MSCI CLIMATE VAR METHODOLOGY PART 4 – PHYSICAL CLIMATE RISK

MSCI ESG Research LLC

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Contents

Physical climate risk methodology

Objectives

Climate change, brought on by the release of greenhouse gas (GHG) emissions and the resultant warming of our atmosphere, will alter the intensity and frequency of chronic (slow to manifest risks, e.g., extreme heat) and acute (natural catastrophes, e.g., tropical cyclones) physical hazards. Physical climate risks represent the ensuing financial burden (or opportunity) borne by businesses and their investors from the impacts of these events. Using climate scenarios analysis, MSCI ESG Research outlines global climate risks for companies in our coverage up until 2100.

As with the transition risk analysis, costs/profits and risk/opportunity can be aggregated to the regional, sectoral, or company level, meaning that we can assign portions of risk or opportunity to several asset classes, which have been integrated into our model. The physical climate risk model is hybrid in nature, meaning that it has top-down and bottom-up elements within the calculations.

MSCI ESG Research actively collaborates with scientific institutes, such as the Potsdam Institute for Climate Impact Research (PIK) and ETH Zürich and has acquired a wealth of global climate data. Developed through a close collaboration with climate scientists, MSCI ESG Research's physical risk framework is highly modular, meaning that new hazards can be added into the model.

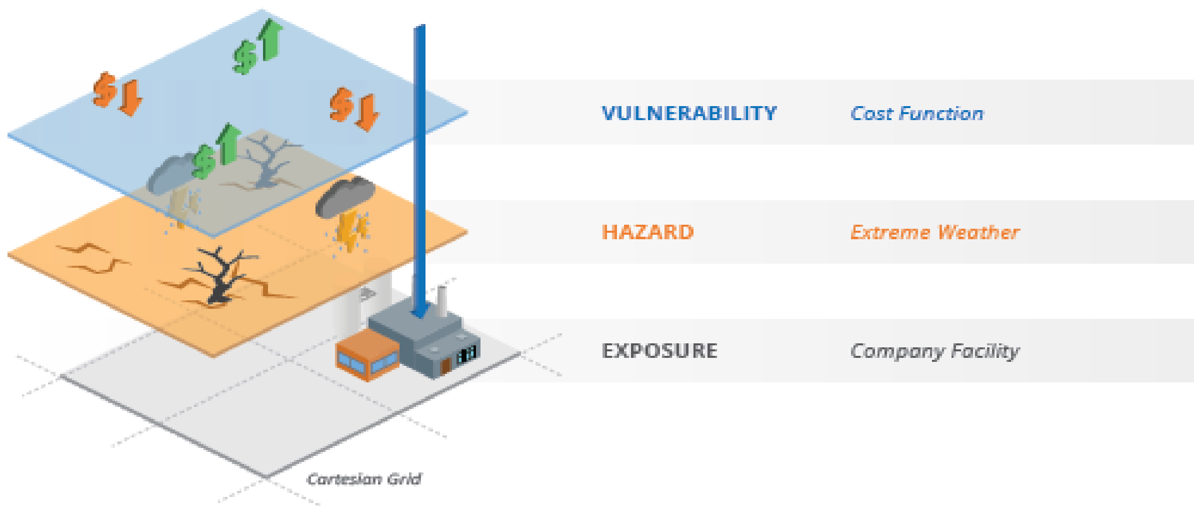
All physical risk modeling has global coverage and is based on our proprietary Asset Location Database (ALD) which contains the company locations of over 27,000 publicly traded companies. The typical model resolution is that of a global 0.5-degree grid (approximately 50x50 km) or finer depending on the hazard type.

Methodological approach to extreme weather analysis

As is custom practice in physical risk modeling, our models follow the mathematical modeling approach depicted in Exhibit 1 considering vulnerability, hazard, and exposure. Forecasted costs derived from our models can be integrated into standard investment metrics (see section 3 on calculating Climate VaR).

Exhibit 1: High-Level Overview of MSCI ESG Research's Physical Risk Calculation

EXPECTED COST = VULNERABILITY x HAZARD x EXPOSURE



Name	Definition	Example
Vulnerability	The propensity or predisposition of an asset to be affected, including sensitivity or susceptibility to financial harm (or opportunity) and capacity to cope and adapt.	• Extreme heat reduces labor productivity in the construction sector. • Extreme snowfall has a negative impact on transport companies.
Hazard	Present and future climatology, including the probability of occurrence and intensity of extreme weather events.	• An increase in the number of very hot days. • A measure of water stress in a certain region.
Exposure	The presence of people, livelihoods, resources, and other assets in places and settings that could be adversely affected.	• Geographical location, size, type and value of asset. • Asset allocation in terms of region and sector of a portfolio.

Source: MSCI ESG Research LLC

Asset level assessment

We believe it is essential to understand the geographical and structural characteristics of an asset to model the effects of extreme weather phenomena. Accordingly, our proprietary Asset Location Database (ALD) is at the heart of the physical risk assessment, driving the 'bottom-up' nature of the model.

In the current ALD, the average number of asset locations per company is 15 and the typical range[1] is between 1 and 87 locations worldwide. For each covered company, the raw ALD data is combined with fundamental financial data, for example sector activity and sectoral revenue breakdown by country. Since fundamental data is more abundant for larger companies, we have a total of 9,135 covered companies with an average of 50 assets per company. Some general properties of the database are detailed in the table below.

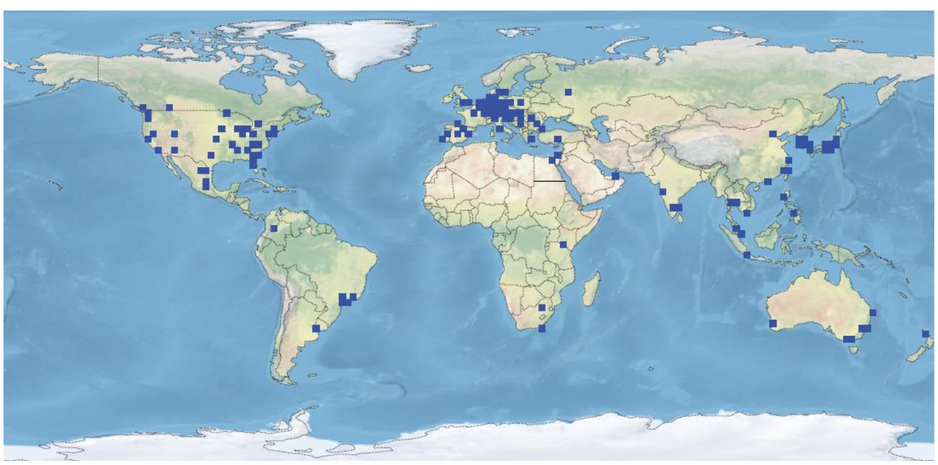
Exhibit 2: General properties of the Asset Location Database

	Total Number	Covered
Asset locations	1,131,937	457,665
Number of companies	74,486	9187
Average number of asset locations per company	15	50

Source: MSCI ESG Research LLC. Data as of March 27, 2024. 'Total number' includes all companies and assets in the ALD. 'Covered' includes all companies that are covered by the physical risk models, as the physical risk models require company level information regarding at least revenue, market cap and WACC.

Illustrated below is an example of the asset level data for a specific company in the ALD, the automobile manufacturer Daimler AG (DE0007100000). The blue squares denote locations of infrastructure assets for the company around the globe. The asset database contains the coordinates and other details about the asset which allow for an extensive view of the risks associated with both the location and operations at the site.

Exhibit 3: Asset Level Data for Automobile Manufacturer Daimler AG



Source: MSCI ESG Research LLC. Data as of Nov. 3, 2021. Company example is Daimler AG, DE0007100000.

[1] 95th-quantile

The ALD is proprietary to MSCI ESG Research and was created using several data sources:

- Manual data collection
- Commercially available databases
- Publicly available government managed data
- Locations from OpenStreetMap and open-source databases

This database is updated with every data release, which is currently every 3 months.

Asset level information is used in the physical risk models to estimate the exposure (see Exhibit 1). In our models we consider two types of exposure:

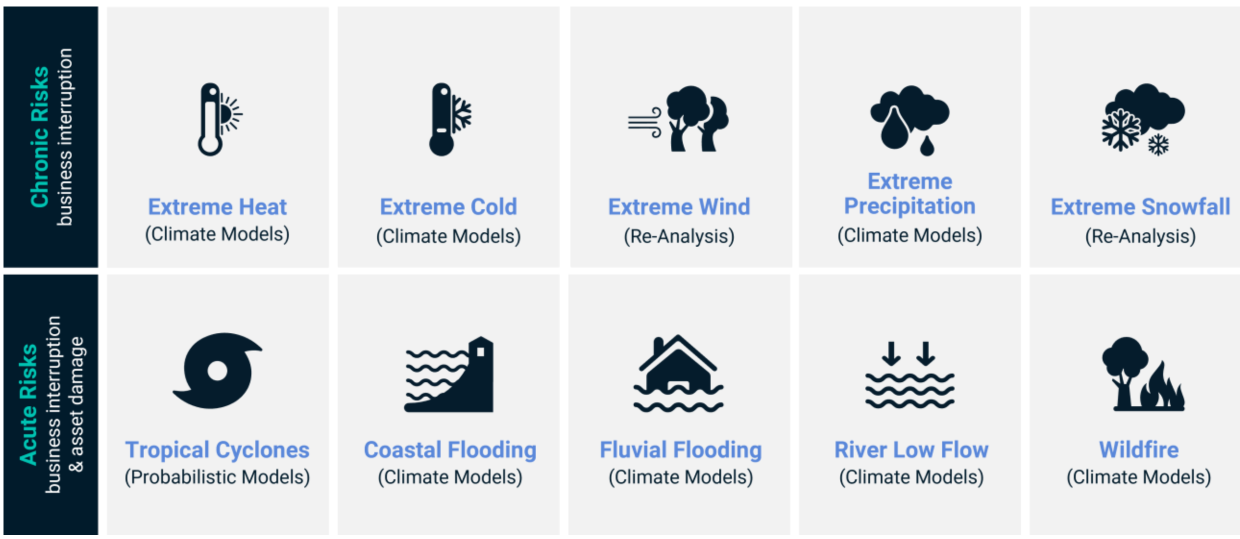
- Asset value exposure to direct loss, which is driven by asset damage and the reinstatement or replacement cost of the asset in question
- Economic output exposure to indirect loss (business interruption), which is the loss of economic added value generated at the asset location

MSCI ESG Research developed an exposure disaggregation model that estimates the value of a company's fixed assets and the revenue produced by these assets based on ALD data. For details on the exposure disaggregation algorithm, please refer to the document "Exposure Estimation Methodology for Physical Risk Models" on ESG Manager.

Financial impacts: asset damage and business interruption

When considering economic impacts, we look at two aspects related to extreme and gradual climate-related weather events:

- **Asset damage**: Direct physical damage to a company's assets at the various locations of operations;
- **Business interruption**: Costs associated with interruption of business operations as a direct consequence of an extreme weather event (acute risk) as well as gradual changes in revenue (chronic risk).



Source: MSCI ESG Research LLC.

Calculating cost of asset damage

Costs associated with asset damage are calculated based on the fixed asset value of company facilities.

The delta of the costs in any given year is then obtained as:

Delta cost = Cost future year - Cost base year

Since we model both, the current (base year) and the future cost (future year), a cost reduction over time will manifest as a net gain. A good example of this is the relationship between heat and cold extremes. Large areas of the northern hemisphere are projected to experience a significant temperature increase, meaning that cold extremes will become less frequent, and the associated costs will be reduced.

Cost = annual damage × fixed asset value

Calculating cost of business interruption

Cost of business interruption is done per sector and extreme weather type and is calculated as:

Cost = number of exceedances × vulnerability × vulnerability reduction × economic output

Combining cost of business interruption and asset damage for acute risks

For acute risks, we estimate the costs of asset damage as the product of annual asset damage and fixed asset value. In addition, we estimate the annual number of days of business interruption which, multiplied by economic output, yields the extra cost of business interruption. Thus, the total cost is given as:

Cost = annual damage × fixed asset value + annual share of economic output lost × annual economic output.

The cost delta is estimated as the difference between future and current costs.

Calculating opportunities

Opportunities in the model represent a reduction in climate-related costs and are indicated by positive values. The most likely case for this to happen is when the hazard's trend is declining. An example would be reduced snowfall, which is a positive effect for transport companies.

Scenario analysis on extreme weather

Climate scenarios modeling analyzes future responses to increasing greenhouse gas emissions by creating probabilistic outcomes of how our global physical systems will respond to a warmer world considering variables such as temperature, sea level rise, and changes to the frequency and severity of extreme weather events.

The use of scenario analysis is an important component of climate risk analysis, especially as it pertains to extreme weather modelling. It can be used to ask "what if" questions such as "*what* physical risks from weather extremes would we face *if* the world would warm by 2°C as compared to 5°C?" MSCI ESG Research's scenario analysis is designed to be closely aligned with the Task Force on Climate-Related Financial Disclosures (TCFD) recommendations that institutional investors are now expected to disclose the risks and opportunities associated with climate change of the companies and assets in which they are invested.

MSCI ESG Research provides physical risks for a variety of scenarios[2] as shown in the Exhibit 4 below. The scenarios are aligned with those recommended by the Network for Greening the Financial System (NGFS) and the Intergovernmental Panel on Climate Change (IPCC). The table also shows how we align physical risk scenarios with transition risk scenarios based on the level of global warming that is reached in each scenario.

[2] Please refer to the document "Introduction to Climate Scenarios" on ESG Manager for more details on the scenario narratives.

Exhibit 4: Overview of aligned MSCI scenarios

Global warming level	MSCI transition scenario	MSCI physical scenario	MSCI alternative physical scenario
1.5°C	1.5°C REMIND Orderly 1.5°C REMIND Disorderly	1.5°C REMIND Orderly 1.5°C REMIND Orderly**	
2°C	2°C REMIND Orderly 2°C REMIND Disorderly	2°C REMIND Orderly 2°C REMIND Disorderly	2°C IPCC SSP1-2.6
3°C	3°C REMIND NDC	3°C REMIND NDC	3°C IPCC SSP2-4.5 3°C REMIND Current Policies
4°C	*	4°C IPCC SSP3-7.0	
5°C	*	5°C IPCC SSP5-8.5	

**The MSCI Climate VaR model only considers additional costs from climate change and regulations. For the scenarios that lead to a warming of over 3°C, climate policies play a negligible role and hence no additional transition costs are expected. However, clients must currently select a transition scenario for portfolio aggregation and therefore we recommend using the 3°C REMIND NDC scenario which has the lowest transition costs.*

***For the 1.5°C REMIND scenario the choice between an orderly or disorderly transition has no significant effect on the associated physical risk. Hence, the same physical scenario can be used for both transition pathways.*

Source: MSCI ESG Research LLC.

Deriving vulnerabilities

As presented in Exhibit 1 in the previous section, vulnerability refers to the quantification of the costs related to a unit of physical impact. It is important to note that information and data on climate vulnerabilities is scarce. One of the main reasons for this is that vulnerability research is typically reliant on proprietary insurance data, which is used for the pricing of insurance premiums and not available for commercial use.

To classify vulnerability for different businesses, MSCI ESG Research has developed a set of sector-specific vulnerabilities derived from scientific publications and augmented by media reports for each hazard type and NACE sector.

Assumptions and limitations

Focus on delta costs

Extreme weather events frequently occur across the globe with large associated costs each year. Most of these costs are well-known to investors and can be considered as already priced into asset valuations. However, climate change can impact both the frequency and intensity of extreme weather events. Given the considerable uncertainty in future socioeconomic developments, effects of climate-related events may not be factored into the price of the asset. Therefore, the goal is to compute the isolated change in extreme weather costs due to climate change. We sometimes refer to this as the “cost delta” to make very clear that the value just carries the “additional cost posed by future climate change.”

Lag of the climate system

The scientific term “climate” refers to the average (long-term) behavior of typical meteorological quantities like temperature, wind, and precipitation. The World Meteorological Organization (WMO) defines the classical period of 30 years as the time horizon that is needed to obtain average values that are independent of natural variability. This time frame stems from the observation that this period is in most cases the shortest decadal period to yield constant results for averages.

Unfortunately, in many cases, climate change is advancing even more quickly posing a dilemma. The classical period of 30 years sometimes does not capture the full extent of climate change, whereas a shorter period may suffer from statistical problems related to natural variability.

Please note that this analysis sometimes works with sub 30-year averages with the intent to find the best compromise in time frames.

Factors that are not covered in the model

There are economic aspects that are not currently covered by the analysis presented in this document due to lack of reliable, calculable data:

- **Insurance**: It’s difficult to know the level of insurance that a given company might hold against extreme weather impacts.
- **Resilience and adaptation**: As with insurance, it is difficult to measure resilience and adaptation measures that a company might have taken or the associated costs to do so.
- **Supply chain risks**: Supply chain risk is relevant with respect to its linkage to physical impacts. Manufacturing can be seriously affected by broken supply chains, as the distribution of products can potentially be blocked. However, supply chains are often non-transparent and complex.
- **Business opportunities**: Some business sectors who might benefit from weather extremes, like insurance companies, or those that provide climate adaptation technology are not covered in this analysis.

Physical climate risk calculation

MSCI ESG Research models two types of climate risk in the context of its extreme weather analysis:

- **Chronic climate risks:** these risks manifest slowly over time and may cause business interruptions.
- **Acute climate risks:** occur from rare natural catastrophes such as tropical cyclones in distinct time intervals. They may cause asset damages as well as business interruptions .

Chronic risks

Chronic risks manifest primarily as reduction in labor productivity and availability or changes in the efficiency of production processes. Accordingly, MSCI ESG Research considers the various effects of business interruption for five climate hazards: extreme heat, extreme cold, extreme wind, extreme precipitation, and extreme snowfall.

We currently use two approaches to model changes in the hazard frequency and intensity until the end of the century. For extreme heat, extreme cold, and extreme precipitation we use climate model projections from phase 3b of the Inter-Sectoral Impact Model Intercomparison project (ISIMIP3b) that are provided by five climate models for extreme heat and extreme precipitation, and three climate models for extreme cold, each of them running three scenarios (SSP1-2.6, SSP3-7.0, and SSP5-8.5). For extreme wind and extreme snowfall we use statistical extrapolation of historical trends that are based on a global historical dataset of 39 years from the ERA Interim Reanalysis project of the European Centre for Medium-Range Weather Forecast (ECMWF). We plan to replace the statistical approach with climate projections to have a consistent methodology across all chronic hazards.

MSCI ESG Research estimates the annual costs of business interruption proportional to the number of days at which the hazard intensity exceeds a relevant threshold shown in Exhibit 5. We assume that a fixed proportion of revenue, specific to each sector, is lost on each of these days.

Exhibit 5: Intensity thresholds for chronic hazards

Hazard	Hazard intensity thresholds
Extreme Heat	From moderate to very high daily mean indoor wet bulb globe temperature (from >10°C to >37°C in steps of 1°C)
Extreme Cold	Low daily maximum temperature (<0°C) Very low daily maximum temperature (<-10°C)
Extreme Wind	Medium gust (>24.3 m/s) Strong gust (>27.8 m/s)
Extreme Precipitation	Moderate precipitation (>20 mm/day) Heavy precipitation (>50 mm/day)
Extreme Snowfall	Moderate snowfall (>5 cm/day) Heavy snowfall (>20 cm/day)

Source: MSCI ESG Research LLC.

Taking the example of extreme heat, research shows that wet bulb globe temperature (WBGT)[3] is a good meteorological indicator for heat impacts on labor productivity.[4] We derive sector-specific productivity loss functions from labor productivity loss per labor type and the labor intensity profile of each NACE sector.

Our vulnerability matrix covers all hazard types and defines specific factors for 88 NACE sectors. Furthermore, we estimate a regional vulnerability reduction that reflects adaptation to the regional climate. The rationale behind this reduction is that the vulnerability to chronic weather extremes is

[3] WBGT is a measure of environmental heat that accounts for temperature, humidity, solar radiation, and wind speed (the latter two factors are only relevant in outdoor environments). Compared to temperature alone, it is a better indicator for the impact of environmental heat on the ability of workers to shed excess heat from their body, see Foster et al. "An advanced empirical model for quantifying the impact of heat and climate change on human physical work capacity," Int. J. Biometeorol. 65, 2021.

[4] Szewczyk et al. "Heat stress, labour productivity and adaptation in Europe—a regional and occupational analysis," Environ. Res. Lett. 16, 2021.

lower in regions where these events are frequent, and the local businesses are experienced in dealing with the consequences. For example, in equatorial regions, days with WBGT > 20°C are more common and therefore there are more likely to be local adaptations to such events. We apply a regional vulnerability reduction, which is dependent on the number of annual threshold exceedances, and can amount up to 50% in some regions where thresholds are commonly exceeded.

Acute risks

Acute physical risks that manifest from catastrophic events such as coastal floods or tropical cyclones are modelled in much greater detail as there is a better understanding of these risks, which historically have been at the focus of the insurance industry.

Tropical Cyclones

Tropical cyclones typically cause severe wind and flood damage. MSCI ESG Research quantifies their impact by employing the open-source natural catastrophe model CLIMADA. This model is a spin-off from an insurance model and is maintained by the Department of Environmental Systems Science at ETH Zurich. CLIMADA uses a stochastic tropical cyclone generator based on an extensive set of historical storms. The distribution of wind speeds is evaluated for each location to calculate economic losses from both asset damage and business interruption. Asset damage costs are obtained using regionally calibrated damage functions. The regional calibration was performed for 9 distinct ocean basins using data from EM-DAT and incorporating damage from related storm surges. MSCI ESG Research extracts information from CLIMADA about the annual expected damage fraction per company location. This fraction is then multiplied by the location's asset value [5]to determine asset damage costs. Business interruption costs are calculated using the windspeed category and the asset type to estimate the duration of downtime. Downtime is then used to calculate the proportion of annual revenue that has been lost.

We employ climate model-based projections of the future frequency and intensity of tropical cyclones under the RCP8.5 scenario to model the generated set of cyclone tracks until 2100.

Coastal flooding

The impacts of coastal flooding can manifest in severe asset damage and prolonged business interruption. As sea level rise is the dominating climatic driver of coastal flooding,[6] to determine associated damages, MSCI ESG Research models the inundation of an asset at a given site depending on the local topography and the statistical distribution of extreme sea levels at the coast.

We employ the CoastalDEM, a bias-corrected version of the global digital elevation model SRTM, to determine if an asset will be inundated by a flood event. We then combine the height of the inundation at the asset site with depth damage functions based on Huizinga et. al. 2017[7] to

[5] The methodology for determining a location's asset value is explained in MSCI ESG Research's: "Exposure Estimation Methodology for Physical Risk Models", page 6

[6] Oppenheimer, M., B.C. et al. "Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities." 2019. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.

[7] Huizinga, J., Moel, H. de, Szewczyk, W. Global flood depth-damage functions. Methodology and the database with guidelines. 2017. EUR 28552 EN. doi: 10.2760/16510.

determine the fractions of asset damage. The duration of business interruption is estimated based on Yang et al. 2015[8].

The occurrence and intensity of flood events is modelled via a Poisson process and extreme value statistics, respectively. The consideration of local flood protection as a means to effectively prevent damage from flood events that are lower or equal to the design of the flood protection is critical in the estimation of risk. We incorporate protection measures into our model by only considering floods with a greater return period greater than that of the protection.

For future years, the local distributions of extreme sea levels are shifted according to the expected regional sea-level rise. The shift typically translates into more frequent and intense flood events. We make use of a large ensemble of sea level rise scenarios also given in the IPCC's 5th Assessment Report. For the considered timespan until 2100, we regard the spread of model runs as a proxy for climate model uncertainty, which is propagated through all following model steps.

Fluvial flooding

The core of the fluvial flooding model is very similar to the coastal flooding model.

We use data from five different state-of-the-art global hydrological models (GHM) driven by the RCP 8.5 climate scenario and the river routing module of the Global Change Analysis Model[9] (GCAM) to compute future discharge in river channels. For each GHM output, inundation areas and flood depths are derived from the Catchment-based Macro-scale Floodplain[10] model (CaMa) based on extreme value statistics applied on the river routing model output.

As with coastal flooding, local flood protection measures are considered, and the same depth damage functions are used to estimate asset damage and business interruption from inundation.

River low flow

MSCI ESG Research assesses the economic impact of river low flow, i.e., water scarcity on the power production sector, specifically on thermal and hydro power plants, which rely implicitly on large amounts of water. Here, it is assumed that all thermal power plants located within 10 km of a river and all hydropower plants are exposed to river low flow risk.

We use current and future simulated daily surface water discharge datasets at 0.5° grid cell resolution from the Inter-Sectoral Impact Model Intercomparisons project (ISIMIP) to derive the river low flow hazard data. It is calculated via the number of days during which the flow of a river is below a local threshold, derived from the 2.5th percentile of historical discharge data. The intensity of this hazard is measured via the number of consecutive days of low flow, considering only events greater than 5 days.

The impact of low flow events is modeled via empirically derived impact functions based on documented low flow events in Europe as reported in the European Drought Impact Report

[8] Lijiao Yang, Hirokazu Tatano, Yoshio Kajitani, and Xinyu Jiang. "A Case Study on Estimation of Business Interruption Losses to Industrial Sectors Due to Flood Disasters," J. Disaster Res., Vol.10, No.5, pp. 981-990, 2015.

[9] "Global Change Analysis Model", Joint Global Change Research Institute, 2019

[10] CaMa-Flood: Global River Hydrodynamics Model. Dai Yamazaki, 2019.

Inventory[11] (EDII) and the associated power losses. The power losses resulting from low flow events documented in the European database are used as a proxy for global power plants.

Costs are calculated based on the economic output.

For further details on the methodology, please refer to the document "River Low Flow Risk Estimation Methodology for Electric Power Producers" on ESG Manager.

Wildfire

Climate change has been a key driver in creating warmer and drier weather conditions that are ideal for the development of wildfires. To determine wildfire risk to an asset, MSCI ESG research estimates five components:

- **Fire weather** – occurrence of weather conditions favorable to wildfire occurrence.
- **Fire ignition** – the probability of wildfire starting given favorable weather conditions.
- **Fire spread** – the probability of wildfire affecting a particular location given an ignition in the vicinity.
- **Fire intensity** – duration of a wildfire once one starts.
- **Fire vulnerability** – relative damage sustained by assets affected by wildfires combined with business interruption.

Fire weather is linked to climate change and varies throughout the modelling horizon (until 2100) depending on the climate scenario. In line with the business-as usual scenario of other hazards, we use fire weather projections for the SSP5-8.5 scenario.

For more details on the methodology and a computation example, please refer to the document "Wildfire Risk Estimation Methodology" on ESG Manager.

Average and aggressive scenario outcome

MSCI ESG Research uses a probabilistic modeling framework to determine the distribution of the annual cost from weather extremes for assets at a given location. This approach allows us to determine the average cost from climate change while also exploring the possibility of much more severe outcomes. By default, we calculate the average scenario by considering the expected value of the cost distribution. The corresponding aggressive scenario is derived from the 95th percentile of the cost distribution and explores the severe downside risk within the distribution tail.

Correlations between risks can have a strong impact on the distribution of aggregated costs. Spatial correlations reflect the likelihood that nearby locations can be affected by the same extreme event, e.g., a hurricane or extreme heat. Correlations between hazard types reflect the joint occurrence of different hazards, such as very low temperatures in conjunction with heavy snowfall.

As MSCI ESG Research integrates extreme weather costs from various global models, we need to make some simplifying assumptions for the aggregation of physical risk. We employ a variance-covariance approach to incorporate correlations in the risk aggregation.

[11] European Drought Impact Report Inventory (EDII) and European Drought Reference (EDR) database. 2015. European Drought Centre.

In this approach we make two crucial assumptions. First, we assume that the correlation structure can be captured by a linear correlation coefficient. Second, we assume that the risks are approximately normally distributed. In particular, the second assumption is known to inadequately reflect extreme weather risks but was chosen to simplify computation. Accordingly, the 95th percentile derived from a normal distribution with the same mean and variance will tend to underestimate the true value.

To apply the variance-covariance approach, we consider the cost distribution calculated for each hazard and business location. Two parameters are inferred from this distribution, the mean and the standard deviation. If the variance-covariance matrix between the different risks is known, it is possible to infer the standard deviation of the correlated sum as:

$$\textbf{Aggregate standard deviation} = \textbf{square root} \ (\mathbf{STD}^{T} \times \mathbf{M} \times \mathbf{STD})$$

Where **STD** is a vector of the standard deviations of the separate risks (with superscript T indicating the transpose of the vector) and **M** is the correlation matrix of those risks.

The aggregated mean is simply given by the sum over the mean values of the individual risks. When the risks have been fully aggregated, we use the assumption of the normal distribution to compute the 95th cost percentile from the aggregated mean and standard deviation.

The process of aggregation is completed in 3 steps:

1. For each company we obtain mean and standard deviation of the total cost per extreme weather type. We model spatial correlations between the individual locations of the company. Generally, nearby locations are more strongly correlated than those farther apart. The correlation is modelled as a function of distance.
2. For each hazard in a portfolio, we aggregate the individual risks coming from each company. This step does not take into account additional spatial correlation, instead it is assumed that these risks are uncorrelated.
3. At the top level of aggregation (the portfolio level, but also for single companies) we aggregate the risks from the different hazards. The interaction between different hazards is considered in a single correlation matrix. With this information the mean and standard deviation of the total extreme weather costs are calculated for each company. Analogously, we calculate total extreme weather costs at the portfolio level.

Create consistent physical risks for aligned scenarios

It is explained above how physical risks are computed for different hazards and how the applied models and scenarios differ according to the specific needs and data availability of the different hazards. An overview of which scenarios are calculated for which hazard is shown in Exhibit 6. For example, expected costs from future heat extremes are computed based on climate model projections from three ISIMIP models running three different scenarios (SSP SSP1-2.6, SSP3-7.0, and SSP5-8.5).

Exhibit 6: Calculated scenarios per hazard

Source	Scenario	Hazard

IPCC AR6	SSP1-2.6, SSP3-7.0, SSP5-8.5	Extreme Heat, Extreme Cold, Extreme Precipitation, Wildfire
IPCC AR5	RCP 2.6, RCP 6.0, RCP 8.5	Tropical Cyclones, Coastal Flooding, Fluvial Flooding, River Low Flow
ERA-Interim	Extrapolation of historical trends	Extreme Wind, Extreme Snowfall

Source: MSCI ESG Research LLC.

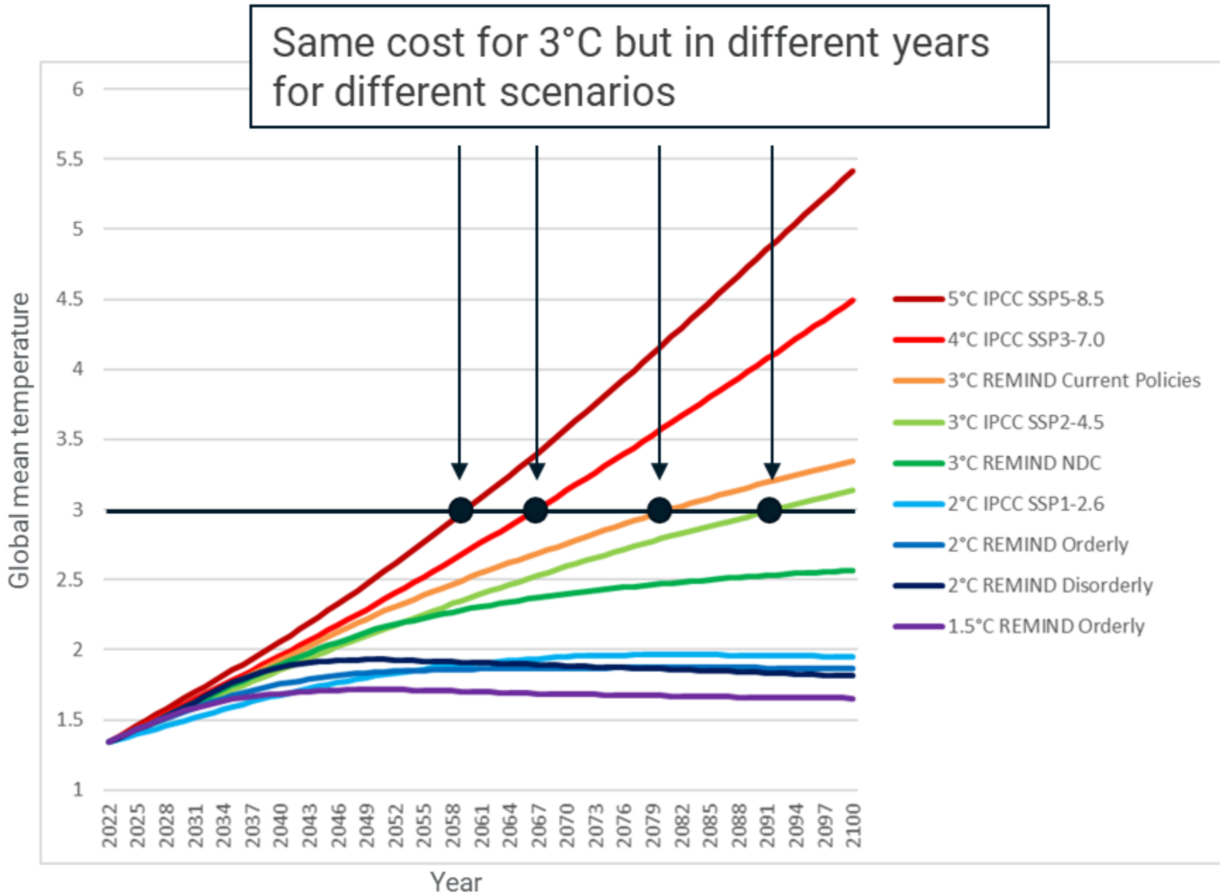
To provide consistent hazard-specific physical risks for the same scenario MSCI ESG Research uses an established mapping approach[12]. The approach builds on the observation that "robust projected geographical patterns of many [climate] variables can be identified at a given level of global warming, common to all scenarios considered and independent of timing when the global warming level is reached."[13]

In other words, it is assumed that a certain level of global warming will on average lead to the same physical impact even if it is reached at different moments in time in different scenarios, as illustrated in Exhibit 7. Here, the global mean temperature time series are shown for different scenarios. Since the temperature time series have different slopes they will reach a warming of 3°C in different years (or not at all) as indicated by the black dots. In these years the associated cost from physical impacts are expected to be the same in all scenarios. Note that the mapping approach is applied to the raw costs and all other modeling steps, including exposure growth and discounting, are only applied afterwards.

[12]The Network of Central Banks and Supervisors for Greening the Financial System (NGFS), "NGFS Climate Scenarios Database – Technical Documentation", 2021.

[13] Intergovernmental Panel on Climate Change, "Climate Change 2021: The Physical Science Basis – Summary for Policymakers." 2021.

Exhibit 7: Physical impacts as a function of temperature



Source: MSCI ESG Research LLC.

The mapping approach has the advantage that physical impacts can be computed for a subset of climate scenarios and then mapped to any other climate scenario based on the underlying global mean temperature pathway. Mapping of physical impacts requires significantly less computation power than their initial computation from climate model projections. It is hence possible to provide the same physical scenario for all hazards and extend the number of provided physical scenarios in general.

MSCI ESG Research uses costs derived from the scenarios shown in Exhibit 4 and maps them onto the aligned scenarios shown in Exhibit 8.

Exhibit 8: Aligned scenarios that are consistent across all hazards

Source	Scenario	Hazard
IPCC AR6	2°C SSP1-2.6, 3°C SSP2-4.6, 4°C SSP3-7.0, 5°C SSP5-8.5	All hazards
NGFS	1.5°C Orderly, 2°C Orderly, 2°C Disorderly, 3°C NDC, 3°C Current Policies	All hazards

Source: MSCI ESG Research LLC.

Exposure growth modelling for company physical risk models

The IPCC states, with high confidence, that the increase in exposure of economic assets has been a major cause of increase in economic losses from weather- and climate-related disasters[14]. With exposure growth modelling, MSCI ESG Research accounts for future changes in the value of exposure, i.e., asset value and revenue, prior to the discounting of costs.[15]

To calculate exposure growth projections, we use data on nominal and real GDP, working-age population, and exchange rates from the "most likely" long-term economic projection from the Organization for Economic Co-operation and Development (OECD)[16], combined with United Nations (UN) demographic projections.

The exposure growth rate is computed as a timeseries of annual rates per country via:

$$E_{t,c} = G_{t,c} \times P_{t,c} \times I_{t,c}$$

where:

- $E_{t,c}$ is the exposure (total GDP) growth rate in nominal, US Dollar-based terms in year t and country c,
- $G_{t,c}$ is the real GDP growth rate per working-age (15–74 years) person (from OECD),
- $P_{t,c}$ is the growth rate of working-age (15–74 years) population (from UN),
- $I_{t,c}$ is the GDP deflator corrected for changes in exchange rate of the currency of country c to the US Dollar (from OECD).

Physical climate risk scores

MSCI ESG Research provides two different scores for assessing physical risk:

Financial risk categories are based on MSCI ESG Research's Climate Value at Risk (Climate VaR) and provide an easy-to-understand assessment of the financial risk from climate change at the company level for different climate change scenarios.

Hazard Percentiles provide a company and asset level raw hazard score for each of the 10 hazards in our physical risk model. The percentiles indicate an asset's hazard level relative to other assets in a reference dataset under different time horizons and climate change scenarios.

Financial risk categories

MSCI ESG Research provides classifications of the financial risk of physical hazards based on the Climate VaR at the company level. For the financial risk categorization, we leverage existing computations of Climate VaR for physical risk and classify the Climate VaR computed for an issuer into seven financial risk categories ranging from risk reduction to severe risk, as shown in Exhibit 9.

[14] "AR5 Synthesis Report: Climate Change 2014". Intergovernmental Panel on Climate Change, 2018.

[15] "Climate VaR Methodology Part 6: Financial modelling." 2020. MSCI ESG Research.

[16] "The Long View: Scenarios for the world economy to 2060." OECD, 2018.

Climate VaRs are categorized separately for each hazard and then aggregated using five different climate change scenarios reflecting different levels of global warming.[17]

Exhibit 9: Financial risk categories based on Climate VaR intervals

Financial risk category	Climate VaR interval [%]
Severe risk	-100 to -25
Significant risk	-25 to -5
Moderate risk	-5 to -0.5
Negligible risk	-0.5 to 0
No identifiable risk	0
Negligible risk reduction	0 to 0.5
Risk reduction	0.5 to 100

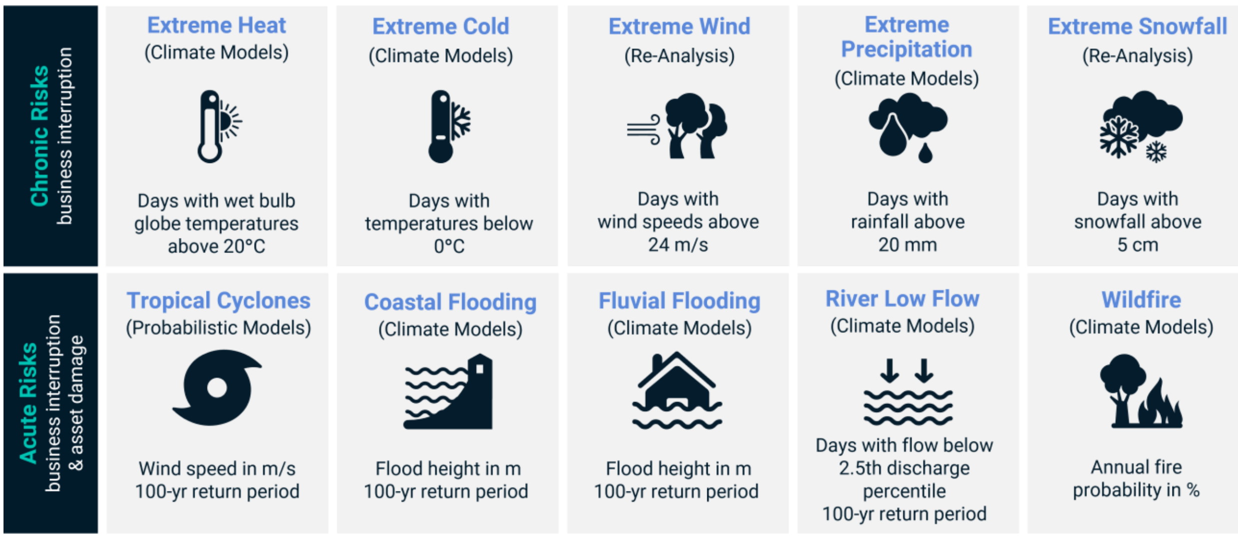
Source: MSCI ESG Research LLC.

[17] Climate scenarios for which the financial risk categories are computed are: 1.5°C: Net Zero 2050 (REMIND), 2°C: Below 2°C (REMIND), 3°C : Nationally Determined Contributions - NDCs (REMIND), 4°C : SSP3-7.0 (IPCC), 5°C : SSP5-8.5 (IPCC).

Hazard percentiles

Hazard data is a key component of MSCI ESG Research's physical risk modeling. The intensity and frequency of individual hazards strongly depends on the location of the asset and is projected to change over time depending on the underlying climate scenario (Exhibit 10). To compute hazard percentiles, the hazard data at the location and company level are evaluated against a global reference dataset (MSCI ACWI Index).

Exhibit 10: Physical hazard data used for computing hazard percentiles



Source: MSCI ESG Research LLC.

Location and company-level hazard percentiles

The computation of hazard percentiles at the location and company-level consists of four steps:

1. **Reference location-level hazard percentiles**: To derive the reference locations' hazard percentiles, we compute the intervals between the hazard data percentiles for all assets in the MSCI ACWI index. The percentiles of the reference dataset are computed for the current year to reflect current hazard levels.
2. **Location-level hazard percentiles**: An asset's hazard level is evaluated against the percentiles of the reference dataset and assigned a percentile score from 1-100. If an asset is assigned a score of 25, this means that 25% of all assets in the reference dataset have a lower hazard level than the assessed asset. Assets with a hazard level of zero are assigned the score 0. Location-level hazard percentiles are computed for current hazard levels and 2050 hazard levels for five different climate scenarios[18].The 2050 hazard levels are evaluated against the same current-year reference dataset to reflect changes in the hazard risk due to climate change.
3. **Reference company-level hazard percentiles**: We aggregate the current-year location-level hazard percentiles (from step 2) per company in the reference dataset (MSCI ACWI index).

[18] Climate scenarios for which the hazard percentiles are computed are: 1.5°C: Net Zero 2050 (REMIND), 2°C: Below 2°C (REMIND), 3°C : Nationally Determined Contributions - NDCs (REMIND), 4°C : SSP3-7.0 (IPCC), 5°C : SSP5-8.5 (IPCC).

For all chronic risks which are manifested in business interruptions, we aggregate location percentiles to the company average (CA) by weighting the location's hazard percentile HP_L with the location's output share O_L:

$$CA = \sum_L HP_L * O_L$$

For all acute risks which manifest in asset damage and business interruptions, we aggregate location percentiles to the company average (CA) by weighting the location's hazard percentile HP_L with the average of the location's asset share A_L and output share O_L:

$$CA = \sum_L HP_L * (O_L + A_L)/2$$

The percentiles of the company reference dataset for the current year are computed in the same way as the asset-level reference but using the company averages (CA) hazard percentiles instead of asset-level percentiles for all companies within the MSCI ACWI index.

4. **Company-level hazard percentiles**: Company-level hazard percentiles are computed in the same way as asset-level hazard percentiles but using the company reference dataset and evaluating the company average hazard levels (CA) (aggregated as in step 3).

Regional company exposure to physical hazards

For each company, we provide its asset share (i.e. percentage of asset value) aggregated per country that is exposed to different levels of physical hazard risks. We summarize regional company exposures into four brackets, referred to as hazard percentile quarters, which are defined by hazard percentile scores as shown in Exhibit 11 (1^{st} quarter = lowest exposure, 4^{th} quarter = highest exposure). Asset shares are based on ALD locations and the fixed asset value disaggregation model developed by MSCI ESG Research (see section 1.3).

Exhibit 11: Hazard percentile quarters

Hazard percentile quarter	Hazard percentile score
1^{st}	0 to 25
2^{nd}	26 to 50
3^{rd}	51 to 75
4^{th}	76 to 100

Source: MSCI ESG Research LLC.

For each combination of company and region it operates in we compute the percentage of asset value (asset share) that is exposed to one of the four brackets of hazard risks by summing up the asset values of locations with hazard percentile scores in the respective hazard percentile quarter and dividing by the total asset value of locations in that country. The asset shares in the four hazard percentile quarters generally sum up to 100% for each country.[19]

This is done for each individual physical hazard, as well as for the aggregation to hazard groups: "aggregate chronic", "aggregate acute" and "aggregate chronic and acute". For the aggregation to "aggregate chronic", the maximum hazard percentile score of all individual chronic hazards is considered to reflect if *any* chronic hazard is affected in the respective quarter. For example, if an asset has a hazard percentile score of 80 for extreme heat and 0 for all other chronic hazards, it would be classified in the fourth quarter for aggregate chronic, as there is a high chronic risk present. For the aggregation to "aggregate acute" the same methodology is applied to acute hazards. For the aggregation to "chronic and acute" the minimum score of "aggregated chronic" and "aggregated acute" is considered. This implies that *both* chronic and acute hazards are at least in the respective quarter, see example in Exhibit 12.

Exhibit 12: Example classification and hazard aggregation for a single asset

Hazard type	Hazard	Hazard percentile score	Hazard percentile quarter
Chronic	Extreme Heat	0	1st
	Extreme Cold	70	3rd
	Extreme Wind	30	2nd
	Extreme Precipitation	36	2nd
	Extreme Snowfall	55	3rd
	Aggregate chronic	-	3rd
Acute	Tropical Cyclones	0	1st
	Coastal Flooding	88	4th
	Fluvial Flooding	76	4th
	River Low Flow	0	1st
	Wildfire	15	1st
	Aggregate acute	-	4th
Both	Aggregate chronic and acute	-	3rd

Source: MSCI ESG Research LLC.

[19] Asset shares of all quarters may not sum up to 100% in the case of incomplete hazard coverage.

Examples

Costs of extreme heat

This section provides an example calculation of company revenue loss associated with reduced labor productivity due to extreme heat. The example is based on an asset of a company located in Spain. At that location, the company is active in the following NACE sectors: Retail trade, except of motor vehicles and motorcycles (NC-47), Computer programming, consultancy and related activities (NC-62), and Information service activities (NC-63). Exhibit 13 presents the basic asset location data required for the computations of Extreme Heat costs.

Exhibit 13: Asset location data required for extreme heat cost calculation

Asset location data	
Coordinates	Latitude: 37.27°N
	Longitude: 5.99°W
Annual revenue breakdown per NACE sector	NC-47: 85% or $29,708,217,400
	NC-62: 8% or $2,796,067,520
	NC-63: 7% or $2,446,559,080

Source: MSCI ESG Research LLC.

Based on the location (using the longitude and latitude) of the asset, heat hazard data is retrieved for days where the daily mean indoor wet bulb globe temperature (WBGT) exceeds threshold values that range from 10°C to 37°C, in steps of 1°C. Example heat hazard data for the asset located in Spain under SSP5-8.5 is shown in Exhibit 14 for five selected years.

Exhibit 14: Heat hazard data and acclimatization factors for WBGT > 20°C at the asset location

Year	Exceedance days [number of days per year]	Increase in exceedance days compared to 2020 [number of days per year]	Vulnerability reduction factor to account for acclimatization [%]
2020	123.7	0.0	78.9
2035	133.6	9.9	78.2
2050	145.1	21.4	77.5
2065	158.3	34.6	76.7
2080	173.6	49.9	76.0

Source: MSCI ESG Research LLC.

Adaptation in the form of vulnerability reduction is integrated via two vulnerability reduction factors, one to account for the acclimatization of workers to heat and the other to account for the protecting effect of air conditioning on labor productivity. We assume that a higher number of exceedance days implies more pronounced acclimatization, which is represented by a lower vulnerability reduction factor (Exhibit 14).

We further assume that a higher prevalence of air conditioning in a business sector implies that a greater share of the economic output generated in that sector is protected from heat impacts on labor productivity. The vulnerability reduction factors for the sectors relevant for this example are shown in Exhibit 15.

Exhibit 15: Labor productivity loss and air conditioning factor per business sector

NACE sector	Labor productivity loss for WBGT > 19°C [%]	Labor productivity loss for WBGT > 20°C [%]	Marginal labor productivity loss for WBGT > 20°C [%]	Vulnerability reduction factor to account for air conditioning [%]
NC-47	1.4	1.8	0.4	50.0
NC-62	0.7	0.9	0.2	33.6
NC-63	0.9	1.2	0.3	37.9

Source: MSCI ESG Research LLC.

Vulnerability is modelled via marginal labor productivity loss as a function of WBGT. Here, marginal refers to WBGT, i.e., the marginal loss at, e.g., 20°C is the difference between the loss at 20°C and the loss at 19°C. Sector-specific productivity loss functions are derived from labor productivity loss per labor type and the labor intensity profile of each NACE sector. The result for the sectors relevant for this example is shown in Exhibit 15.

With the given data, one can calculate the annual cost associated with extreme heat for one WBGT threshold, $T = 20°C$. The total annual cost for the asset is then the sum of the annual cost per threshold over all thresholds. For one particular year Y:

$$\mathrm{cost}(Y) = \sum_{T=10°\mathrm{C}}^{37°\mathrm{C}} \mathrm{cost}(Y,T)$$

The cost per year and WBGT threshold has contributions from all NACE sectors in which revenue is generated at the asset location. For the present example, there are contributions from three sectors:

$$\mathrm{cost}(Y,T) = \sum_{S=\text{NC-47, NC-62, NC-63}} \mathrm{cost}(Y,T,S)$$

The cost per year, WBGT threshold and NACE sector is calculated using the cost-of-business-interruption formula from Section 0:

$$\mathrm{cost}(Y,T,S) = \frac{1}{365} * \text{ annual number of exceedances}(Y,T) * \text{vulnerability}(T,S) \\ * \text{vulnerability reduction}(Y,T,S) * \text{annual revenue}(S)$$

As outlined above, for extreme heat, vulnerability reduction has two components:

$$\text{vulnerability reduction}(Y, T, S) = \text{acclimatization factor}(Y, T) * \text{air conditioning factor}(S)$$

For simplicity, in this example we only perform the calculation for one year, $Y = 2050$, and one WBGT threshold, $T = 20°\text{C}$, pulling values from Exhibits 13–15:

$$\text{cost}(2050{,}20°\text{C,NC-47}) = \frac{145.1}{365} * 0.4\% * 77.5\% * 50.0\% * \$29{,}708{,}217{,}400 = \$18{,}305{,}552$$
$$\text{cost}(2050{,}20°\text{C,NC-62}) = \frac{145.1}{365} * 0.2\% * 77.5\% * 33.6\% * \$2{,}796{,}067{,}520 = \$578{,}886$$
$$\text{cost}(2050{,}20°\text{C,NC-63}) = \frac{145.1}{365} * 0.3\% * 77.5\% * 37.9\% * \$2{,}446{,}559{,}080 = \$857{,}023$$

It follows that the cost for year 2050 and WBGT threshold 20°C amounts to

$$\text{cost}(2050{,}20°\text{C}) = \$18{,}305{,}552 + \$578{,}886 + \$857{,}023 = \$19{,}741{,}461$$

Similar calculations are performed for all years and WBGT thresholds to arrive at an annual cost timeseries for the asset location. In MSCI Climate VaR methodology part 6: Financial modelling, we explain how we aggregate such cost timeseries over time and asset locations to arrive at company-level Climate Value at Risk.

Glossary

Name	Definition
Acute Risk	Acute physical risks refer to those that are event-driven, including increased severity of extreme weather events, such as cyclones, hurricanes, or floods.[20]
Aggressive Scenario	[see also **Average Scenario**] We take two complementary views on physical climate risk, referred to as the average and aggressive scenarios. The aggressive scenario explores the severe downside risk within the distribution of physical risk and extreme weather costs. It relates to the 95th percentile of the cost distribution. As the variance of the cost distribution is driven by uncertainty from the climate system and other modelling uncertainty, the aggressive scenario can be considered as a worst case scenario.
Average Scenario	[see also **Aggressive Scenario**] We take two complementary views on physical climate risk, referred to as the average and aggressive scenarios. The average scenario considering the most likely impact of climate change over the modelled 15y period. Mathematically it refers to the expected value of the cost distribution.
Climate	Climate in a narrow sense is usually defined as the average weather -or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities - over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization (WMO). The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.[21]
Climate Model	[see also **Climate**] A qualitative or quantitative representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes and accounting for some of its known properties. Climate models are applied as a research tool to study and simulate the climate and for operational purposes, including monthly, seasonal and interannual climate predictions.[21]
Chronic Risk	Chronic physical risks refer to longer-term shifts in climate patterns (e.g., sustained higher temperatures) that may cause sea level rise or chronic heat waves.[20]

[20] Source: Recommendations of the Task Force on Climate-related Financial Disclosures, 2017

[21] Source: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate, 2019, Glossary

ERA Interim	[see also **Reanalysis**] ERA-Interim is a global atmospheric reanalysis that is available from 1 January 1979 to 31 August 2019. It has been superseded by the ERA5 reanalysis.[22,23]
Exposure	The presence of people, livelihoods, resources, and other assets in places and settings that could be adversely affected.
GCM	[see also **Climate Model**] A general circulation model (GCM) is a type of climate model. It employs a mathematical model of the general circulation of a planetary atmosphere or ocean. GCMs and global climate models are used for weather forecasting, understanding the climate, and forecasting climate change. The acronym GCM originally stood for General Circulation Model. Recently, a second meaning came into use, namely Global Climate Model. While these do not refer to the same thing, General Circulation Models are typically the tools used for modelling climate, and hence the two terms are sometimes used interchangeably.
Hazard	Present and future climatology, including the probability of occurrence and intensity of extreme weather events.
Physical Climate Risk	Physical risks resulting from climate change can be event driven (acute) or longer-term shifts (chronic) in climate patterns. Physical risks may have financial implications for organizations, such as direct damage to assets and indirect impacts from supply chain disruption. Organizations' financial performance may also be affected by changes in water availability, sourcing, and quality; food security; and extreme temperature changes affecting organizations' premises, operations, supply chain, transport needs, and employee safety.[20]
Reanalysis	An atmospheric reanalysis (also: meteorological reanalysis and climate reanalysis) is a meteorological and climate data assimilation project which aims to assimilate historical atmospheric observational data spanning an extended period, using a single consistent assimilation (or "analysis") scheme throughout. A reanalysis project involves reprocessing observational data spanning an extended historical period using a consistent modern analysis system, to produce a dataset that can be used for meteorological and climatological studies

[22] For a detailed documentation of the ERA-Interim archive see Berrisford et al. (2011) "The ERA-Interim archive Version 2.0," ERA Report 11/2011, https://www.ecmwf.int/en/elibrary/73682-era-interim-archive-version-20

[23] For an open-access journal article describing the ERA-Interim reanalysis see Dee et al. (2011) "The ERA-Interim reanalysis: configuration and performance of the data assimilation system," Q.J.R. Meteorol. Soc, 137, https://doi.org/10.1002/qj.828

Relative Concentration Pathways (RCP)	Representative concentration pathways (RCPs) Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use / land cover. The word 'representative' signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. The term 'pathway' emphasizes the fact that not only the long-term concentration levels, but also the trajectory taken over time to reach that outcome are of interest. RCP2.6: One pathway where radiative forcing peaks at approximately 3 W m−2 and then declines to be limited at 2.6 W m−2 in 2100 (the corresponding Extended Concentration Pathway (ECP) assuming constant emissions after 2100). RCP4.5 and RCP6.0: Two intermediate stabilization pathways in which radiative forcing is limited at approximately 4.5 W m−2 and 6.0 W m−2 in 2100 (the corresponding ECPs assuming constant concentrations after 2150). RCP8.5: One high pathway which leads to >8.5 W m−2 in 2100 (the corresponding ECP assuming constant emissions after 2100 until 2150 and constant concentrations after 2250).[21]
Vulnerability	The propensity or predisposition of an asset to be affected, including sensitivity or susceptibility to financial harm (or opportunity) and capacity to cope and adapt.

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