



# Physical Climate Risk Assessment



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## Client

example company

example street

example town

example country

### Physical Climate Risk Assessment of site

example site of example company

example street

example town

example country

Lat: XX.XXXXXX / Long: XX.XXXXXX

Date: XX.XX.2024

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## About Physical Climate Risk Reporting

HRC Physical Climate Risk Reporting provides a comprehensive evaluation of climate-related physical risks to which the site analysed is and/or will be exposed to in the wake of climate change. This report contains all information required to complete essential steps of EU Taxonomy-compliant climate risk and vulnerability assessments.

All organizations falling under the EU Corporate Sustainability Reporting Directive must report in accordance with the EU Taxonomy<sup>1</sup>.

Since 2022, the EU Taxonomy Regulation has been a key component of the EU Green Deal. It is a cornerstone of the EU framework for sustainable finance and part of the "Action Plan on Financing Sustainable Growth" issued by the EU Commission in March 2018<sup>1</sup>. This plan including regulations was established to enable channelling of capital flows towards environmentally sustainable economic activities. "Sustainable economic activity" lacked clear regulatory definitions in the EU until that point<sup>1</sup>. Since the EU Taxonomy has conclusively defined "sustainable economic activity", it is considered an important classification system nowadays allowing for unambiguous assessments and rankings of economic activities in terms of their environmental sustainability<sup>1</sup>. Thus, the EU Taxonomy is a crucial tool for market transparency that supports direct investment in economic activities that are most suitable to help reduce effects of climate change.

All companies with the aim of achieving EU taxonomy conformity for their economic activities must follow the detailed requirements for a "robust climate risk and vulnerability assessment" (according to the Commission Delegated Regulation (EU) 2021/2139, Annex A). This is necessary on the one hand for the contribution to the two climate-related objectives *adaptation to climate change* and *mitigation of climate change*. On the other hand, the implementation of a "robust climate risk and vulnerability assessment" is also part of the "do-no-significant-harm" (DNSH) criteria for the two above mentioned climate-related objectives and must therefore be carried out for every economic activity for which EU Taxonomy conformity needs to be achieved.

Climate change induced increases of frequency and intensity of most physical climate risks necessitate this kind of physical climate risk and vulnerability assessment. In case of physical climate risks endangering sites of an organisation and company by e.g., exceedance of certain thresholds related to key parameters of single physical climate risks like water depths in cases of floodings, maximum wind speeds in cases of storms or when these key parameters yield higher intensities compared to historical conditions, sites can experience physical damages leading to high losses and/or business interruptions as worst case.

This report provides an extensive analysis and information on acute and chronic climate risks at site level, in the wake of different climate scenarios and time spans.

<sup>1</sup>German Environment Agency (2022) - [https://www.umweltbundesamt.de/sites/default/files/medien/2666/dokumente/climate-risk-assessments-for-taxonomy-reporting\\_final\\_bf\\_221122.pdf](https://www.umweltbundesamt.de/sites/default/files/medien/2666/dokumente/climate-risk-assessments-for-taxonomy-reporting_final_bf_221122.pdf)

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## About the methodology of HRC Physical Climate Risk Reporting

### **Key Terminology**

#### *Climate-related risk vs. climate-related hazard*

Key terms of this report like “risk” or “hazard” can be used in many ways. To describe the process of a climate risk and vulnerability assessment in a comprehensible manner, consistent terminology is important. Following the Climate Delegated Act, the assessment of physical climate risks must consider the state-of-the-art methodologies “in line with the most recent report of the Intergovernmental Panel on Climate Change” (IPCC). In 2023, this is IPCC assessment report six (IPCC AR 6).

A climate-related risk is the potential for adverse consequences for human or ecological systems (lives, livelihoods, health and wellbeing, economic, social, and cultural assets and investments, infrastructure, services provision, ecosystems, and species). A climate-related risk is a result of interactions between climate-related hazards and the exposure and vulnerability of human or ecological systems as well as physical assets. It integrates the likelihood of exposure to a hazard and the magnitude of its impact. It is dynamic in the sense that these three elements can change over time with changing socioeconomic or climatic conditions.

A climate-related hazard is a potential source of harm. Climate-related hazards are the potential occurrence of a natural or human-induced physical event or trend that could expose human or ecological systems as well as physical assets to adverse consequences, such as damage or disruption, loss of infrastructure, loss of life or injury and/or other health-related impacts.

#### *Return period*

A metric widely used to describe the probability of physical (climate) risks occurring, such as flooding. Return periods indicate the probability of a risk of a given intensity occurring each year. For example, a flood event with a statistical return period of 100 years has a 1/100 (or 1 %) annual occurrence probability. The quantification of probabilities of occurrence is an important indicator in the assessment of physical (climate) risks.

#### *Vulnerability*

Vulnerability describes the degree to which pre-existing conditions or characteristics of human and ecological systems interact with a hazard and their individual exposure to determine the level of adverse impacts they may experience. The vulnerability of a site is for example expressed in terms of sensitivity, susceptibility, or lack of ability to cope with and adapt to a climate-related hazard.

#### *Climate Scenarios*

Climate scenarios are analytical tools used to explore the potential impacts of climate change under different (socioeconomic) conditions. Their purpose is to support and inform decisions that anticipate the physical impacts of climate change and create strategies to mitigate and adapt. Climate scenarios explore different trajectories across the 21st century, based on a range of different potential developments in society in terms of human activity and global emissions. They describe plausible climate futures, rather than predict future outcomes, considering climate science, social science, and economics to project how the evolution of human activity might interact with our climate system. This report applies scenario definitions consisting of two complementary components: the Shared Socioeconomic Pathways (SSPs) and the Representative Concentration Pathways (RCPs).

The **Representative Concentration Pathways (RCPs)** were established in the 5th IPCC report published in 2013. They are defined as 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<sup>2</sup>. The word representative signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics<sup>2</sup>. The term pathway emphasizes the fact that not only long-term concentration levels but also the trajectory taken over time to reach that outcome are of interest<sup>2</sup>. The RCP 6.0 scenario is not applied in this report. This scenario is not suitable for a physical climate risk and vulnerability assessment due to lacking availability of regionalised data (the available global climate data with a resolution of approx. 100 km x 100 km would not provide sufficient insights)<sup>1</sup>.

The **Shared Socio-Economic Pathways (SSPs)** were developed to complement the RCPs with varying socio-economic challenges to adaption and mitigation in the 6th IPCC report published in 2021. Based on five narratives, the SSPs describe alternative socio-economic futures in the absence of climate policy intervention, comprising sustainable development (SSP1), regional rivalry (SSP3), inequality (SSP4), fossil-fueled development (SSP5) and middle-of-the-road development (SSP2)<sup>2</sup>. The combination of SSP-based socio-economic scenarios and Representative Concentration Pathway (RCP)-based climate projections provides an integrative frame for climate impact and policy analysis<sup>2</sup>. In this report, given pathway scenarios relate to the most recent terminology, therefore, SSPs are used (table 1).

### *Paris Agreement*

Following negotiations at COP21 in 2015, 191 members of the United Nations signed the Paris Agreement, making a legally binding commitment to limit global average temperature increase to less than 2 °C, and preferably to 1.5 °C and put national adaptation plans in place.

### *Adaptation*

Adaptation is the process of adapting to climate change. It involves identifying options, capacity-building and taking actions to cope with the impacts of climate change. Adaptation aims to avoid adverse impacts, mitigate risks, and capture opportunities. Identifying and assessing adaptation solutions to physical climate risks is prescribed by the CSRD as well as the EU Taxonomy and formally written into the Paris Agreement and Sustainable Development Goal (SDG) no. 13 as a critical component of climate action, along with mitigation.

### **Climate scenarios of HRC Physical Climate Risk Reporting**

The EU taxonomy stipulates the consideration of physical climate risks under **different scenarios**, mostly related to different global temperature developments in future. This way, the changing risk exposure of the analysed sites can be anticipated and assessed, not only over time, but also in relation to climate change, which is viewed progressing **at different rates of increasing global temperature driven by greenhouse gas concentrations emitted to the atmosphere in the different scenarios**.

<sup>2</sup>IPCC (2018): Annex I, Glossary - <https://www.ipcc.ch/sr15/chapter/glossary/>

This report applies the following different scenarios:

## Different Scenarios of physical climate risks

| Scenario Designation   | Shared Socioeconomic Pathway (SSP) | Explanation                                                                                                                                                                                                                                                          |
|------------------------|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Paris-aligned          | SSP1-2.6 *                         | Sustainability-driven pathway: The mitigation and adaptation challenges are small. With an additional radiative forcing of 2.6 W/m <sup>2</sup> by 2100 (compared to pre-industrial 1850), global warming is projected to be below 2 °C by the end of this century.  |
| Emissions Peak in 2040 | SSP2-4.5 *                         | Middle of the road: The mitigation and adaptation challenges are medium. With an additional radiative forcing of 4.5 W/m <sup>2</sup> by 2100 (compared to pre-industrial 1850), global warming is projected to be between 2 °C and 3 °C by the end of this century. |
| Business as Usual      | SSP5-8.5 *                         | "Worst case scenario". Especially the mitigation challenges are high. With an additional radiative forcing of 8.5 W/m <sup>2</sup> by 2100 (compared to pre-industrial 1850), global warming is projected to be over 4 °C by the end of this century.                |

\* In the context of climate change, scenario definitions consisting of two complementary components are currently applied: the Shared Socioeconomic Pathway (SSPs), which describe potential future socioeconomic developments, and the Representative Concentration Pathway (RCPs), which depict possible concentration pathways of atmospheric greenhouse gases and thus potential future developments of the climate. The climate scenarios are based on a combination of information on socio-economic development (SSP) and the resulting development of greenhouse gas concentrations and climate (RCP).

Table 1: Scenario description of physical climate risks according to IPCC and EarthScan (Mitiga Solutions)

All scenarios can potentially occur and are linked to different concentrations of greenhouse gases emitted in the global atmosphere. This report shows how the site-specific risk exposure can change under different climate scenarios and their impact in terms of different assumed manifestations of climate change.

Under the aspect of risk exposure to climate-related risks, the EU taxonomy requires the consideration of **different points in time in the future**. A decadal approach is recommended. The EU Taxonomy defines that *current* climate risks correspond to a period to 10 years from now. The indication "short-term" refers to the year 2025. *Future* climate risks are grouped in a period of 10 to 30 years ("medium-term": 2040). In addition, this report provides climate data for 2060, thus, completing the assessment of a "long-term" projection.

## Climate risk data of HRC Physical Climate Risk Reporting

This report is based on data from EarthScan™ (Mitiga Solutions) and ARGOS (HDI Global SE). Both tools use scientific climate data (including CMIP6, ERA5, NASA GDDP or CORDEX) to determine the risk exposure of a specific site as accurately as possible. The data outputs are continuously validated. The validation process includes a range of sanity checks, differential mapping, scientific and statistical validation. This report is thus orientated towards the requirements of the EU Taxonomy for the data basis of a physical climate risk and vulnerability analysis.

## Physical Climate Risk Table

|                                                     | Business as Usual Scenario |      |                     | Emissions Peak in 2040 Scenario |      |                          | Paris-aligned Scenario |      |      |
|-----------------------------------------------------|----------------------------|------|---------------------|---------------------------------|------|--------------------------|------------------------|------|------|
|                                                     | 2025                       | 2040 | 2060                | 2025                            | 2040 | 2060                     | 2025                   | 2040 | 2060 |
| <b>Temperature-related risks</b>                    |                            |      |                     |                                 |      |                          |                        |      |      |
| Changing temperature (chronic)                      | B                          | C    | D                   | B                               | C    | C                        | B                      | C    | C    |
| Heat Stress (chronic)                               | B                          | C    | D                   | B                               | C    | C                        | B                      | C    | C    |
| Temperature variability (chronic)                   |                            |      |                     |                                 |      |                          |                        |      |      |
| Permafrost thawing (chronic)                        | A                          | A    | A                   | A                               | A    | A                        | A                      | A    | A    |
| Heat wave (acute)                                   | B                          | C    | D                   | B                               | C    | C                        | B                      | C    | C    |
| Cold wave/ frost (acute)                            |                            |      |                     |                                 |      |                          |                        |      |      |
| Wildfire (acute)                                    | A                          | A    | A                   | A                               | A    | A                        | A                      | A    | A    |
| <b>Wind-related risks</b>                           |                            |      |                     |                                 |      |                          |                        |      |      |
| Changing wind patterns (chronic)                    |                            |      |                     |                                 |      |                          |                        |      |      |
| Storm (cyclone, hurricane, typhoon) (acute)         | A                          | A    | A                   | A                               | A    | A                        | A                      | A    | A    |
| Storm (blizzard, dust- and sandstorm) (acute)       | C                          | C    | C                   | C                               | C    | C                        | C                      | C    | C    |
| Tornado (acute)                                     | E                          | E    | E                   | E                               | E    | E                        | E                      | E    | E    |
| <b>Water-related risks</b>                          |                            |      |                     |                                 |      |                          |                        |      |      |
| Changing precipitation patterns and types (chronic) | E                          | E    | F                   | E                               | E    | E                        | E                      | E    | E    |
| Precipitation or hydrological variability (chronic) |                            |      |                     |                                 |      |                          |                        |      |      |
| Ocean acidification (chronic)                       | A                          | A    | A                   | A                               | A    | A                        | A                      | A    | A    |
| Saline intrusion (chronic)                          | A                          | A    | A                   | A                               | A    | A                        | A                      | A    | A    |
| Sea level rise (chronic)                            | A                          | A    | A                   | A                               | A    | A                        | A                      | A    | A    |
| Water stress (chronic)                              |                            |      |                     |                                 |      |                          |                        |      |      |
| Drought (acute)                                     | A                          | B    | B                   | A                               | A    | B                        | A                      | A    | A    |
| Heavy precipitation (acute)                         | E                          | E    | F                   | E                               | E    | E                        | E                      | E    | E    |
| Flood (acute)                                       | B                          | B    | B                   | B                               | B    | B                        | B                      | B    | B    |
| Glacial lake outburst (acute)                       | A                          | A    | A                   | A                               | A    | A                        | A                      | A    | A    |
| <b>Solid-mass related risks</b>                     |                            |      |                     |                                 |      |                          |                        |      |      |
| Coastal erosion (chronic)                           | A                          | A    | A                   | A                               | A    | A                        | A                      | A    | A    |
| Soil degradation (chronic)                          |                            |      |                     |                                 |      |                          |                        |      |      |
| Soil erosion (chronic)                              |                            |      |                     |                                 |      |                          |                        |      |      |
| Solifluction (chronic)                              | A                          | A    | A                   | A                               | A    | A                        | A                      | A    | A    |
| Avalanche (acute)                                   | A                          | A    | A                   | A                               | A    | A                        | A                      | A    | A    |
| Landslide (acute)                                   | A                          | A    | A                   | A                               | A    | A                        | A                      | A    | A    |
| Subsidence (acute)                                  |                            |      |                     |                                 |      |                          |                        |      |      |
| <b>Legend</b>                                       |                            |      |                     |                                 |      |                          |                        |      |      |
| A minimal risk                                      |                            |      | D medium risk       |                                 |      | (grey) no data available |                        |      |      |
| B low risk                                          |                            |      | E high risk         |                                 |      |                          |                        |      |      |
| C moderate risk                                     |                            |      | F extreme high risk |                                 |      |                          |                        |      |      |

Table 2: Risk exposure of example under the influence of different climate scenarios

## Physical Climate Risk analysis of site in example

In the following, the climate-related risk exposure is considered in a differentiated manner. The Physical Climate Risk Table (table 2) shows the risk exposure of example under the influence of different climate scenarios (Business as Usual, Emissions Peak in 2040 and Paris-aligned). Furthermore, the risks shown in table 2 with an **increased exposure ( $\geq$  moderate risk) are generally explained and further elaborated for the Business as Usual scenario (BAU) as it is recommended by supervisory authorities to at least refer to the worst-case scenario. Exemplary adaptation solutions are then proposed to mitigate the risk.**

### Temperature-related risks

Temperature-related risks refer to adverse weather or climatic events and conditions resulting from variations in temperature with significant impacts on the environment, natural ecosystems, agriculture, and human activities. Temperature-related physical climate risks can occur as temperature changes, heat stress, wildfires, heat and cold waves or permafrost thawing. Respective temperature related climate risks posing a risk to analysed site are explained below.

The Physical Climate Risk Table shows that the site in example, is at minimal (A) to medium (D) risk to temperature-related climate hazards. This site is mostly exposed to changing temperatures, heat stress and heat waves.

#### Changing temperature

Changing temperature is a chronic climate-related hazard that refers to alternations in the average air and/or water temperature patterns of a region or the earth's climate system, resulting from various natural processes and human activities. This phenomenon is characterised by slow and continuous changes which encompass both warming (increasing temperature) and cooling (decreasing temperature) trends. The impact of changing temperature can occur in form of heat waves, altered precipitation patterns, melting ice and glacial retreat, ocean warming, permafrost thawing, or shifts in climate zones. Effects of these respective hazards can result in e.g., crop failures, overheated cities and production sites, flooding, and increased extreme weather events.

#### *Adaptation solutions*

In large parts of the world temperatures have risen chronically as the global mean air temperature has increased 1.1 °C from the early-industrial period (18<sup>th</sup> century) compared to recently (2021). Adaptation solutions should, therefore, include checking the heat resilience of building materials at the site. Furthermore, the cooling of buildings, production areas and infrastructure classified as essential should be ensured during the process of rising average temperatures. Another important factor is the working temperature (especially in production areas). For health and safety reasons and to prevent endangering operational processes, the working temperature at the site should be controllable by air conditioning and/ or sunshades.

#### Heat stress

Heat stress refers to the adverse health and environmental effects resulting from prolonged exposure to high temperatures. This chronic hazard is primarily characterised by significantly higher-than-average temperatures that can persist for extended periods. Therefore, it can severely affect natural ecosystems and anthropogenic activities and infrastructure by droughts, reduced water availability, stress on plant and animal populations and wildfires. Cities are particularly vulnerable to heat stress and extreme heat events due to the urban heat island effect. This phenomenon occurs when urban areas trap and retain heat causing temperatures to be significantly higher than in surrounding areas.

Human health and infrastructure are particularly vulnerable in this context. Site-level impacts include the risk of expansion or melting of building materials such as tarmac or asphalt. The consequences can be damaged roads and/or buildings, disrupted networks of transportation, power, and communication. Since metal rusts faster when exposed to high temperatures, the risk of weakened concrete structures with internally reinforced steel may also be increased.

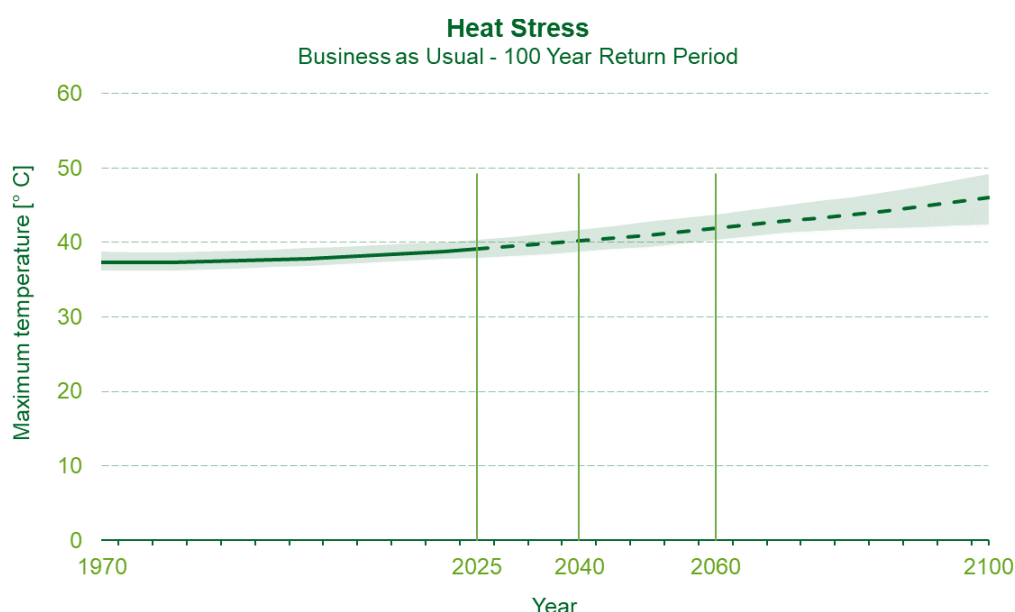


Figure 1: Heat stress risk at site in example over time (1970 to 2100) shown by increasing maximum temperature of the BAU climate scenario (with the metric marker set for 2025)

#### Heat stress

| Percentile | Business as Usual Scenario |       |       | Emissions Peak in 2040 Scenario |       |       | Paris-aligned Scenario |       |       |
|------------|----------------------------|-------|-------|---------------------------------|-------|-------|------------------------|-------|-------|
|            | 2025                       | 2040  | 2060  | 2025                            | 2040  | 2060  | 2025                   | 2040  | 2060  |
| 95th       | 40.34                      | 41.65 | 43.74 | 40.23                           | 41.36 | 42.46 | 40.14                  | 40.83 | 41.40 |
| 50th       | 39.11                      | 40.20 | 41.89 | 39.15                           | 40.04 | 40.90 | 38.94                  | 39.54 | 39.93 |
| 5th        | 37.98                      | 38.76 | 40.33 | 38.18                           | 38.85 | 39.64 | 37.93                  | 38.41 | 38.89 |

Development of **Max. temperature** under different scenarios and a **return period of 100 years**. Temperature given in °C.

Table 3: Values of average max. temperature (°C) with ranges of uncertainty (5<sup>th</sup> and 95<sup>th</sup> percentile) at site in example

Under a business-as-usual scenario, heat stress over the site in example will on average increase relative to 1970s levels (figure 1, table 3). Expected maximum temperature (under a statistical 100-year

return period) will show an increase of 2.91 °C by 2040 from a baseline of 37.29 °C in 1970 to 40.20 °C (figure 1, table 3). For the year 2060, the max. temperature is expected to increase to 41.89 °C (increase of 4.60 °C from the 1970s, figure 1, table 3).

As the blue line represents the median values (50<sup>th</sup> percentile) of the max. temperatures at the site in example, the blue area represents the upper (95<sup>th</sup> percentile) and lower (5<sup>th</sup> percentile) limits representing ranges of uncertainties of the values of max. temperatures (figure 1, table 3).

### *Adaptation solutions to heat stress*

For protection of industrial plants as well as densely populated areas from heat stress, the installation of shading systems and - where possible - the partial removal of impervious surfaces can be a first aid measure. Also, the planting of vegetation (especially in urban areas) has proven to be effective protection against overheating. In industrial context, organisations must adapt their water management to their risk of heat stress. Heat stress can affect water availability. Cooling processes, the dependence on waterways or water-dependent production processes must be checked for their resilience to water shortages. Furthermore, building materials can be damaged by heat. Their durability should also be checked on a regular base. Another crucial factor is the working temperature. For health and safety reasons and to prevent endangering operational processes, the working temperature of the site should be monitored and remain controllable by air conditioning and/ or sunshades.

### **Heat waves**

A heat wave is a prolonged period of excessively hot weather, which may be accompanied by high humidity, and is typically defined based on specific temperature thresholds for a region or location. Classified as acute hazards, heat waves can vary in intensity depending on the additional occurrence of wind, humidity, and radiation. They can last from two days to months and therefore can lead to potentially high economic damage to industry and agriculture. In addition to crop failures, heat waves can also cause severe damage to infrastructure. Energy networks can fail, roads can become temporarily impassable, or waterways can dry up. Extreme heat can also damage materials, e.g., through deformation, and harm heat-sensitive tanks.

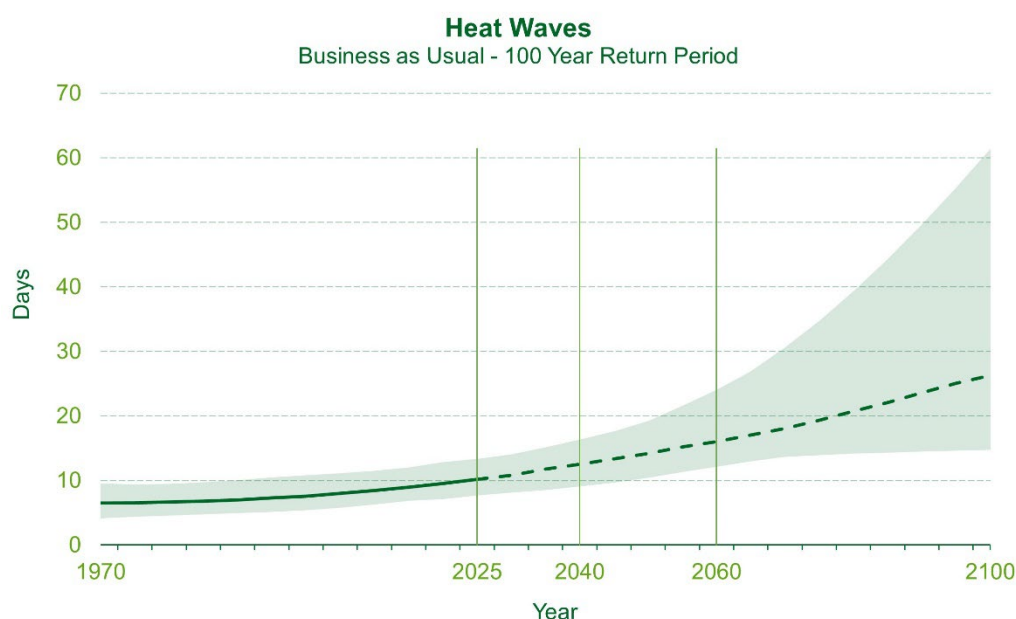


Figure 2: Heat stress risk at site in example over time (1970 to 2100) shown by increasing number of heat wave days in the BAU climate scenario (with the metric marker set for 2025)

## Heat waves

| Percentile | Business as Usual Scenario |       |       | Emissions Peak in 2040 Scenario |       |       | Paris-aligned Scenario |       |       |
|------------|----------------------------|-------|-------|---------------------------------|-------|-------|------------------------|-------|-------|
|            | 2025                       | 2040  | 2060  | 2025                            | 2040  | 2060  | 2025                   | 2040  | 2060  |
| 95th       | 13.33                      | 16.36 | 24.01 | 13.09                           | 15.21 | 17.83 | 12.49                  | 14.33 | 15.61 |
| 50th       | 10.17                      | 12.53 | 16.04 | 10.10                           | 11.88 | 13.79 | 9.88                   | 11.31 | 12.44 |
| 5th        | 7.65                       | 9.05  | 12.16 | 8.03                            | 9.42  | 10.88 | 7.86                   | 8.63  | 9.13  |

Development of **heat wave days** under different scenarios and a **return period of 100 years**. Values given in days.

Table 4: Heat wave days with ranges of uncertainty (5<sup>th</sup> and 95<sup>th</sup> percentile) at site in example

Under a business-as-usual scenario, heat waves in example will on average increase relative to 1970s levels (figure 2, table 4). Expected heat waves under a statistical 100-year return period will show an increase of 6.05 days on average by 2040 from a baseline of 6.48 days in 1970 to 12.53 days (figure 2, table 4). For the year 2060, an additional increase of 3.51 days to 16.04 days is projected under these conditions (figure 2, table 4).

As the blue line represents the median values (50<sup>th</sup> percentile) of number of days of a heat wave at the site in example, the blue area represents the upper (95<sup>th</sup> percentile) and lower (5<sup>th</sup> percentile) limits representing ranges of uncertainties of number heat wave days (figure 2, table 4).

### Adaptation solutions to heat waves

Like other temperature-related physical climate risks, densely populated areas are particularly vulnerable to heat. Humans are not well adapted to heat; thus, technical adaptations should include the installation of air conditioning or other structural measures to reduce indoor temperatures. It is also advisable to set up extended emergency services at sites increasingly affected by heat waves. In the industrial context, organisations must adapt their water management to their risk of prolonged and intense heat waves. Cooling processes, the dependence on waterways or water-dependent production processes must be checked for their resilience to water shortages. Furthermore, the heat resistance of site buildings should be checked regularly as well as vulnerable production sites (e.g., heat-sensitive tanks). For health and safety reasons and to prevent endangering operational processes, the working temperature at the site should be monitored and remain controllable by air conditioning and/or sunshades.

## Wind-related risks

Wind-related hazards refer to weather events or conditions driven by changes in atmospheric circulation patterns and wind patterns resulting from global climate change. These changes pose risks like structural damages to buildings, infrastructure disruption or agricultural failures. Wind-related hazards include changing wind patterns, increased wind speed risks, storms, tornadoes, dust storms, blizzards. Wind is a climate hazard itself, but it can also indirectly amplify or mitigate many other climate-related physical risks. The type of these wind-related hazards posing a risk to analysed site is explained below.

The Physical Climate Risk Table (table 2) shows that the example is at minimal (A) to high (E) risk to wind related hazards. In this risk category, the site is mostly exposed to wind risk (extra-tropical storm systems e.g., winter storms) and tornados.

### Wind risk

Storms are complex systems driven by atmospheric and oceanic exchanges of heat and energy. In the category of **extra-tropical storms** applicable for example, wind speeds higher than 20.8 m/s can be considered as stormy (table 5). Strong winds and storms are common natural hazards that can cause widespread damages especially to buildings and infrastructure. During wind speeds of 24.5 m/s, even medium-sized objects can start moving or tiles can be lifted off roofs. Wind speeds over 32.7 m/s correspond to the highest scale level of extra-tropical storms and can bring severe devastation. Storms can disrupt operations and limit access to sites through damaged infrastructure, leading to business interruption. Post-storm clean-up processes can lead to even longer closures. Additionally, extreme wind events can damage power infrastructure leading to power outages. It should be considered that wind also contributes to the amplification of other climate-related risks: It plays a crucial role in the spread of wildfires, carrying embers over greater distances making wildfires more destructive and difficult to control. Moreover, wind can contribute to the spread of corrosive salt spray further inland from coastal areas.

Beaufort wind speed scale from ARGOS (HDI Global SE)

| Zone | Beaufort | Description     | Windspeed up to |      | Impact                                                                                                                   |
|------|----------|-----------------|-----------------|------|--------------------------------------------------------------------------------------------------------------------------|
|      |          | Windspeed       | m/s             | km/h | On land                                                                                                                  |
| 5    | 12       | Hurricane force | >32.7           | >118 | Severe widespread damage to vegetation and structures, debris and unsecured objects are hurled up                        |
| 4    | 11       | Violent storm   | 32.7            | 118  | Widespread vegetation and structural damage likely                                                                       |
| 3    | 10       | Storm           | 28.5            | 102  | Trees are broken off or uprooted, structural damage likely                                                               |
| 2    | 9        | Strong gale     | 24.5            | 88   | Some branches break off trees, and some small trees blow over, construction/temporary signs and barricades blow over     |
| 1    | 8        | Fresh gale      | 20.8            | 74   | Some twigs broken from trees, cars veer on road, progress on foot is seriously impeded                                   |
| 0    | 7        | Moderate gale   | 17.2            | 61   | Whole trees in motion, effort needed to walk against the wind                                                            |
|      | 6        | Strong breeze   | 13.9            | 49   | Large branches in motion, whistling heard in overhead wires, umbrella use becomes difficult, empty plastic bins tip over |
|      | 5        | Fresh breeze    | 10.8            | 38   | Branches of a moderate size move, small trees in leaf begin to sway                                                      |
|      | 4        | Moderate breeze | 8.0             | 28   | Dust and loose paper raised, small branches begin to move                                                                |
|      | 3        | Gentle breeze   | 5.5             | 19   | Leaves and small twigs constantly moving, light flags extended                                                           |
|      | 2        | Light breeze    | 3.4             | 11   | Wind felt on exposed skin, leaves rustle, wind vanes begin to move                                                       |
|      | 1        | Light air       | 1.6             | 5    | Smoke drift indicates wind direction, leaves and wind vanes are stationary                                               |
|      | 0        | Calm            | <0.3            | <2   | Calm, smoke rises vertically                                                                                             |

Table 5: Beaufort wind speed scale from ARGOS (HDI Global SE)

Under a business-as-usual scenario, wind risk in example will on average show no significant increase relative to 1970s levels (figure 3, table 6). The expected extreme wind speed under a statistical 100-year return period by 2040 (35.79 m/s) will yield similar values as in 1970 (35.84 m/s) (figure 3, table 6). This wind speed corresponds to **hurricane force** (table 5). For the year 2060 (35.80 m/s), no significant increase of extreme wind speeds is projected under these conditions (figure 3, table 6).

As the blue line represents the median values (50<sup>th</sup> percentile) of extreme wind speeds at the site in example, the blue area represents the upper (95<sup>th</sup> percentile) and lower (5<sup>th</sup> percentile) limits representing ranges of uncertainties of the values of extreme wind speeds (figure 3, table 6).

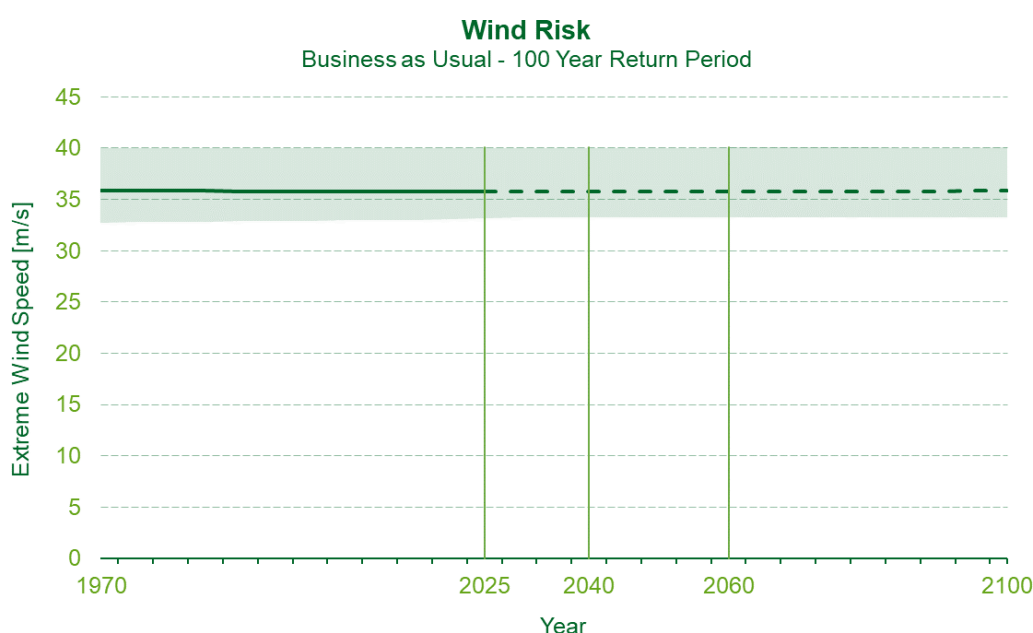


Figure 3: Wind risk at site in example over time (1970 to 2100) shown by wind speeds of extreme wind events in the BAU climate scenario (with the metric marker set for 2025)

#### Wind Risk

| Percentile | Business as Usual Scenario |       |       | Emissions Peak in 2040 Scenario |       |       | Paris-aligned Scenario |       |       |
|------------|----------------------------|-------|-------|---------------------------------|-------|-------|------------------------|-------|-------|
|            | 2025                       | 2040  | 2060  | 2025                            | 2040  | 2060  | 2025                   | 2040  | 2060  |
| 95th       | 40.01                      | 39.99 | 40.05 | 40.09                           | 39.99 | 40.01 | 40.04                  | 40.14 | 40.22 |
| 50th       | 35.78                      | 35.79 | 35.80 | 35.76                           | 35.72 | 35.68 | 35.76                  | 35.72 | 35.68 |
| 5th        | 33.16                      | 33.22 | 33.25 | 32.99                           | 32.93 | 32.80 | 33.15                  | 33.20 | 33.05 |

Development of **extreme wind speed** under different scenarios and a **return period of 100 years**. Wind speed given in m/s.

Table 6: Values of max. wind speeds (m/s) with ranges of uncertainty (5<sup>th</sup> and 95<sup>th</sup> percentile) at site in example

### Adaptation solutions to storms

Studies have shown that losses from severe windstorms can be minimized by regular maintenance and (immediate) organisation before a storm. The risk of building damage due to inadequately fastened components at the site should be mitigated. With consistent compliance to building standards, the structure and building envelope can be adequately protected against storms. Construction companies can normally provide the relevant documentation of such. Many damages are due to inadequate or missing verifications or insufficient consideration of the interfaces. Especially outdoor storage facilities can pose high risks. In this case ensure wind-resistant accommodation. In general, emergency plans should be developed for the event of severe storms or high winds to always control operations. This ensures the safety of staff and reduces the potential of property damage and business interruptions.

### Tornado

A tornado is a narrow, violently rotating column of air that extends from a thunderstorm to the ground. Because wind is invisible, it is hard to see a tornado unless it forms a condensation funnel consisting of water droplets, dust, and debris. Tornadoes occur in many parts of the world, including Australia, Europe, Africa, Asia, and South America. Even New Zealand reports up to 20 tornadoes each year. Two of the highest concentrations of tornadoes outside the U.S. have been detected in Argentina and Bangladesh. Tornadoes can generate extremely high winds, often exceeding wind speeds of 90 m/s, and are typically accompanied by intense thunderstorms. They are known for their potential to uproot trees, destroy buildings and infrastructure and endanger human lives.

Available data shows a high risk regarding tornadoes. From a statistical point of view, example is hit at least once every 100 years by a tornado with wind speeds up to 116 m/s (Fujita F4 event, table 8). Tornadoes with a higher intensity are possible but are subject to an annual occurrence probability lower than 1%.

### Fujita Scale from ARGOS (HDI Global SE)

| Zone | Fujita | Impact       | Windspeed |      | Description                                                                                                                                                                                  |
|------|--------|--------------|-----------|------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|      |        |              | m/s       | km/h |                                                                                                                                                                                              |
| 4    | F5     | Incredible   | >116.0    | >418 | Strong frame houses leveled off foundations and swept away; automobile-sized missiles fly through the air in excess of 100 meters (109 yds); trees debarked; incredible phenomena will occur |
| 3    | F4     | Devastating  | 116.0     | 418  | Well-constructed houses leveled; structures with weak foundations blown away some distance; cars thrown and large missiles generated                                                         |
|      | F3     | Severe       | 92.0      | 331  | Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown                                         |
| 2    | F2     | Considerable | 70.0      | 252  | Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground                           |
|      | F1     | Moderate     | 50.0      | 180  | Peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos blown off roads                                                                                     |
| 1    | F0     | Light        | <32.0     | <117 | Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged                                                                                    |
| 0    | < F0   |              |           |      |                                                                                                                                                                                              |

Table 7: Fujita scale

#### *Adaptation solutions to tornados*

For the safety of employees, it is advantageous for companies whose sites are in tornado-prone areas to invest in early warning systems such as smartphone alerts. Sufficient shelters should be available in the building. Employees should be trained on what to do in the event of a tornado and be aware of evacuation plans. In this regard, it is recommended to update emergency response plans for tornado-specific procedures. Also, it needs to be ensured that buildings comply with appropriate building standards. In case of uncertainties, constructional documentation can provide technical insights.

## **Water-related risks**

Alternations in global climate patterns impact water systems worldwide. Water-related hazards like flooding and heavy precipitation, but also water stress (when water demand exceeds the available amount or when poor water quality restricts its use) and drought can cause widespread damages to ecosystems, infrastructure, human societies, and business productions in the industrial sector. Other, more indirect hazards such as ocean acidification or sea level rise also pose risks to the environment, human societies, and industry. Respective water related climate risks posing a risk to analysed site are explained below.

The Physical Climate Risk Table (table 2) shows that example is at minimal (A) to extreme high risk (F) risk in water-related hazards. In this category, climate-related physical risks at the site emanate primarily from changing precipitation patterns and heavy precipitation.

### **Changing precipitation patterns and types**

Physical risks resulting from the change in precipitation patterns refer to chronic alternations in the timing, frequency, intensity, and geographic distribution of rainfall and snowfall. These alternations can manifest for example as **shifts in seasonal rainfall** or as **prolonged droughts**. For this site it is assumed that precipitation patterns will develop towards an increase in the number of rainfall events and an increasing intensity of these.

Changes in precipitation patterns can have significant impacts on ecosystems, water resources, agriculture, and infrastructure. The consequences of such chronic risks range from increased flood risks to food insecurity, water scarcity, or damage to critical infrastructure, e.g., inland waterways.

#### *Adaptation Solutions*

The water supply must be guaranteed during dry periods. Where possible, water reserves should be built up or rainwater stored. Regarding heavy rainfall events, the site drainage system must be designed for the expected rainfall amounts. Maintenance and servicing intervals for all drainage systems must be shortened and should be carried out at least twice a year, particularly in view of the expected accumulation of these events. An inspection of the site drainage system is strongly recommended for this purpose. This includes the drainage of roof surfaces. Flat roofs should be retrofitted with emergency spills if this has not already been done. An emergency response plan should be drawn up and implemented to ensure a standardised procedure in the event of an incident. If necessary, this should be supplemented by early warning systems (e.g., alert apps) and mobile or stationary protective measures.

## Heavy precipitation

Heavy precipitation is an acute extreme weather event that is difficult to predict. It refers to an intense amount of rain or snow falling within a relatively short period of time compared to average conditions for a specific region. Heavy precipitation events can have profound impacts on ecosystems, infrastructure and human communities, especially densely populated areas with a relatively high percentage of sealed surfaces. This hazard can lead to the highly increased risk of water ingress in buildings, flood, flash flood, landslide, and waterlogged infrastructure due to the rapid accumulation of water. This can cause serious damage to building materials, machinery, stored goods or communication infrastructure and lead to breakdowns or even business interruption.

Under a business-as-usual scenario and a statistical 100-year return period, the risk for the site in example will on average increase relative to 1970 risk levels. The expected max 5 day precipitation under a statistical 100-year return period will show an increase of 13.07 mm on average by 2040 from a baseline of 425.81 mm to 438.87 mm (figure 4, table 8). For the year 2060, an additional increase of 15.52 mm to 454.39 mm is projected under these conditions (figure 4, table 8). As the blue line represents the median values (50<sup>th</sup> percentile) of max. 5 day precipitation at the site in example, the blue area represents the upper (95<sup>th</sup> percentile) and lower (5<sup>th</sup> percentile) limits representing ranges of uncertainties of the values of water amounts (figure 4, table 8).

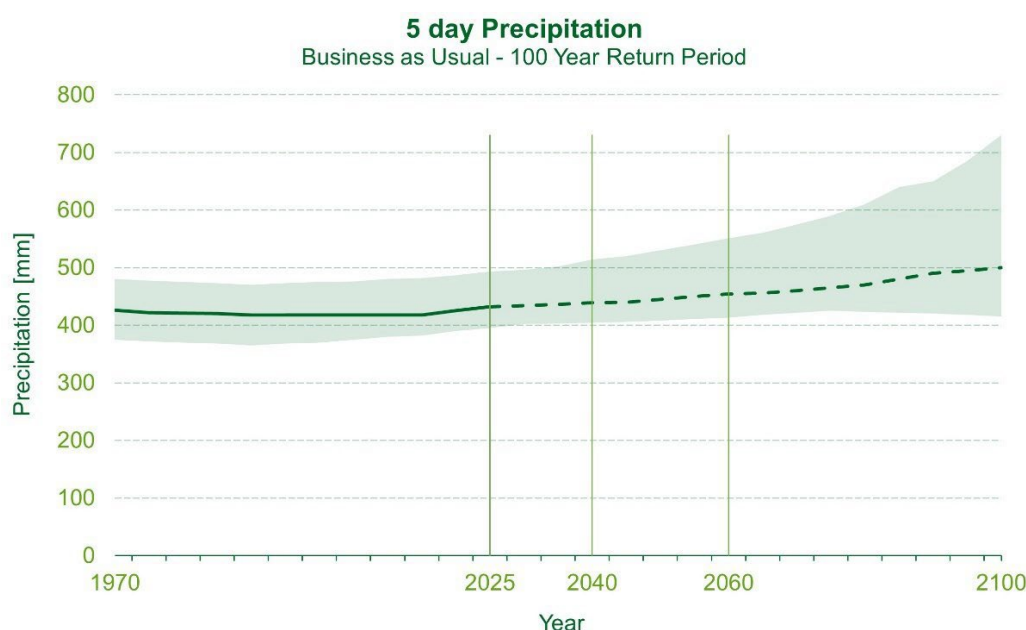


Figure 4: Max 5 day precipitation risk at the site in example over time (1970 to 2100) shown by water amounts in the BAU climate scenario (with the metric marker set for 2025)

### Precipitation risk

| Percentile | Business as Usual Scenario |        |        | Emissions Peak in 2040 Scenario |        |        | Paris-aligned Scenario |        |        |
|------------|----------------------------|--------|--------|---------------------------------|--------|--------|------------------------|--------|--------|
|            | 2025                       | 2040   | 2060   | 2025                            | 2040   | 2060   | 2025                   | 2040   | 2060   |
| 95th       | 493.23                     | 514.03 | 551.18 | 490.28                          | 504.11 | 521.17 | 490.39                 | 511.91 | 524.89 |
| 50th       | 431.89                     | 438.87 | 454.39 | 428.59                          | 432.54 | 438.56 | 430.04                 | 433.82 | 438.60 |
| 5th        | 401.74                     | 404.78 | 413.39 | 397.70                          | 403.89 | 408.16 | 398.12                 | 398.78 | 408.10 |

Development of **max. five day precipitation** under different scenarios and a **return period of 100 years**. Values given in mm.

Table 8: Max 5 day precipitation risk (mm) with ranges of uncertainty (5<sup>th</sup> and 95<sup>th</sup> percentile) at site in example

### Adaptation solutions

To better assess the risk exposure of different areas of your site, public municipal hazard maps can be helpful. Some municipalities publish hazard maps for the heavy precipitation area, which also indicate the topography of the landscape, the direction of water flow and the collection points of precipitation. This is important information for the development and implementation of mitigating adaptation solutions. For example, additional drainage systems (e.g., retention basins, if realisable) can be put in place for areas where water collects. Roof drainage systems should also be regularly maintained and extended, if necessary. Additionally, it is important to reinforce a flood-proof critical infrastructure or key storage facilities to minimise flood damage from heavy precipitation.

Fundamental to successful management that ensures internal operations and on-site occupational safety is preparedness: develop and practice emergency response plans and contingency plans specifically for heavy precipitation events, including evacuation and resource allocation. In the long term, proactive investments in restoring and protecting natural ecosystems such as wetlands and forests also help absorb excess rainwater and reduce flooding.

### Solid mass-related risks

Solid-mass-related hazards encompass chronic changes like coastal or soil erosion as well as acute phenomena like avalanches or landslides. Their occurrence has become more frequent and severe due to global warming inducing alterations of precipitation patterns. Solid mass-related hazards pose risks to densely populated areas, infrastructure, and ecosystems in vulnerable regions. Such regions often yield typical geographical and/or climatic characteristics: Mountainous areas are highly susceptible. But also, areas with uneven, hilly landscapes, outside of traditional mountain ranges can be vulnerable to landslides, soil erosion or solifluction exacerbated by heavy precipitation or thawing permafrost. Coastal areas around the world are also endangered by solid mass-related hazards since changing sea-level-rise and storm patterns can erode the shoreline. Special vulnerable regions include those with receding ice or volcanic areas.

The Physical Climate Risk Table (table 2) shows minimal (A) direct risk from solid-mass-related hazards for the analysed site. There is no data indicating critical thresholds for these hazards.