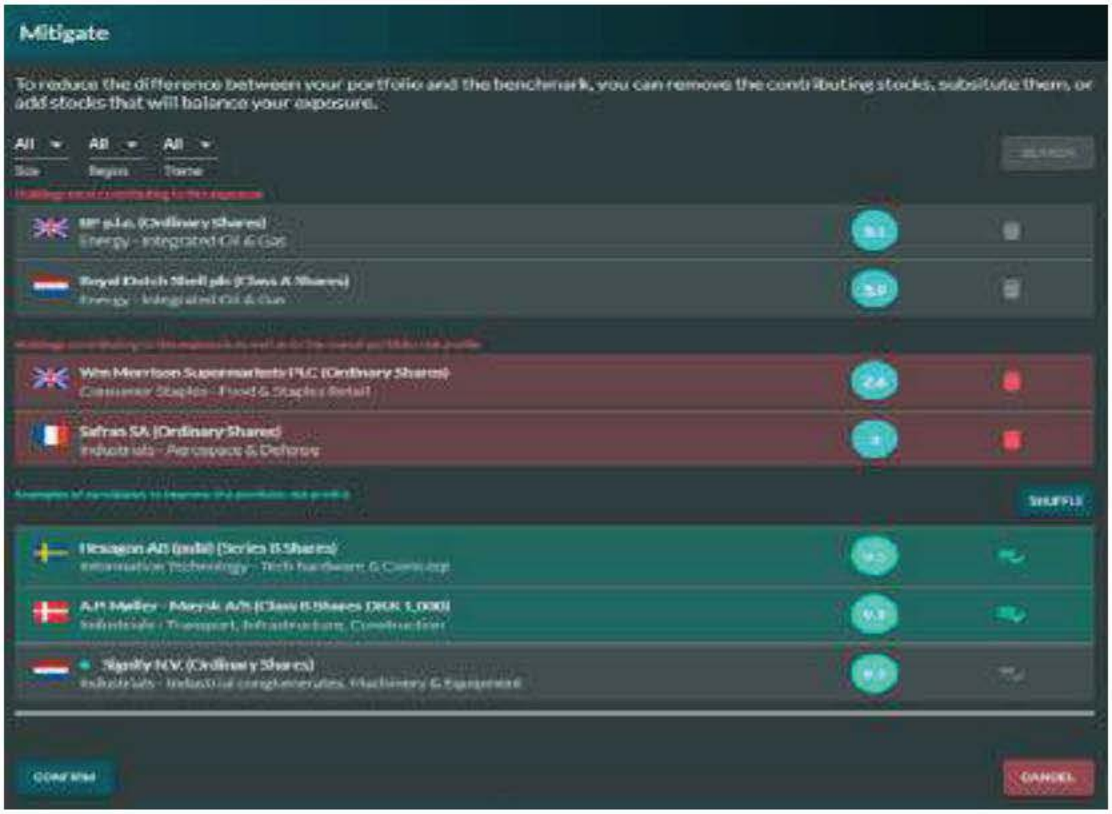
Source: WillisTowersWatson, 2021.

To mitigate the difference between the benchmark and the portfolio, these energy companies could be replaced to reduce climate VaR—for example, by divesting from BP and Royal Dutch Shell (Figure 4).

15 Analysis provided for illustrative purposes only to demonstrate a potential approach to understand the explicit and unintended risks of the climate transition in an investment portfolio. It is not a recommendation to buy or sell any security.

The transition tool also identifies other actions a portfolio manager could employ that would reduce climate VaR as well as tracking error (Figures 4 and 5). In this example, selling WM Morrison and Safran will reduce climate VaR and reduce the tracking error of the portfolio simultaneously.

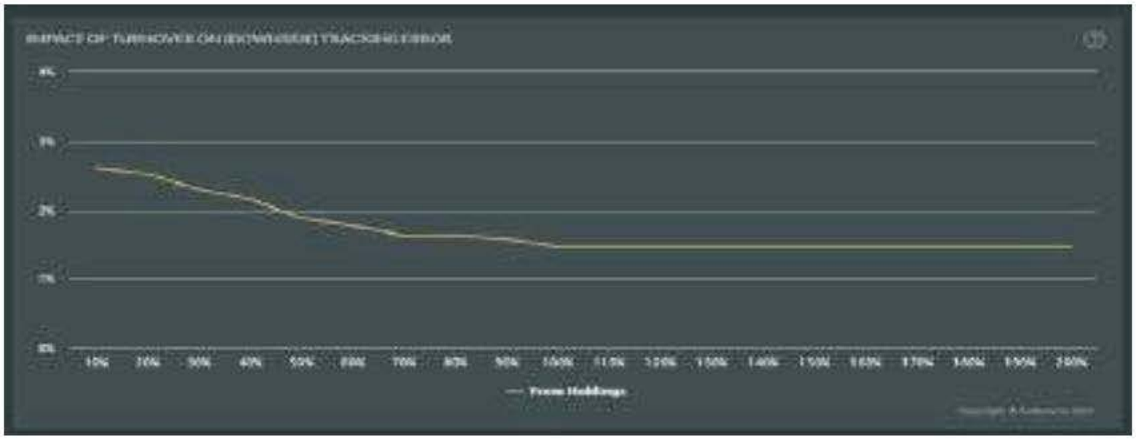
Figure 4



Source: WillisTowersWatson, 2021.

The tool enables easy optimizations to achieve certain objectives. In this example, by rotating 25% of the portfolio, which equates to 50% turnover, the tracking error declines from 2.6% to 1.9% (Figure 5).

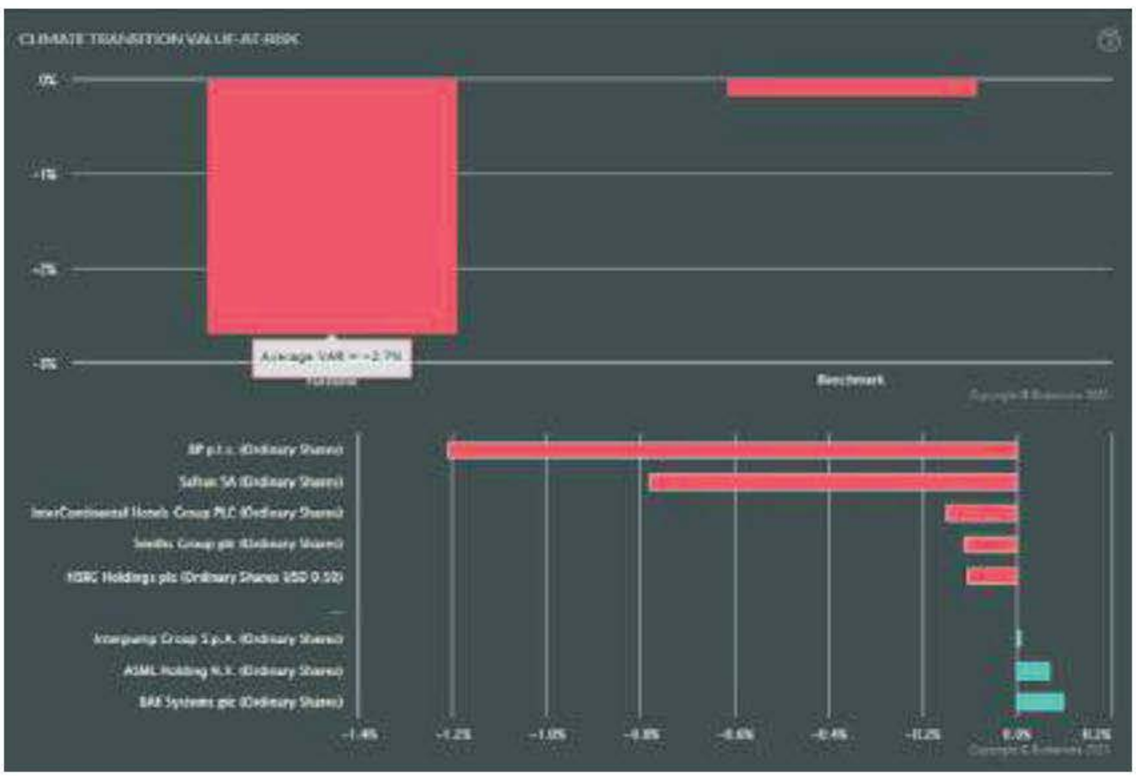
Figure 5



Source: WillisTowersWatson, 2021.

In addition, with this optimization, the portfolio's climate VaR is reduced from -6% to -2.7% (Figure 6).

Figure 6



Source: WillisTowersWatson, 2021.

Potential enhancements for the climate transition analytics tool

There are several enhancements to consider for the tool. In particular, we think it could be helpful to expand the tool's integration of proprietary climate research insights:

Expanding stock coverage

- Consideration should be given to increase the number of individual stocks modelled bottom-up by sector analysts relative to the number of stocks whose climate VaRs are estimated by the tool's machine learning application. As of September 2021, 75% of the World CTI weights were set using climate VaRs ascertained by sector analysts, which means 25% were estimated by the tool utilizing machine learning. From Manulife Investment Management's perspective, we don't have high confidence in estimated climate VaRs; however, we have no quantitative evidence to support any particular shortcomings associated with the tool's estimates.

Integrating physical climate risk data

- By integrating WTW physical climate risk models with the model of climate transition risk, the tool could offer a comprehensive climate risk picture that could also account for climate transition scenario assumptions. Note that Manulife Investment Management did not review the physical climate risk models and so cannot speak to their efficacy or quality.

Participant:

GLS Bank

Provider:
right. based on science

Risk types covered by tool:
Transition risk

Introduction

As a social-ecological bank, GLS Bank is firmly committed to the goal of limiting global warming to 1.5°C above pre-industrial levels. Providing full and detailed impact transparency ("*Wirkungstransparenz*") is a core promise we make to our customers.

We therefore partnered with right. based on science GmbH (right.) to calculate the climate impact of our "*GLS Bank Aktienfonds*" (DE000A1W2CK8), a mixed fund of mainly equities and bonds from particularly climate-friendly companies. right. developed the X-Degree Compatibility (XDC) Model, which is recognized by the Task Force on Climate-Related Financial Disclosures (TCFD). The XDC Model calculates the impact a company, a portfolio or any other economic entity has on global warming and expresses it in a degree Celsius (°C) value (Temperature Alignment). It answers the question: "What degree of global warming would occur by 2050 if everyone behaved as the company/entity in question?"

Our aim with this analysis was to assess whether our *GLS Bank Aktienfonds* already meets the 1.5°C target, identify where action is still needed and potentially use the information as a basis for active engagement. The results were insightful. However, the close collaboration on this analysis also revealed the need for additional emission data, for a methodology to measure the emissions of a green bond, easier integration of emission reduction goals, as well as the "fair" consideration of scope 2 and 3 emission data.

Process

We analysed the Temperature Alignment/climate impact of "*GLS Bank Aktienfonds*" by using right.'s "*XDC Portfolio Explorer*", a web-based software built on the XDC Model. It can be accessed by registering directly on the website. Once the user is logged in, a portfolio must be uploaded for analysis.

1. We created and uploaded a csv-file containing the ISIN codes and portfolio weights of all securities in the "*GLS Bank Aktienfonds*".

2. The software then calculated XDC metrics for the fund itself as well as each security, providing
   - Temperature Alignment values (XDCs) for the fund as well as each security,
   - an indication of alignment/misalignment to a 1.5°C, 1.75°C as well as a 2.0°C scenario,
   - sector benchmarks (Sector XDCs) for each company in the fund as well as the fund itself.
3. We downloaded the results, again as a csv-file.
4. We analysed the results and had a deeper look especially at those companies not yet aligned with the Paris Agreement in order to see whether (1) there are other reasons (e.g. on the social side) to keep them within the fund, (2) they have a climate strategy and thus in a scenario-based approach would be aligned or (3) could/should be replaced.

Main challenges encountered

At GLS Bank we have our own sector classification. However, the XDC Model and XDC Portfolio Explorer make use of the classification according to NACE (Statistical Classification of Economic Activities in the European Community). This created a need to co-develop a customized sector classification to meet our requirements.

Another main challenge was the question of dealing with Scope 3 emissions and the risks of double counting. As a default, the tool counts Scope 1 at 100%, and Scopes 2 and 3 at 50% each to compensate for double-counting. Since Scope 3 emissions usually make up the largest share of a company's carbon footprint, excluding these emissions from the analysis would mean a blind spot, neglecting all upstream and downstream activities as well as the significance of integrating the full value chain in the transition. Including Scope 3 emissions brings concerns of double-counting, since these emissions are not solely attributable to one company. We decided to follow the XDC Portfolio Explorer default here and include Scope 3 at 50%.

Data and coverage

We used the XDC Portfolio Explorer to analyse the contribution to global warming of the "*GLS Bank Aktienfonds*" (i) at security level (102 companies) as well as (ii) at portfolio level. The data required from our side were: unique identifiers (ISINs) and portfolio weights for all securities, provided in a csv-file.

The analysis draws on additional data to calculate the XDC metrics. These are all sourced by right. and integrated in the XDC Portfolio Explorer software:

Company level data

- Current economic productivity, as measured by gross value added (GVA). Source: FactSet Research Systems.
- Current greenhouse gas emissions for scopes 1, 2, and 3. Source: Urgentem.

Global economy data

- Current economic productivity as measured by GVA. Source: World Bank.

Growth rates ("Middle of the Road/Current Trends Continue" scenario)

- Annual growth rate of the entity's emissions and GVA. Source: Shared Socioeconomic Pathways (SSPs) or E3ME (by Cambridge Econometrics).

The tool covers all geographies and sectors. Wherever XDC values could not be calculated, this was indicated in the software. 97.4% of securities in our portfolio were covered (102 out of 105). The remaining three securities were excluded from the analysis.

To project the future developments from the base year until 2050, the XDC Model works with assumptions derived from socio-economic and climate mitigation scenarios, as well as macro-economic data. Geographically, the XDC Model and XDC Portfolio Explorer include both (i) country-specific assumptions forapproximately 185 countries as well as (ii) five world regions: OECD, Asia, Middle East & Africa, Latin America, and Reforming Economies.

The sector is defined by a NACE code; normally either a 1- or 2-digit NACE code, except in special circumstances where a higher granularity may also be used. All International Energy Agency (IEA) sectors are considered to derive sector-specific target pathways from the IEA mitigation scenarios. The IEA sectors are then converted to the more detailed NACE sector classification system.

Risk factors and scenarios

The temperature alignment analysis used here mainly focuses on the "inside-out" risk perspective of double materiality. This concept was stated by the EU Commission in June 2019 in a supplement to its Guidelines on Non-Financial Reporting (NFRD): Complementary to the "outside-in" perspective, the "inside-out" perspective describes the influence of a company on the climate, which can be financially material and therefore also has to be reported.

By this, we also followed TCFD recommendation 1 on "Portfolio Alignment"[16]

> **We recommend all financial institutions measure and disclose the alignment of their portfolios with the goals of the Paris Agreement using forward-looking metrics. Hence, the key risk factor explored was the alignment of our "*GLS Bank Aktienfonds*" with the Paris Agreement.**

16 Consultation just ended. https://assets.bbhub.io/company/sites/60/2021/05/2021-TCFD-Portfolio_Alignment_Technical_Supplement.pdf

The **target scenarios** used in XDC Portfolio Explorer are based on International Energy Agency (IEA) mitigation scenarios "2°C Scenario" (2DS), "Beyond 2°C Scenario" (B2DS) (corresponding to max. 1.75°C global warming), and "Net Zero by 2050" (NZE2050) (corresponding to max. 1.5°C global warming). The focus of the analysis conducted here was the 1.5°C benchmark. Further target benchmarks based on mitigation scenarios from the Network for Greening the Financial System (NGFS) and the One Earth Climate Model (OECM) are also available, but were not employed by us.

The **baseline scenario** used to project future development until 2050 is derived from Shared Socio-Economic Pathway 2 (SSP2), also known as the "Middle of the Road" or "Current Trends Continue" scenario. Soon, all SSPs will be available with the XDC Portfolio Explorer.

Outputs and insights

For the fund as well as each security, a range of metrics were calculated by the tool and provided for download:

Table 1: XDC metrics and results

Output	Unit	Description
Baseline XDC	°C	The expected degree of global warming if the entire world were to operate at the same Economic Emission Intensity (EEI)* as the company/fund until 2050.
Target XDC	°C	The sector-specific temperature benchmark for the company to be aligned to the selected target scenario (in our case 1.5°C based on IEA NZE2050).
Sector XDC	°C	The expected degree of global warming if the entire world were to operate at the same Economic Emission Intensity (EEI) as the 'typical' company within a specific sector (sector median) until 2050.
XDC Gap	±°C	The difference between Baseline XDC and Target XDC—it shows by how much the portfolio or the single security is aligned/misaligned with the selected scenario.
Alignment assessment	Aligned/Not aligned	Summary of the analysis.
*EEI is defined as emissions over gross value added (CO_2e/PPP$)		

Further results provided were Baseline XDC and Target XDC values per emission scope for each security (see Fig. 1) as well as a dashboard overview of the portfolio's sector breakdown and the Top/Bottom Five securities in the portfolio by XDC Gap (see Fig. 2).

Figure 1: Analytics Tab of XDC Portfolio Explorer with results for GLS Bank Aktienfonds (redacted)

Figure 2: Overview Tab of XDC Portfolio Explorer with results for GLS Bank Aktienfonds (redacted)

The information retrieved from this analysis provides information is a strong basis for engagement with those portfolio companies that are not yet aligned to the 1.5°C target. As companies are the ultimate entities that cause emissions, this is where solutions to significantly reduce emissions must be found and implemented. The XDC Model is already used by companies and the methodology was first developed for application in the real economy. This allows us, as a financial institution, to 'speak the same language' tocompanies and track progress in the transition with one shared approach—at the same time, this is the language that climate science and global policy have already set out:°C.

While this example analysis was conducted as a snapshot view of the Temperature Alignment/Paris Alignment of the fund, we see great potential for integrating the use of XDC Portfolio Explorer in the earlier stages of the investment process, informing decisions about e.g. portfolio allocation and optimization. The software allows fund managers to test in advance how rebalancings would affect overall Portfolio Alignment. This enables active steering towards the 1.5°C goal we have determined for the fund. The forward-looking nature of the analysis (developments until 2050) is also a key factor here.

We at GLS Bank are quite familiar with "impact transparency" (*Wirkungstransparenz*) and the challenges it poses. In this case, a key learning—although it almost goes without saying—is that the simplification of portfolio alignment metrics such as the XDC cannot capture the full complexity of climate change and earth system processes. However, science-based alignment metrics expressed in°C—such as the XDC Model—have a great potential to close the gap between abstract climate change and financial actor's perception of how they can contribute to reaching the goal of the Paris Agreement. We have already extended the XDC analysis to include our own investment portfolio (treasury) and other investment funds, our credit portfolio, customer portfolios and our own operations.

As the XDC Model allows for conducting forward-looking scenario analysis by adapting the input data for the calculation along chosen assumptions at security level (e.g. high-growth projections, net-zero targets, transition to green energy etc.), we aim to analyse the climate strategies of our portfolio companies. This will allow us to determine the transition companies in our portfolio and to actively engage with them on setting emission reduction targets that are ambitious enough to align with 1.5°C.

Suggested enhancements for providers

Once familiarized with the various XDC metrics (see Table 1), the tool is very intuitive to use. The data requirements are minimal and since the software is web-based, no installation or setup is needed.

The XDC Portfolio Explorer should support steering towards below 2°C through engagement or divestment by suggesting alternative securities to portfolio managers that would be suitable to replace a security which has a detrimental impact on portfolio alignment.

While the XDC Model can cover various asset classes and multi-asset portfolios, including (i) public listed equity, (ii) private equity, (iii) private debt, (iv) corporate bonds, (v) sovereign bonds and (vi) Real Estate, not all asset classes are available yet in the software. This would allow for more comprehensive analyses.

We would also like to see an uncertainty quantification of the XDC Model. Currently this is being worked on by right. but is not yet finalized.

Participant:

Standard Chartered Bank

Provider:
Baringa and BlackRock

Risk types covered by tool:
Transition risk

Introduction

In 2021, a number of regulatory stress tests were planned (e.g. Hong Kong Monetary Authority and Bank of England) to focus on climate change and the associated risks to financial institutions. In order to support its climate risk capability for scenario analysis, Standard Chartered Bank (Standard Chartered) worked with Baringa, using a Climate Change Scenario Model.

In June 2021, BlackRock and Baringa announced a long-term partnership focused on innovation and ongoing co-development of transition risk models. BlackRock acquired Baringa's Climate Change Scenario Model and integrated it within Aladdin Climate. This Climate Change Scenario Model is used by financial institutions and corporates with more than $38 trillion of assets around the world to help them (i) understand the climate risk exposure and the value that may be lost from balance sheet or investment assets; (ii) how deployed capital and investments are impacting the climate with comparisons against benchmarks; and (iii) identify opportunities to re-allocate capital to improve impact on climate and make commercial returns. The Climate Change Scenario Model is designed to provide full integration of both physical and transition risk modelling across a range of assets. It is modularised to enable clients to select those components relevant to them and to enable straight-forward integration of third-party scenarios and physical risk analysis.

This case study focuses on the Standard Chartered pilot in early 2021 of 100 corporate clients to run though the Climate Change Scenario Model to determine Probability of Default and Temperature Alignment. Under the 2-degree orderly scenario, it showed that energy clients were the most susceptible to transition risk with Weighted Average Probability of Defaults rising to over 8% by 2050, compared to <1% as at 2019. Using the same clients, analysis produced an average temperature alignment of 3.14°C, which indicates that Standard Chartered's portfolio is broadly in line with global trends. Since the pilot, Standard Chartered has extended the Climate Change Scenario Model coverage across its corporate and sovereign portfolios, augmented its scenario analysis and has used the insight in their 2021 TCFD Report.

Collaboration process

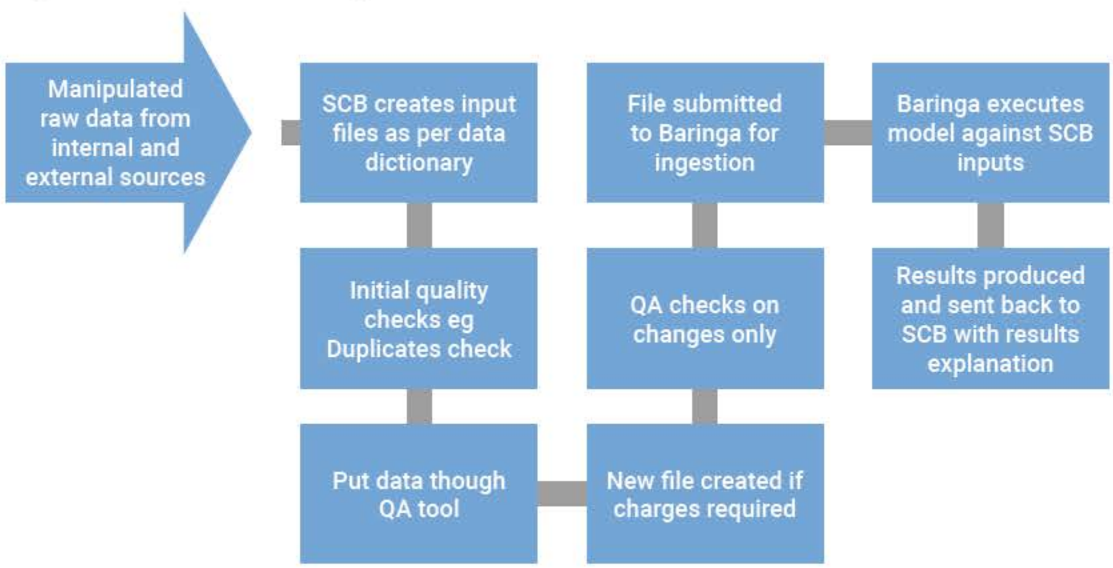
It is possible to choose several integration options with the Climate Change Scenario Model. For a swift implementation, Standard Chartered utilised the Climate Analytics Service (CAS) which provides Data-as-a-Service output capabilities. This is where Standard Chartered pass the requisite input files containing company emissions, financials and production data, as defined by the Climate Change Scenario Model input data dictionary, to Baringa for ingestion into the model. Once Baringa has executed a modelling run and quality assurance (QA) has been performed, the results are shared back to Standard Chartered via output files, as defined by the Climate Change Scenario Model output data dictionary.

The Climate Change Scenario Model is now integrated within BlackRock's Aladdin Climate, where it is available both as an integrated Software-as-a-Service offering and Climate Analytics Service (CAS) offering for banks, asset managers, asset owners and corporates to support a range of investment and climate disclosure needs.

The data dictionaries and QA act as preventive and detective control layers in the run process. Furthermore, to help ensure the integrity of the model, rigorous internal and external validation has taken place.

The external validation was performed by Kroll, and Professor Steve Pye of the UCL Energy Institute.

Figure 1: Flowchart showing Model execution

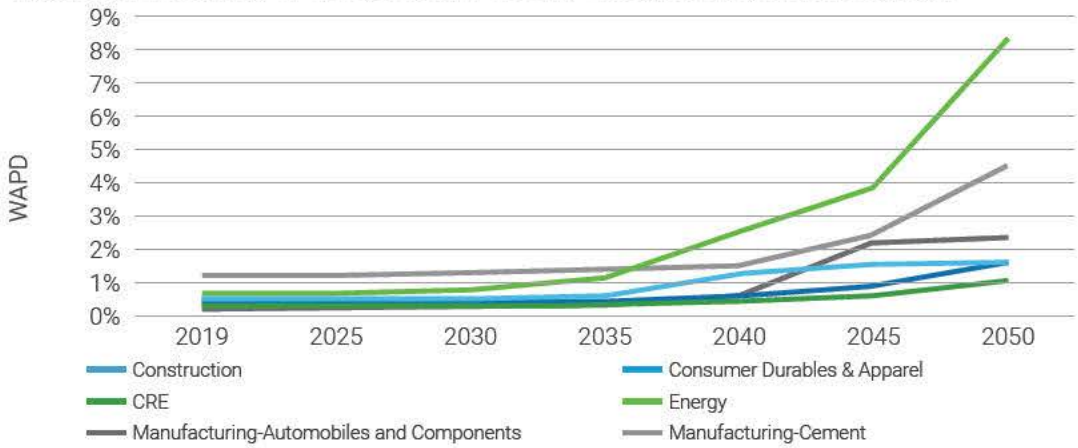


Outputs and insights

One of the key outputs Standard Chartered used was the evolution of Probability of Default. Here, the model assesses the changes in company financials, and consequent changes in credit ratings and probability of default under orderly and disorderly transition scenarios. From the preliminary scenario analysis work, aggregated results on

100 corporate clients, the below chart shows how Probability of Default changes over the 30-year time horizon across the different client sectors. The pathway of Probability of Default is driven by changes to underlying company earnings and debt which is modelled within Climate Change Scenario Model based on the 2 Degrees scenario (explored further under Risk Factors and Scenarios section). This Probability of Default quantifies the transition risk for each individual client and at a portfolio level for Standard Chartered. The results from the below chart highlight the largest transition risk sectors; Energy and Manufacturing.

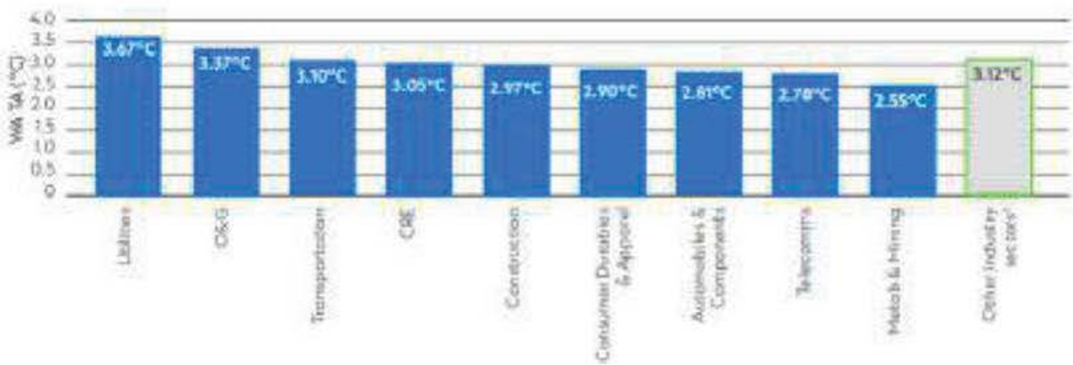
Figure 2: Probability of Default under orderly 2 degrees transition scenario



This chart is sourced from Standard Chartered's [2020 TCFD report]

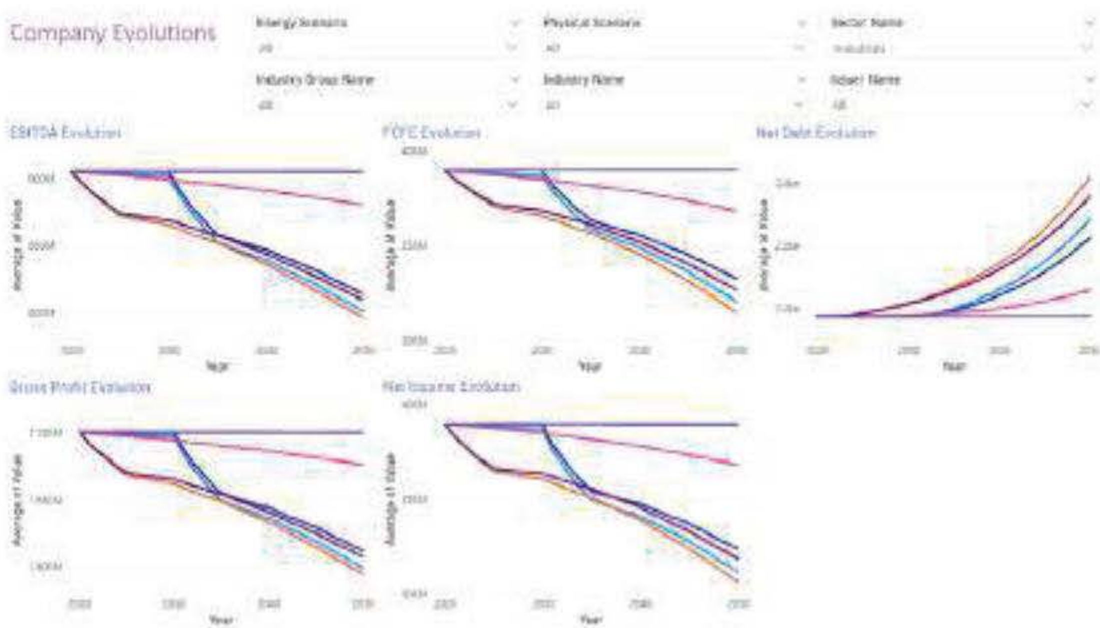
Another key output from the Climate Change Scenario Model is Temperature Alignment. Temperature alignment is a way of quantitatively assessing a company's impact on the climate and is calculated based on emissions intensities, and volume of hydrocarbon produced. In 2021, Standard Chartered applied the Climate Change Scenario Model to around 2000 of its clients within the corporate portfolio. Standard Chartered's portfolio Temperature Alignment is 3.10C, with Utilities and Oil & Gas sectors scoring the highest (furthest from Paris Agreement alignment). This allows Standard Chartered to assess how their portfolio compares with global and regional economies to track its progress on supporting a net-zero pathway.

Figure 3: Temperature alignment



This chart is sourced from Standard Chartered's 2021 TCFD report: https://av.sc.com/corp-en/content/docs/tcfd-climate-change-disclosure.pdf

Figure 4: Company evolutions across 3 scenario 2020–2050



Data and coverage

For the initial pilot, Standard Chartered wanted to conduct scenario analysis against 100 corporate lending clients assessing transition risk, it was later extended to around 2000 clients. The data which Standard Chartered provided covered individual company financials and emissions.

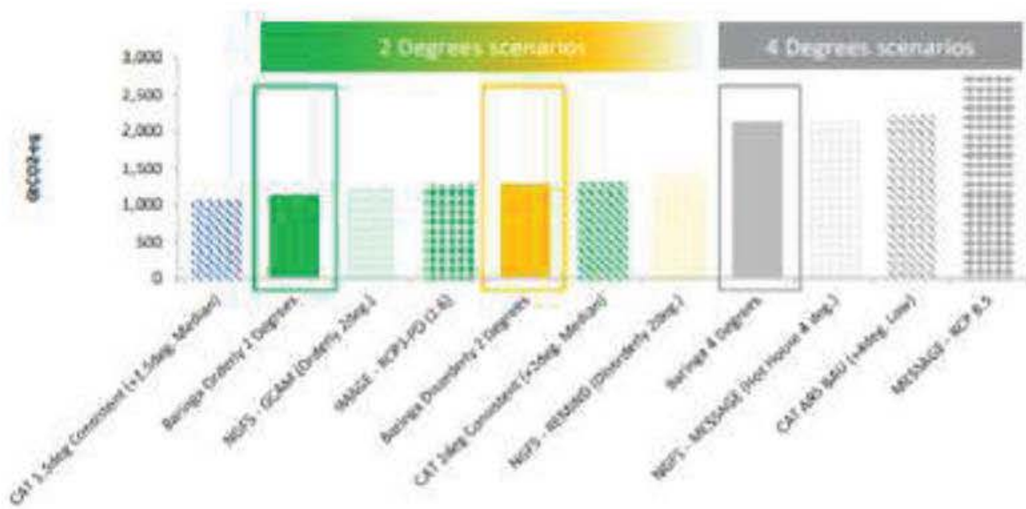
To get the richest results, Standard Chartered provided additional data points for Oil & Gas and Electric Utilities companies which detailed their production figures. Outputs include remodelled company financials, equity valuations, Probability of Default evolution and temperature alignment per company. In addition to these services, the Climate Change Scenario Model also covers other asset classes such as corporate bonds, sovereign bonds, property and vehicles. The Climate Change Scenario Model can ingest physical risk outputs from other providers to create a combined view of transition and physical risk.

Risk factors and scenarios

To assess the transition risk of their corporate clients, Standard Chartered utilised three scenarios: Baringa Orderly 2 Degrees, Baringa Disorderly 2 Degrees and Baringa 4 Degrees. As Standard Chartered commented in their TCFD 2020 report, these scenarios use assumptions focused on government policies, availability and deployment of technologies to limit emissions to a certain target. Outputs from scenario analysis indicate how variables such as energy demand and supply, economic activity, macroeconomic and other socio-economic factors will evolve, based on the specified set of underlying scenario assumptions. Furthermore, specific sets of assumptions for transition risk scenarios usually surround technological advancement, timing and ambition levels of policy actions and societal preference.

To assess the temperature alignment of the Standard Chartered portfolio, the Climate Change Scenario Model uses historical emissions or production data to evaluate how a company's emissions intensity will evolve into the future. The model maps future emissions intensity and hydrocarbon production against sub-industry/region benchmarks to compute company Temperature Alignment.

Figure 5: Benchmarking of Standard Chartered—Baringa scenarios to external scenarios



Use cases

Standard Chartered utilised the Climate Change Scenario Model outputs initially to feed into TCFD 2020 disclosures where aggregated Probability of Default and Temperature Alignment were shown for the selected 100 corporate clients. Standard Chartered has since applied the Climate Change Scenario Model to almost 2000 of its corporate clients.

Beyond this, the Climate Change Scenario Model, now integrated within Aladdin Climate, has many business use cases, including:

- Probability of Default and Temperature Alignment
- Equity and debt valuation changes
- Contribution into external reporting such as TCFD and other climate/sustainability disclosures
- Multi-jurisdictional regulatory stress tests e.g. Bank of England, Hong Kong Monetary Authority
- Internal stress testing, credit and market risk assessments
- Sensitivity analysis and supports net-zero business planning.

Standard Chartered uses the Probability of Default output from the Climate Change Scenario Model in its climate stress testing and as a risk identification metric and proxy for gross transition risk. Client level climate risk assessments are being integrated into Standard Chartered credit underwriting processes. At Standard Chartered, the Temperature Alignment score helps provide a quantitative measure when evaluating potential climate related reputational risks and is used in client and transaction reviews for selected clients operating in some high carbon sectors. For more information on how Standard Chartered uses the Climate Change Scenario Model in its risk identification processes, refer to the Standard Chartered 2021 TCFD report.[17]

Suggested enhancements for providers

As with all models, development is ongoing and we continue to explore ways in which to enhance and expand our functionality and coverage. These can be broadly characterized into three main areas of focus within the development roadmap to enhance the:

- breadth of sectors covered by specific models
- climate specific functionality within the model, including enhancing competitive dynamics and the impact of company transition plans and costs of abatement
- operation of balance sheet, cash flow, debt and capital funding dynamics across the long term modelling horizon

Authors
Ian Clarke, Expert in Banking, Baringa

17 av.sc.com/corp-en/content/docs/tcfd-climate-change-disclosure.pdf

Participant:

European Bank

Provider:
PricewaterhouseCoopers (PwC)

Risk types covered by tool:
Physical and Transition Risk

Introduction

As part of the UNEP-FI TCFD pilot programme, we as a bank performed a climate risk analysis of our loan portfolio with the help of PwC. The Climate Excellence Tool of PwC allows us to perform a climate risk screening, enabling us to identify physical and transition risks on a sectoral, portfolio and individual asset level. These screenings can subsequently be used to calculate financial impact on asset level as well as aggregated on portfolio level. Within Climate Excellence, we can review the overall risk to the selected portfolio across time and sector exposure as well as explore company-specific vulnerabilities and resilience in a given scenario. The entire corporate client loan portfolio was analyzed. The analyses returned that the portfolio faces elevated physical risk from droughts and coastal and fluvial flooding across regions. Transition risk in the analysis depended on the hypothetical adaption activities of companies (inaction, mainstream, achiever). Under the inaction scenario, agriculture, mining, manufacturing, electricity, and real estate all faced significant transition risks. Based on these results, further sectoral deep dives were proposed from PwC to analyse the asset-specific impact within sectors.

Process

1. In an onboarding session, the dashboard is introduced, including the different possible views for the relevant stakeholders to learn about the tool functions and features (such as the scenario and time filters, the different views on adaptive capacity pathways of companies etc.)
2. In a next step, we choose the preferred scenarios (both for transition and physical risks) and the scope for the analysis (time horizon, depth of analysis, define the portfolio for analysis)
3. After the log-in to the Climate Excellence Tool, we can see a template for preparing the portfolio in the according structure for the upload
4. After uploading the portfolio, the results can be analyzed on different levels within the tool. The tool is structured top-down for different use cases. At first, there is a portfolio overview showing the different sectors present in the portfolio as well as an overall materiality assessment at the sector- or region level for the identification of risk and opportunity hotspots in the portfolio. On the next window, individual companies can be benchmarked across or within sectors and lastly individual companies' results can be split into the different risk drivers (e.g. what sectoral activities, geographies or also technologies (transition) and hazards (physical) drive the changes).

5. The Climate Excellence Tool provides the option to download the scenario analysis results for further evaluation and integration into the bank's processes.

6. To aid the interpretation of results, a degree of upfront effort is required to foster understanding on the different levels of the analysis and the underlying model assumptions and scenario narratives. Furthermore, for the successful integration in the internal processes, additional effort and collaboration across departments is highly recommended.

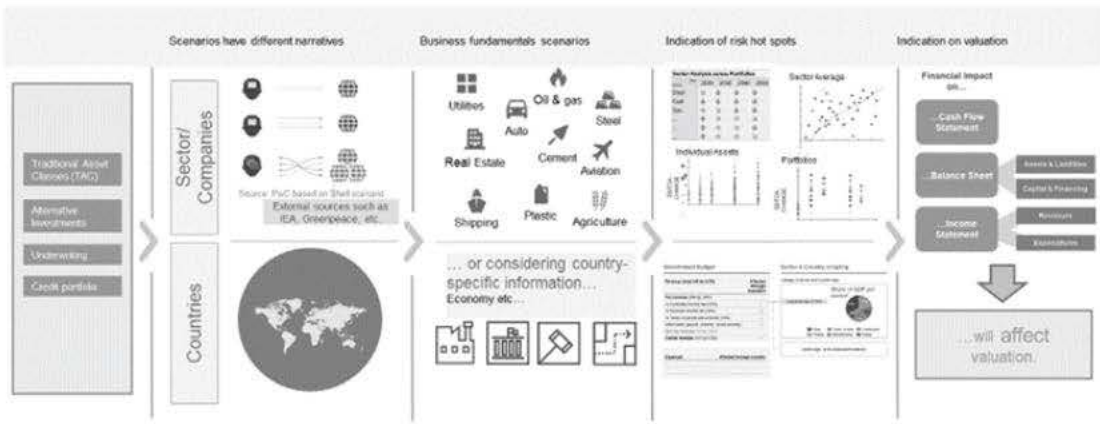


Figure 1 Conceptual image of Climate Excellence analysis

Data & Coverage

- **Data upload:** For the analysis with Climate Excellence, the loan portfolio data is required to be transformed according to the provided template. Furthermore, if not available internally already, the internal sector classification needs to be translated to the NACE sector logic.
- **Input required:** The entire corporate loan portfolio was analyzed and the following data for the portfolio was required:
  - Company Identifier: ISIN, LEI OR Company Name
  - Classification: Main NACE Code and country of operations
  - Exposure: Loan Amount
- **Coverage of the analysis:**
  - 99% of the analyzed portfolio of our corporate clients was covered in the tool
  - The Climate Excellence tool covers all NAICS (translation into NACE sectors is performed and used in the Tool) sectors up to the most granular level (given NAICS is the most granular sector classification system) and all world regions are covered.
  - The results for the high-emitting sectors are based on granular sector models, while the results for sectors with lower relevance are based on factor models (e.g. price changes), which are in turn derived from the high-impact sectors.

	Risk types	Time horizon	Scenarios	Sectoral coverage	Regional coverage	Additional Feature
Transition	Market, technology, regulation	2025, 2030, 2040, 2050	1.8°C, 2.0°C, 3.0°C	Full sectoral coverage	Worldwide coverage, with regional partly national granularity	Company specific analysis incl. asset level data with technology breakdown
Physical	Both acute and chronic: Heatwaves, Thunderstorms, Droughts, Hurricanes, Flood, sea level rise, fire	2030, 2050, 2100	2.0°C, 3.0°C, 4.0°C	Full sectoral coverage	Worldwide coverage, with national granularity	Company specific analysis

Table 1: Climate Excellence Coverage

- **Results integration:** The scenario analysis results in Climate Excellence provide sufficient depth of analysis and a high degree of portfolio coverage for potential subsequent integration in the user's organization, e.g. in Probability of Default (PD) calculations.

Risks factors and scenarios

During the trial period demo, the **key risk drivers** for high-risk sectors were analyzed in focused sector deep dives

- We are able to see the sectoral, regional and technological drivers for individual companies: the analysis happens down to NACE-level 4, depending on materiality, further results are presented, with a driver analysis (e.g. on the sector, country and technology level (transition) and hazard-level (physical), where applicable and meaningful
- Technology-level outputs are based on Asset-Level Data and the technological mix of the company (e.g. for a steel company it's the mix of different steel ovens in the company's portfolio)

Figure 2 Climate Excellence Transition Outputs

Temperature pathways and scenarios analyzed:

Focus during trial period on one scenario for transition and physical risks respectively:

- 1.8°C (triggering transition risks) based on IEA ETP B2DS and ETP WEO SDS
- 3.0 - 4.0°C (triggering physical risks) based on IPCC RCP 6.0

Outputs and insights

Output

- During the trial period, the focus was on EBITDA changes compared to the base year for individual counterparties
- Where data availability does not allow for granular counterparty analysis EBITDA results are based on sector-geography combinations
- Sales (for transition) and EBIT (for physical) are also available as additional output variables

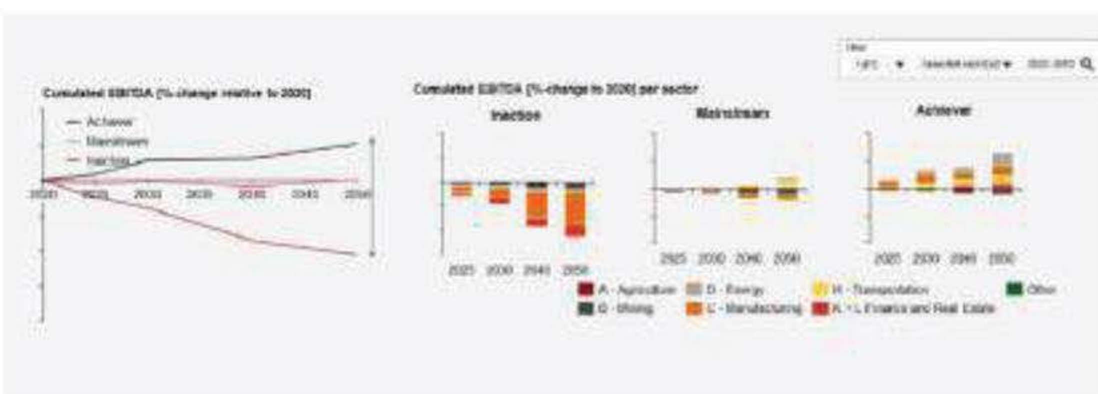


Figure 3 Illustrative results view on portfolio level

- The tool provides insights into the order-of-magnitude financial impacts within and across scenarios
- Sector- and scenario- or even geography-specific risk drivers with significant financial impacts based on changes to revenues and costs
- Understanding of the company-, project-, plant- or product-specific characteristics that imply vulnerability
- The combination of physical and transitory risks helped us a lot in classifying the risks and contributed to a very good understanding of a scenario future world.

Insights on integration options

- Company results as EBITDA change (and Sales) can, for example, be integrated in the respective Probability of Defaults (PD) and Loss given Default (LGD) models of the individual institutions. In this way, for example, a risk premium and its variance can be determined via the modelled adjustment capabilities of companies. Alternatively, based on company results, clusters of risk factors can be integrated.

- Based on the analysis, knowledge is built up across the bank w.r.t. to sector-specific transition and physical risks. Content insights are used for sectoral outlooks and understanding of the required changes in a low-carbon future. Insights are condensed and used to ask further, climate-related questions in the credit processes. Additionally, results are included in future steering concepts.

- The analysis can be directly linked to our Net Zero strategy, thereby covering both sides of the double materiality.

- Optional extension: Evaluation of capex requirements over time (see parallel project: Pathways to Paris) and also embed this for PD and LGD considerations

Suggested Enhancements for the tool provider

The performed analysis of the Financial Institution's portfolio provided a comprehensive geographic and sectoral overview over transition and physical risks within the time period of 2020–2050 and 2020–2100 respectively. The procedure and methodology were well-documented and easy to understand. Outputs provided by the Climate Excellence Tool were integrated within a wider scenario narrative to aid interpretation. Climate Excellence focuses on the financial impact, thus risks and opportunities from climate scenarios. In future versions, the impact side could be included in the tool.

As of now (31.12.2021), PwC has extended the functionality of Climate Excellence modules and now includes the IEA NZE 1.5°C scenario, as well as various Network for Greening the Financial System (NGFS) scenarios. Also, an upgrade of functionality to allow for the analysis of combined impact (thus aggregate transition and physical risk) is available. The analysis' backend has been fed with more recent portfolio data to improve the baseline fidelity of its outputs. Also, the Climate Excellence output has been integrated to generate a climate risk score based on the client's PD model.

An extension to include more extensive analyses of other parts of the client's portfolio, e.g. commercial real estate and mortgages will follow.

UN environment programme

finance initiative

United Nations Environment Programme Finance Initiative (UNEP FI) is a partnership between UNEP and the global financial sector to mobilise private sector finance for sustainable development. UNEP FI works with more than 450 members—banks, insurers, and investors—and over 100 supporting institutions—to help create a financial sector that serves people and planet while delivering positive impacts. We aim to inspire, inform and enable financial institutions to improve people's quality of life without compromising that of future generations. By leveraging the UN's role, UNEP FI accelerates sustainable finance.

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