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CLIMATE CHANGE ADAPTATION HANDBOOK FOR HIGH-SCHOOLS



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This handbook contributes to the Sustainable Development Goals 4, 11 and 13. Its content is designed to support high-school teachers in their efforts to provide quality education (SDG 4). By providing information and inspiration on adaptation strategies and plans for urban areas, it fosters engagement towards sustainable cities and communities (SDG 11). By raising awareness and understanding about the cascading impacts of climate change, it supports broader climate action (SDG 13).

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This handbook was developed within the scope of the CLARKS Project – Climate Adaptation and Resilience Key in Schools – funded by the European Commission under the ERASMUS+ programme, with partners from Portugal, Finland, and Spain. The project aims to develop, implement, and disseminate an innovative learning and participatory methodology designed to empower teachers and students as agents of change in the field of climate change adaptation.

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1

INTRODUCTION

1. Introduction

It is unequivocal that human influence has warmed the atmosphere, ocean, and land, already affecting numerous weather and climate extremes across every region of the globe. This is evident through shifts in extreme events such as heatwaves, heavy precipitation, droughts, and tropical cyclones, amongst others. An estimated 3.3 to 3.6 billion people live in areas highly vulnerable to climate change, which has also led to significant damage and increasingly irreversible losses in terrestrial, freshwater, cryosphere, and marine ecosystems. It also has an impact on other systems, including human health and infrastructure. This handbook provides **concise information on the impacts of climate change** in natural and human systems, supported by the latest scientific research.

For schools, this global challenge offers a unique opportunity to inspire and equip the next generation with the knowledge and skills needed to navigate an increasingly uncertain world. Imagine a classroom where students not only learn about the adverse impacts of climate change but also actively contribute to developing solutions. It is essential to engage all generations in climate change mitigation efforts and support the development of adaptation measures that address both current impacts and future challenges. The effectiveness of these actions depends on widespread awareness of climate change's effects and the strategies available to respond, fostering a coordinated and impactful effort from all stakeholders. This handbook is intended to provide supporting information to **guide the visioning of climate change adaptation**.

Numerous scientific articles, books, reports, institutional documents, and web pages demonstrate and explain the causes and consequences of climate change. As a result, people have access to a vast amount of information. However, this abundance can be overwhelming, making it difficult to understand the full diversity and complexity of the topic. This handbook is intended to serve as a concise and accessible guide for teachers and students to learn about climate change, **organise their existing knowledge**, and stay informed with the most recent data.

The handbook begins with an overview of climate change (Section 2), followed by an explanation of how climate-related risks arise from the interplay between climate-hazards, vulnerability, exposure, and adaptive capacity (Section 3). To explore the impacts of climate change in a practical way, five overarching systems, referred to as target areas, are considered: ecosystems, food and water, human health, infrastructure, and socio-economics, as defined in Section 4. For each target area, Section 5 describes how climate-related hazards have already affected them and outlines potential future conditions. Finally, Section 6 presents a series of proposed lines of adaptation for each target area to address the ongoing and expected impacts of climate change.



2

CLIMATE CHANGE

2. Climate Change

Earth's climate varies considerably across different regions and over time. Climate change refers to long-term shifts in temperature and weather patterns, which can occur naturally due to factors such as changes in the sun's activity, the Earth's orbit, large volcanic eruptions, or plate tectonics, as well as internal variations within the climate system itself¹. However, since the 1800s, human activities have accelerated climate change, primarily due to the burning of fossil fuels, which produce **greenhouse gases** (GHG) emissions. The primary sources of human GHG emissions include oil and gas operations, as well as agriculture, energy, transportation, and daily activities such as driving a car and using heating systems².

Greenhouse gases are gases in the atmosphere that have the property of being mostly transparent to visible sunlight but not to infrared radiation (primarily associated with heat) emitted by the Earth's surface. These gases (including water vapour, carbon dioxide, methane and nitrous oxide) trap the infrared energy and send a part of it back to the surface, thus warming the lower atmosphere and the planet's surface. This phenomenon is known as the greenhouse effect³.

The rise in GHG emissions has led to an increase in global atmospheric temperature, as these gases absorb heat energy and trap it near the Earth's surface. The process is analogous to that of a greenhouse, which lets in sunlight but retains the resulting heat⁴. Due to these emissions, the global mean temperature has already risen by approximately 1.2°C above pre-industrial levels⁵.



By Mujahid360 on Freepik

This is illustrated in Figure 1, which shows the observed change in global mean surface temperature relative to the average temperature from 1850 to 1900. Data plotted in the graph are the Observed Global Mean Surface Temperature (GMST) change, obtained by considering four datasets from instrumental weather observation services (starting in the mid-19th century). For each period, the mean temperature change was obtained relative to the average temperature of 1850–1900.

Observed global mean surface temperature change

Relative to 1850-1900 using four datasets

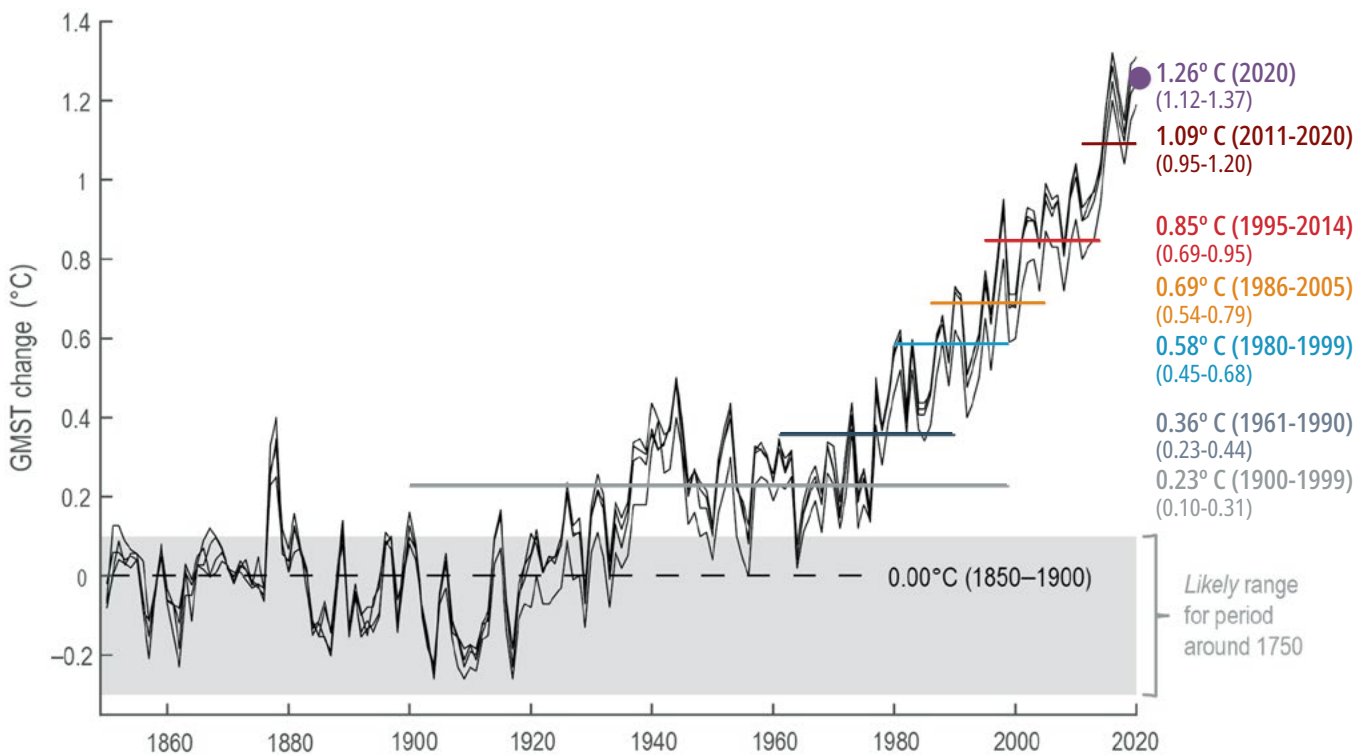


Figure 1 - Global warming over the instrumental period is evident in the increase of global mean surface temperature (GMST). Different reference periods are indicated by the coloured horizontal lines, and an estimate of total GMST change up to that period is given, enabling a translation of the level of warming between different reference periods. The small numbers in brackets under each temperature value show the 90% uncertainty range. This means there is a 90% likelihood that the true temperature change lies within that range. The value shown above the brackets is the best estimate, or the most likely value based on the available data. Source IPCC (2021)⁶.

Since 2000, the planet has experienced the ten warmest years on record, and in 2024, the Earth’s average land and ocean surface temperature was 1.3°C above the 20th-century average, marking the highest temperature in the climate records from 1850 to 2024⁷. These values represent global averages; however, in certain parts of Europe, temperatures have increased more rapidly, rising by approximately 2.1°C⁸.

The climate records from 1850 to 2024 are data provided by the NOAA – National Oceanic and Atmospheric Administration, the U.S.A. agency responsible for monitoring, understanding, and providing information about weather and climate, fisheries, ocean and coast, and satellite data, including real-time data.

The evolution of the Earth's climate, as illustrated, for example, in Figure 1, refers to past and present conditions. However, it is of critical importance to understand what may happen in the future. Predicting the Earth's climate is not a straightforward task, as it depends on how various factors will develop, including human behaviour. The different possibilities for future climatic conditions, projections or models of what could occur, are known as scenarios. Scenarios are a key element of climate change research and assessment. They help to highlight the long-term consequences of near-term decisions and allow researchers to explore a range of possible futures in the context of fundamental uncertainties. To estimate how the Earth's climate might respond under varying levels of global warming, the Intergovernmental Panel on Climate Change (IPCC) has developed a set of future climate scenarios.

IPCC – Intergovernmental Panel on Climate Change is an international organisation established by the United Nations Environment Programme (UN Environment) and the World Meteorological Organisation (WMO) in 1988. Through its assessments, the IPCC determines the state of knowledge on climate change. It identifies where there is agreement in the scientific community on topics related to climate change and where further research is needed.

These scenarios are climatic projections based on a range of assumptions and drivers, including population growth, technological and economic development, governance, land use and management practices, lifestyles, anthropogenic GHG emissions, and mitigation efforts⁶. It is important to note that these scenarios are not predictions, but rather projections, “what if” situations that explore the potential consequences of different pathways.

Since 1990, the IPCC has published six Assessment Reports, each providing a comprehensive evaluation of climate change, including its causes, impacts, and possible responses. Over time, four main sets of scenarios have been developed to project and explore future climate conditions: the 1992 IPCC Emission Scenarios (IS92), the Special Report on Emissions Scenarios (SRES), the Representative Concentration Pathways (RCPs), and, most recently, the Shared Socio-economic Pathways (SSPs)⁹.



Photo by Shawn, Unsplash

In the latest version of the IPCC scenarios, the number in each SSP (for example, SSP1 or SSP3) refers to a specific socio-economic development storyline (ranging from 1 to 5), which outlines futures such as sustainability-focused or fossil fuel-driven development. SSP1 envisions a more optimistic and environmentally conscious future, while SSP5 represents a future where economic growth is prioritised, often at the expense of environmental sustainability. Figure 2 shows simulated changes in global surface temperature relative to 1995–2014 under different scenarios. In the figure, each scenario also includes a second number (e.g. SSP1-1.9), which corresponds to the approximate global effective radiative forcing value projected for the year 2100⁶.

Effective radiative forcing refers to the measure of how much additional energy is entering or leaving the Earth's climate system as a result of changes such as increased GHG. When more energy enters the atmosphere than escapes back into space, it leads to warming. The SSP scenarios incorporate values ranging from 1.9 (a low-emissions, optimistic scenario with warming remaining below 1.5°C) to 8.5 (a high-emissions, pessimistic scenario with warming exceeding 4°C)¹⁰.

Global surface temperature change relative to 1850-1900

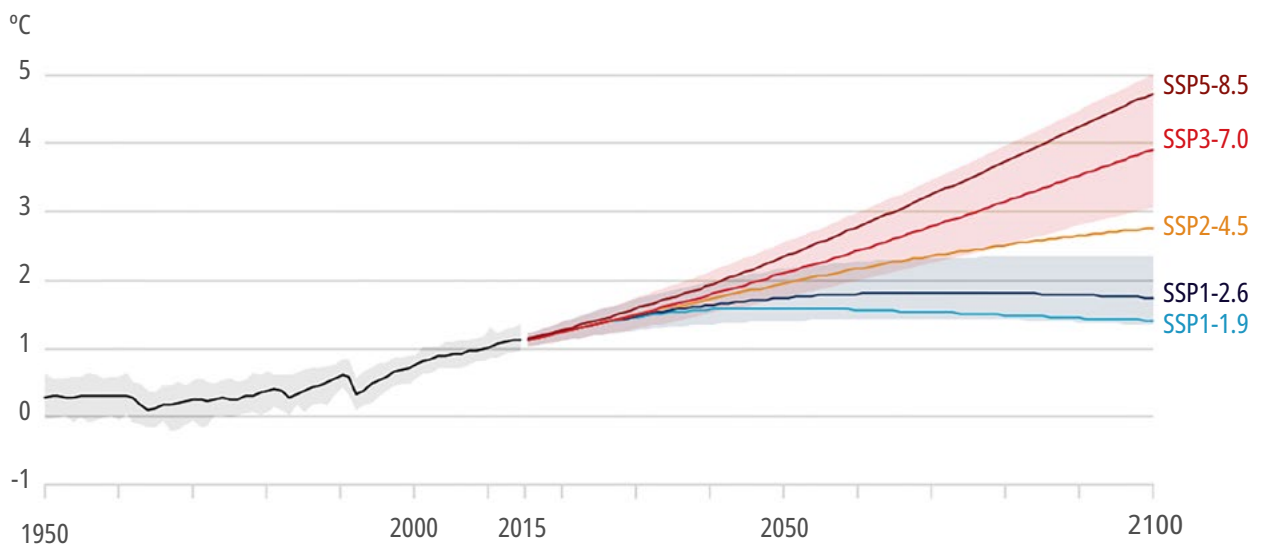


Figure 2 - Global surface temperature changes in °C relative to 1850-1900. Very likely ranges are shown for SSP1-2.6 and SSP3-7.0. Source IPCC (2021)¹⁰.

The scenarios of the IPCC, which range from SSP1-1.9 to SSP5-8.5, as illustrated in Figure 2, are therefore projections based on potential temperature changes and GHG emissions. Further details on these scenarios are provided in Figure 3.

Scenario	Temperature and GHG emissions by 2100	Characteristics
SSP1 - 1.9 SSP1 Sustainability Taking the Green Road	Increase of temperature < 1.5°C Very low CO ₂ emissions – net zero around 2050	<ul style="list-style-type: none"> • Decline in population (~7 billion in 2100) • High income and reduced inequalities • Effective land-use regulation • Less resource intensive consumption • Environmentally friendly technologies and lifestyles
SSP1 - 2.6 SSP1 Sustainability Taking the Green Road	Increase of temperature < 2°C Low CO ₂ emissions – net zero around 2050	<ul style="list-style-type: none"> • Medium population growth (~9 billion in 2100) • Medium income • Technological progress • Production and consumption patterns are a continuation of past trends • Only a gradual reduction in inequality occurs • Medium challenges to mitigation and adaptation
SSP2 - 4.5 SSP2 Middle of the Road	Increase of temperature < 3°C Intermediate CO ₂ emissions	<ul style="list-style-type: none"> • High population growth (~13 billion in 2100) • Low income and continued inequalities • Material-intensive consumption and production • Low rates of technological change • High challenges to mitigation and adaptation
SSP3 - 7.0 SSP3 Regional Rivalry A Rocky Road	Increase of temperature < 4°C High CO ₂ emissions	<ul style="list-style-type: none"> • Peak and decline in population (~7 billion in 2100) • High income, reduced inequalities, and free trade • Resource-intensive production, consumption and lifestyles • High challenges to mitigation and low challenges to adaptation
SSP5 - 8.5 SSP5 Fossil-fueled Development Taking the Highway	Increase of temperature > 4°C Very high CO ₂ emissions – double by 2050	<ul style="list-style-type: none"> • High challenges to mitigation and low challenges to adaptation

Figure 3 – IPCC Shared Socio-economic Pathway scenarios and related characteristics. Adapted from IPCC (2021)⁶ and IPCC (2022)¹¹.

Climate change has already caused significant impacts worldwide and is expected to continue doing so, as outlined in the scenarios discussed earlier. Other severe consequences include intense droughts, water shortages, widespread wildfires, rising sea levels, flooding, melting polar ice, catastrophic storms, and declining biodiversity¹². These processes exacerbate existing social inequalities and have profound effects on health and well-being. Additionally, they pose risks to food security and disrupt economic activities such as agriculture, aquaculture, and tourism¹³. These consequences are further described in the following sections.



3

UNDERSTANDING THE RISK

3. Understanding the Risk

3.1 Key Concepts

To accurately assess climate change risks, it is essential to understand several key terms, which are defined here. Different sources offer varying definitions and interpretations of these terms; however, to maintain consistency with this handbook and its focus on climate change, we have adopted the definitions provided by the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Office for Disaster Risk Reduction.

- ▶ **Risk:** The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems¹⁴.
- ▶ **Hazard:** A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation¹⁵.
- ▶ **Exposure:** The presence of people, livelihoods, species or ecosystems, environmental functions, services and resources, infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected¹⁴.
- ▶ **Vulnerability:** The propensity or predisposition to be adversely affected, encapsulating concepts such as sensitivity, susceptibility and lack of capacity to cope¹⁴.
- ▶ **Adaptation:** In human systems, the process of adjustment to actual or expected climate and its effects, to moderate harm or exploit beneficial opportunities¹⁴.
- ▶ **Adaptive capacity:** The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities or to respond to consequences¹⁶.
- ▶ **Mitigation (of climate change):** A human intervention to reduce emissions or enhance the sinks of greenhouse gases¹⁴.

A sink of greenhouse gases is a natural or artificial reservoir that absorbs and stores these gases from the atmosphere by chemical, physical and biological mechanisms. Examples include oceans, forests, and soils¹⁷.

3.2 Risk Variables

In the context of climate change, risks arise from the interaction between climate-related hazards, exposure, vulnerability, and adaptive capacity (see Figure 4). To better understand the risks and impacts of climate change, the IPCC and the European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation (ETC-CCA) have proposed a set of indicators. Indicators are measurable quantities that signal when a particular variable reaches a threshold beyond which significant consequences occur. Here, the most relevant indicators are explained following, whenever possible, the definitions provided by the Climate ADAPT platform from the European Environment Agency⁸.

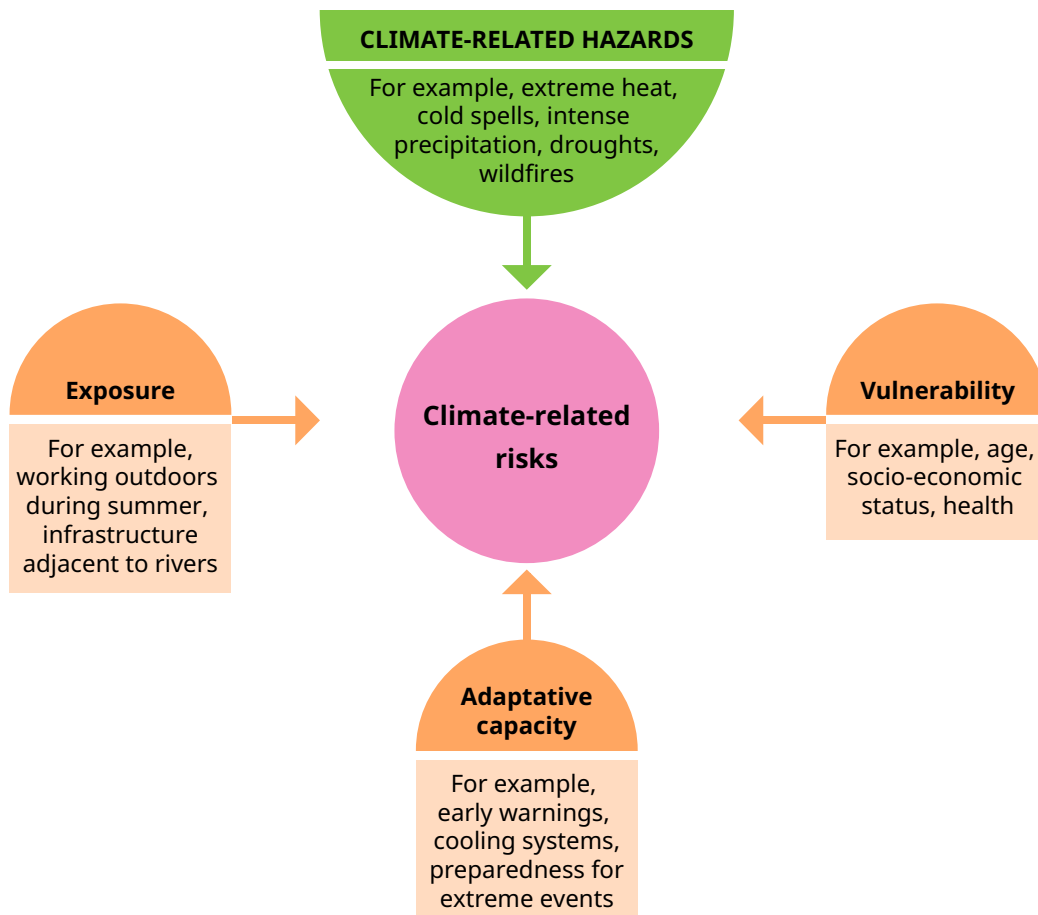


Figure 4 - Elements of climate-related risks: Climate-related hazards, Exposure, Vulnerability and Adaptive capacity, with examples of each element. *Adapted from European Climate Risk Assessment EEA (2024)*¹².

For the selection of relevant hazard, exposure, vulnerability and adaptive capacity indicators, global indicators at the national or international level were considered. For downscaling purposes, other indicators that better suit local adaptation needs may be considered. It should be noted that the definition of indicators can vary depending on the source consulted, as they may be developed for different contexts and are also subject to improvement in the future.

3.2.1 Indicators of Hazards

When considering the impacts of climate change, it is important to consider the climatic impact drivers. These are physical climate conditions that, when they exceed tolerance levels, can affect ecosystems and society¹⁸. These conditions are categorised into five groups based on their relationship to specific environmental factors: temperature (heat and cold), water availability (wet and dry), wind, freezing conditions (snow and ice), and marine environments (coast and ocean)¹⁸. Such physical conditions can give rise to climate-related hazards, which are climate events capable of causing damage, including heat-waves, extreme precipitation, droughts, and more^{12,18}.

Heat and Cold

Temperature changes can have significant effects, for example, on vegetation cover and distribution, as well as on the timing and conditions of crop-growing periods. Elevated temperatures can cause heat stress, impacting human health (example in Box A), ecosystems, and infrastructure¹². Table 1 identifies and describes indicators of extreme heat and cold. It is relevant to note that heatwaves are not defined by a fixed temperature, as their occurrence depends on the local climate, which exhibits variations between regions.

Table 1 - Indicators of climate-related hazards for heat and cold conditions.

Climate-related hazard	Indicator	Description
Extreme heat	Hot days	Total number of days when the daily maximum temperature remains above 30°C ¹⁹ .
	Heatwave	A period of at least 3 consecutive days exceeding 99% of the daily maximum temperature, between May and September, over a reference period ²⁰ .
Cold spells and frost	Frost days	Total number of days with a daily minimum temperature below 0°C ²¹ .

How to do it?

How to calculate a heatwave:

To understand how climatological heatwave days are calculated, imagine that in a certain country the daily maximum temperature was recorded between May and September for each day from 1991 to 2020 (in degrees Celsius, °C). This resulted in a total of 4,590 maximum temperature records. These values are then sorted in descending order, with the hottest days first. To determine the 99th percentile threshold, it is necessary to calculate how many days correspond to 1% of the total period of 30 years. Considering 1% of 4,590 days is 46 days, then the 46th value in the sorted list represents the maximum temperature threshold for that country. For example, if this value is 37°C, it means that during 99% of the summer days between 1991 and 2020, the daily maximum temperature was below 37°C. For a heatwave to be officially recognised during a certain period, the temperature of 37°C or higher must be recorded for at least three consecutive days.

Box A

In June 2025, Western Europe experienced two heat-wave events, with record temperatures reaching up to 46°C in Portugal and Spain during this period²². Between May and July 2025, Spain reported 1,180 heat-related deaths, a sharp increase compared to the same period in the previous year, which recorded 114 cases²³.



Photo by Ant Rozetsky, Unsplash

Wet and Dry

Heavy precipitation can have adverse effects, such as causing flooding that damages infrastructure (example in Box B). Similarly, a lack of precipitation leads to drought conditions, which increase the risk of wildfires, reduce crop productivity, and may trigger pest outbreaks. Water shortages can also compromise hydropower production and affect household water supply¹². Table 2 identifies and describes indicators of extreme precipitation and drought. As with temperature, extreme precipitation and drought cannot be defined by fixed meteorological values. Instead, they are dependent on regional climate conditions, which are established by a baseline reference period.

Box B

In 2022, a heavy rainfall event occurred on 12–13 December and severely affected the Lisbon area (Portugal). During this period, 134.6 mm of rain fell in just 24 hours, breaking previous records. The event caused severe flooding across the Lisbon district, with over 150 incidents reported, including damage to hospitals and parts of the airport. The total damage was estimated at EUR 185 million²⁴.

Table 2 - Indicators of climate-related hazards for wet and dry conditions

Climate-related hazard	Indicator	Description
Extreme precipitation	Extreme precipitation days	Total number of days in a year with daily precipitation exceeding the 95th percentile threshold of rainy days over a reference period ²⁵ .
	Extreme precipitation total	The total sum in a year of the precipitation values of extreme precipitation days ²⁶ .
Drought	Meteorological droughts duration	Total number of months in a year with anomalously low precipitation conditions based on the 3-month Standardised Precipitation Index (SPI-3) relative to a reference period ²⁷ .
	Meteorological drought magnitude	The cumulative severity of drought events in a year based on SPI-3, relative to a reference period ²⁹ . The magnitude of the event is defined as the sum of SPI-3 absolute values in the months of the drought episode.

How to do it?

The Standardised Precipitation Index (SPI-3) is a meteorological drought indicator to monitor precipitation anomalies over 3-month accumulation periods. It accounts for the deficit (or surplus) of precipitation accumulated over 3 months with respect to the corresponding value from a 30-year baseline historical period. Should the precipitation values be found to be lower than that value, this would be indicative of drought conditions²⁸.

How to calculate an extreme precipitation day:
 In the same way as the example for the heatwave days, to calculate the extreme precipitation days, the same steps would be followed, but with records of daily precipitation in millimetres (mm). In this case, it would be necessary to consider a 95% threshold, which means find the value that is exceeded only 5% of the time. Considering a 30-year period (a typical reference period), 548 days would correspond to 5%. When organising the values in a decreasing order, the 548th value would correspond to the maximum precipitation threshold. If the precipitation in a given day is higher, it is considered an extreme precipitation event.

Box C

On 1 November 2024, Storm Lyly set a national record in Finland for 10-minute average wind speeds, reaching 33.5 m/s. This event marked the first occurrence of hurricane-force winds recorded in the country and led to widespread damage. In southwestern Finland, fire brigades responded to around 1,000 wind-related incidents. Approximately 100,000 m³ of trees were brought down, and around 40,000 households were left without power³⁰.

Wind

Changes in wind speed and direction can disrupt pollen and seed dispersal, affecting plant reproduction and the natural regeneration of ecosystems. Additionally, extreme wind events, such as severe windstorms or cyclones, can cause widespread damage to infrastructure, increase tree fall and forest degradation (example in Box C)¹⁸. Table 3 identifies and describes the indicators of extreme wind.

Table 3 - Indicators of climate-related hazards for wind conditions

Climate-related hazard	Indicator	Description
Extreme wind	Extreme wind days	Total number of days in a year with daily wind speed (measured 10 m above ground) exceeding the 98 th percentile threshold, over a reference period ³¹ .
	Severe windstorm	Wind speed above 25 m/s (the same as 89 km/h or 48 knots) ³² .

How to do it?



Designed by Freepik

How to calculate extreme wind days:

The methodology used for heatwave days and extreme precipitation days can be applied to obtain the extreme wind days. In this case, it would be necessary to calculate the wind speed that corresponds to the 98th percentile of the records, once arranged in decreasing order. This implies finding the value that is exceeded only 2% of the time. Considering a 30-year reference period, 219 days would correspond to the 2%. If the wind speed in a given day is faster than the 219th strongest value in the record, it is considered an extreme wind day.

Snow and Ice

Reduced snowfall can negatively affect winter tourism and recreational activities, which have direct consequences on local economies. Several impacts can occur due to changes in the duration of sea ice; for example, it can alter the viability of shipping lanes, affecting the distribution of goods. Heavy snowfalls may significantly impact infrastructure and transportation, and ice conditions can lead to an increase in slipping injuries (example in Box D)¹⁸. Table 4 identifies and describes indicators of excess snow and ice.

Box D

In January 2022, Storm Valtteri swept across southern Finland, bringing heavy snowfall and strong winds, which led to the accumulation of approximately 20–30 cm of snow in many areas³⁵.

Table 4 - Indicators of climate-related hazards for snow and ice conditions

Climate-related hazard	Indicator	Description
Excess of snow and ice	Snow season length	Number of days of snow water equivalent higher than 100 mm ¹⁸ .
Heavy snow	Heavy snow	Number of days with snowfall accumulating to 10 cm or more in depth in 12 hours or less ³³ .

Snow water equivalent is defined as the depth of water that would cover the ground if the snow cover were in a liquid state. Essentially, it is the depth of water that would be formed if all the snow on the ground were to melt uniformly and spread over the area³⁴.

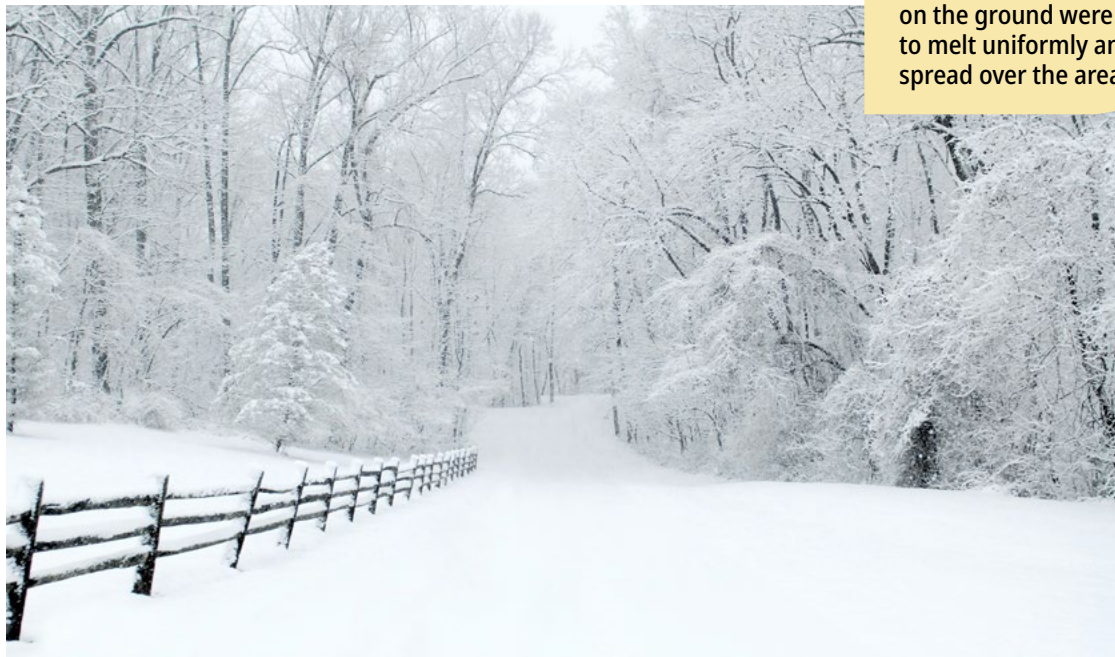


Photo by Annie Nyle on Unsplash

A forest in winter under a snowstorm.

Marine and coastal environments

Marine and coastal environments are also significantly impacted by climate-related hazards, such as sea-level rise and marine heatwaves (example in Box E). Rising sea levels can have major impacts on coastal areas, including flooding, coastal erosion, and saltwater intrusion into freshwater systems. Similarly, rising ocean temperature disrupt marine biodiversity and negatively affect the natural cycles and functioning of these ecosystems¹⁸. Table 5 identifies and describes indicators of sea-level rise, extreme events and marine heatwaves.

Box E

Between June and July 2025, Portugal experienced a marine heatwave, with sea surface temperature reaching 25.1°C. Under normal conditions during this period, water temperature typically ranges between 18°C and 22°C³⁶.



Photo by Ana Matias

Coastal erosion in Fuzeta (Ilha da Armona, Portugal).

Table 5 - Indicators of climate-related hazards for marine and coastal environments

Climate-related hazard	Indicator	Description
Sea level rise	Relative sea-level rise	Changes in the sea water elevation relative to land, with respect to the average conditions over a reference period ³⁷ .
Extreme events	Extreme sea-level	Total water level value for a return period of 100 years caused by tidal and storm surge levels as well as their interactions, but without including sea level rise ³⁸ . Return period is an estimate of the average time interval between occurrences of an event (e.g., flood or extreme rainfall) of (or below/above) a defined size or intensity ³⁹ . For example, a 100-year flood, i.e., a flood with a 100-year return period, is an event that is statistically expected to occur, on average, once every 100 years.
	Extreme wave height	The 95 th percentile of daily maximum of significant wave height over a chosen period and region ⁴¹ . Storm surge is the rise in seawater level during a storm, measured as the height of the water above the normal predicted tide. The surge is caused primarily by strong winds pushing water onshore ⁴⁰ .
Marine heatwave	Marine heatwave days	Day exceeding the daily climatological 90 th percentile of sea surface temperature during the May to September season and a reference period ⁴² .
	Marine heatwave index	Total number of days under marine heatwave conditions (days) ⁴² .

How to do it?

How to calculate an extreme wave height:

To estimate an extreme wave height, it is necessary to consider the significant wave heights. The wave height is the vertical distance between the crest (peak) and the trough of a wave. Significant wave height is the average height of the highest one-third of waves. With a record of waves on a certain measuring station, the daily maximum significant wave height is then obtained. To find the 95th percentile, the same method is applied as described to obtain extreme precipitation days, i.e., the daily maximum values are organised in decreasing order, and the 548th value (if the record is of 30 years, for example) correspond to the extreme wave height threshold.

How to calculate a marine heatwave day:

To estimate a marine heatwave, the sea surface temperature exceeding the 90th percentile is calculated using the same methodology that was described to obtain heatwave days, but in this case, using the sea surface temperature values. Being defined by the 90th percentile (instead of the 99th percentile of the atmospheric heatwaves), it is necessary to find the value that is exceeded 10% of the time. Considering a 30-year reference period with 4590 days, 459 days would correspond to 10%. Then the 459th value in the sorted list in decreasing order represents the 90th percentile for that measuring station. Therefore, if the sea surface temperature at a given measuring location is warmer than the 459th warmest day in 30 years, it is considered a marine heatwave day.

3.2.2 Indicators of Exposure

The key drivers of exposure, vulnerability and adaptive capacity may differ greatly according to the types and characteristics of impacts under consideration. Identifying appropriate metrics (e.g., as single variable indicators or as compound indices) can be demanding and particularly challenging, and they can be applied to a range of sectors, scales and circumstances. Another challenge is the lack of homogeneous coverage and quality of many key variables through time and across Europe, which hampers the quantification of indicators at the spatial resolution necessary to discern regional patterns of impacts.

Exposure is defined by the IPCC as the presence of people, livelihoods; species or ecosystems, environmental functions, services and resources, infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected^{43,44,45}. Exposure is location-based and can be quantified using spatial data. Popular metrics applied to define aspects of exposure include population indicators that describe who is exposed to a given hazard in a particular place and the value of assets at risk. Figure 5 illustrates the measurement of exposure.

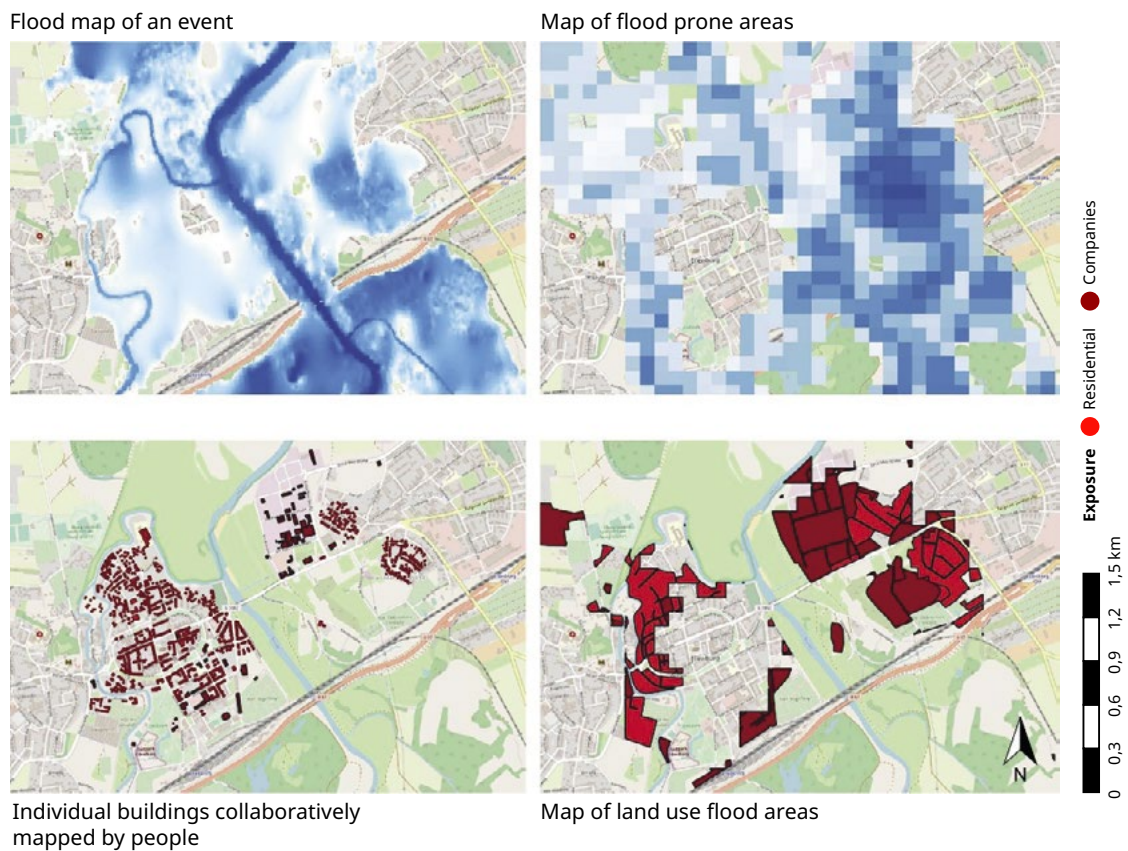
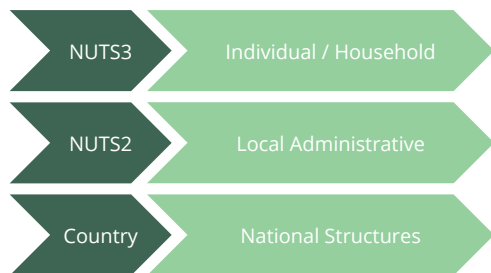


Figure 5 – To map exposure to a hazard, it is necessary to combine the hazard maps with the people and assets distribution maps. In this figure (based on a real case in Germany⁴⁶), the several maps that can be used are shown.

The analysis of exposure, as well as the analysis of hazard, vulnerability and adaptive capacity, can be made at several spatial scales. To reference countries' regions for statistical purposes, the EU has developed a classification known as NUTS (Nomenclature of territorial units for statistics)⁴⁷. NUTS divide each EU country into 3 levels: NUTS1, NUTS2 and NUTS3. NUTS 1 are major socio-economic regions, NUTS 2 are basic regions (for regional policies), and NUTS 3 are small regions (for specific diagnoses).

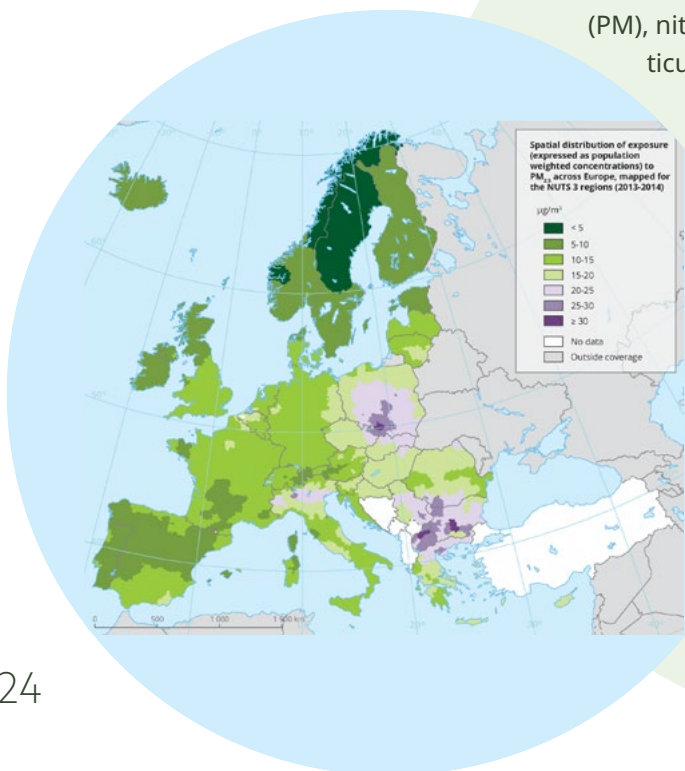
For exposure, vulnerability and adaptive capacity purposes, the Joint Research Centre (JRC), the European Commission's science and knowledge service, considers the 3 levels: Country, NUTS2 and NUTS3. Indicators estimated at the level of NUTS3 represent individuals' and households' social and economic conditions (example in Box F). Indicators estimated at the NUTS2-level focus on local administrative structures. The approach to indicators at the country level aims to constrain the choice of indicators to country structures and management.



Source: JRC, 2021.

Box F

Citizens are exposed to several air pollutants, which can reach concentrations above the levels recommended by the World Health Organization (WHO). There are three key air pollutants: fine particulate matter (PM), nitrogen dioxide and ozone. PM2.5 refers to particulate matter with a diameter of 2.5 micrometres or smaller. These tiny particles are a common air pollutant, and due to their small size, they can penetrate deep into the lungs and even enter the bloodstream. PM2.5 is often a mixture of droplets and solid particles such as dust, dirt, soot, or smoke, and can come from various sources, including vehicle emissions, industrial processes, residential heating, and natural sources like wildfires. The European Environment Agency produced maps that show the spatial distribution of exposure to PM2.5 across Europe⁴⁸. The map combines the population dataset and the air quality maps. The colour gradient shows the population-weighted average by NUTS 3 region for the years 2013 and 2014.



3.2.3 Indicators of Vulnerability

These indicators provide information on the degree to which an individual or group of people may be susceptible to risk. There are many indicators of vulnerability and ways to organise them. In particular, the JRC developed a flexible approach for vulnerability assessment, not exclusively related to the impacts of climate change. In this framework, indicators were grouped in four dimensions: social, economic, political and environmental⁴⁹.

In Tables 6 to 9, there are indicators of vulnerability in terms of social, economic, political and environmental dimensions. The main data source to obtain these indicators is Eurostat, and other sources are the World Bank (WBG), UNESCO, Worldwide Governance Indicators (WGI), European Environment Agency (EEA, ClimateADAPT), University of Gothenburg (GU), World Resources Institute (WRI) and Copernicus (CORINE).

Table 6 - Indicators of vulnerability on the social dimension from the framework concept developed by the Joint Research Centre

Indicator	Description	Level
Projected population change (increase)	Vulnerability will increase if the population grows. This indicator presents the dynamics of vulnerability. Future projection is used since the current situation is covered by population density.	Country
Children at-risk-of-poverty	Children at risk of poverty also indicate a future trend: for children already at risk of poverty, the likelihood that they will be more vulnerable in terms of financial resources and/or social exclusion should be considered. This can further have an influence on political structures.	
Disabled people with a need for assistance	People with a need for assistance are more vulnerable because of their dependency. This indicator takes disabled people and people who reported the need for assistance into account, since young and old dependency is covered by age dependency. It only covers the working-age population (15-64 years).	
Change in Age-dependency	A positive demographic change increases the population with age dependency. This indicator presents the dynamics of vulnerability. Future projection is used since the current situation is covered by age-dependency.	



Photo by Freepik

Self-reported unmet need for medical care	This indicator explains the vulnerability of people who are unable to afford medical needs. In case of a disaster and the need for medical services, they will be more economically vulnerable, and this can have an effect on their health.	Country
Perceived good health	People with perceived good health are less vulnerable due to their ability to manage themselves and help others.	
Life expectancy	Life expectancy takes only the overall health situation of the population into account. Thus, the higher the expectancy, the better the health situation.	NUTS2
People at risk of poverty or social exclusion	This indicator is based on economic indicators (people living in households with very low work intensity, severe material deprivation rate, and at risk of poverty rate), which can lead to social exclusion.	
Primary and lower secondary education (levels 1 and 2)	A higher rate of people with a lower level of education tends to increase the vulnerability due to a low level of awareness.	
Population density	Population density can be seen as an indicator for, firstly, the total population that may be exposed and, secondly, the denser the places are, the higher the vulnerability.	NUTS3 (...)

Net migration	Net migration from the previous year indicates the tendency of (inter-)national immigration and therefore, the number of people living in the NUTS 3 for less than 1 year. People living in a place for less than one year can have a higher vulnerability, which can be attributed to less local knowledge of disaster risk, preparedness and response or due to language issues.	(...) NUTS3
Young dependency	Young people can be more sensitive and less responsive to extreme weather events.	
Old dependency	Old people are more susceptible to harm during extreme events.	

Table 7 - Indicators of vulnerability on the economic dimension from the framework concept developed by the Joint Research Centre

Indicator	Description	Level
Income Inequality	The Gini coefficient describes the inequality of incomes in a country. The greater the gap between low and high salaries is, the more people are vulnerable (example in Box G).	Country
Cultural heritage	The indicator is a mix of structural, economic and social aspects. Buildings included in the list of UNESCO Heritage Sites are usually more vulnerable to extreme events due to their age and the way they are built. Consequently, if a site is heavily damaged, it will have a high cost of reconstruction. In addition, heritage sites are landmarks, and their loss has a social impact on the communities.	

The **Gini coefficient** measures the extent to which the distribution of income within a country deviates from a perfectly equal distribution. A coefficient of 0 expresses perfect equality, where everyone has the same income, while a coefficient of 100 expresses full inequality, where only one person has all the income⁵⁰.

Box G

Gini coefficient for several countries as examples. Higher values mean more inequality.

Country	Gini coefficient (2024)
Slovakia	21.7
Finland	26.1
Spain	31.2
Portugal	31.9
Turkey	44.8

Severe material deprivation rate	The material deprivation rate stands for existing poverty. Poverty is traditionally defined by the availability of financial means.	NUTS2
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Photo by ft1photoart, Freepik

Easter Island (Rapa Nui) moai statues, UNESCO world heritage site in Chile, threatened by sea-level rise.

Table 8 - Indicators of vulnerability on the **political dimension from the framework concept developed by the Joint Research Centre**

Indicator	Description	Level
Political Stability	Political Stability can imply the efficiency of a government, its international cooperation and its focus on the needs of the country.	Country
Regional Quality of Government index (EQI)	The EQI is a result of a survey on regional-level governance within the EU. The data focuses on both perceptions and experiences with public sector corruption, services and their allocation and quality. This indicator represents citizens' opinions and therefore implies their trust in the government.	NUTS2

Table 9 - Indicators of vulnerability on the environmental dimension from the framework concept developed by the Joint Research Centre

Indicator	Description	Level
Common farmland bird index	Birds are high in the food chain; hence, they can be considered a good indicator for the overall state of health of ecosystems and biodiversity. The farmland bird indicator acts as a proxy to assess the biodiversity status of agricultural environments across Europe. A high level of biodiversity is related to a more resilient environment, since the diversification of the ecological niches guarantees the subsistence of the main environmental processes.	Country
Natura 2000 protected areas	The Natura 2000 network is composed of Special Protection Areas (SPA) and proposed Sites of Community Importance (pSCI) that are subsequently designated under the Habitats Directive as Special Areas of Conservation (SAC). Protected areas identify ecosystems with a high ecological value, which should include a high level of biodiversity as well. Since a well-diversified environment is less vulnerable, countries that have a high % share of Natura 2000 areas have a less vulnerable environment.	

Natura 2000 is the largest coordinated network of protected areas covering the most valuable and threatened species and habitats⁵¹.



Photo by Mr Xerty, Unsplash

The Bay of Mont Saint-Michel is a designated Natura 2000 site due to its ecologically important intertidal zone, which includes mudflats, reefs, salt marshes, dune systems, and rocky islets. It serves as a habitat for 22 protected plant species and more than 100,000 waterbirds.

<p>Urban area classified as green space</p>	<p>Green spaces, such as parks, trees and gardens, can help cities' resilience to the effects of climate change and extreme weather events. They have a cooling effect during periods of hot temperatures and decrease the effect of the superficial run-off in case of extreme precipitation in urban areas. In addition, green areas are also related to the more developed areas of a city, hence they can highlight the more prosperous districts, which usually are the most resilient.</p>	<p>NUTS2</p>
<p>Urban land cover</p>	<p>There is robust evidence that the amount of artificial areas, such as buildings and other structures, intensifies heat and can exacerbate the urban heat island effect. This will make an area more sensitive to the effects of high temperature and heatwaves.</p>	
<p>Soil erosion</p>	<p>Given that soil erosion by water is one of the most widespread forms of soil degradation in Europe, the indicator is a local measure of the environmental vulnerability of an area.</p>	<p>NUTS3</p>

Cities are generally warmer – up to several degrees Celsius at night – than their surroundings. This warming effect, called the urban heat island effect (UHI), occurs because cities both receive and retain more heat than the surrounding countryside areas and because natural cooling processes are weakened in cities compared to rural areas. Tall buildings close to each other absorb and store heat and also reduce natural ventilation. Human activities, which are very concentrated in cities, also directly warm the atmosphere locally, due to heat released from domestic and industrial heating or cooling systems, running engines, and other sources. Finally, urban warming also results directly from the heat-retaining properties of the materials that make up cities, including concrete buildings, asphalt roadways, and dark rooftops. These materials are very good at absorbing and retaining heat, and then re-emitting that heat at night⁵².

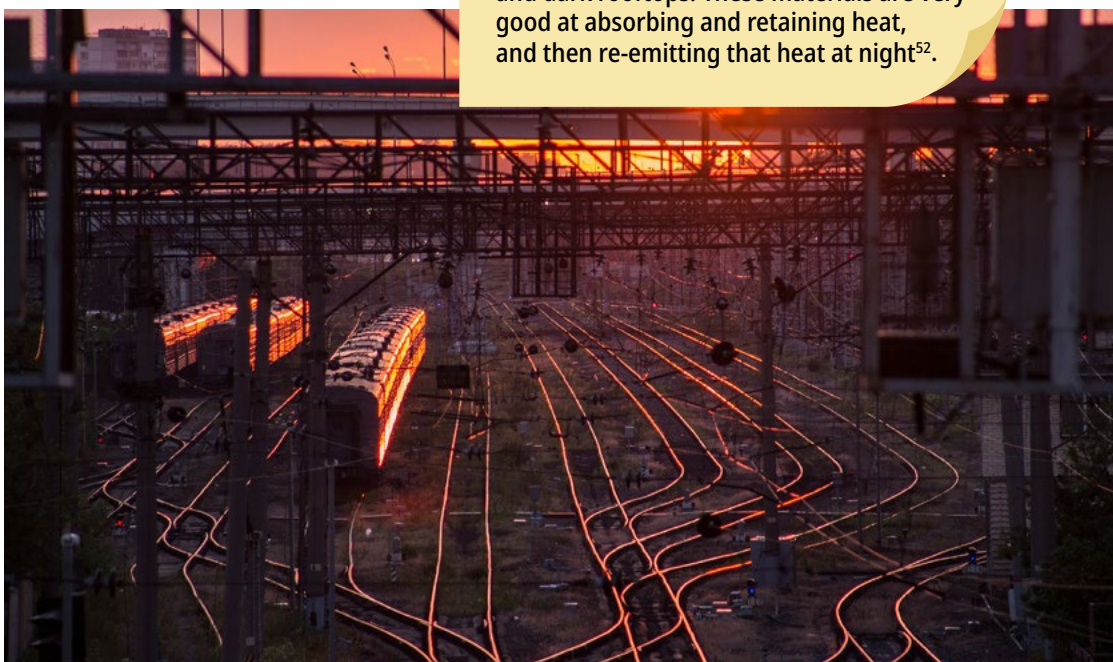


Photo by Aleksandr Popovs, Unsplash

3.2.4 Indicators of Adaptive Capacity

Adaptive capacity plays an essential role in reducing the risks related to climate change and benefiting from it. Adapting to climate-related risks is not only about coping with them but also about enabling conditions for the people to handle, prepare and learn from them. The JRC approach for vulnerability assessment also defines indicators for adaptive capacity in the dimensions: social, economic, political and environmental. Tables 10 to 13 present factors that contribute to an increased adaptive capacity.

Table 10 - Indicators of adaptive capacity in the social dimension, based on the conceptual framework developed by the Joint Research Centre

Indicator	Description	Level
Long-term care (health) expenditure	A higher expenditure for long-term care identifies the capability of a country to take care of people who need medical assistance. Thus, it is related to the economic welfare of a community: higher expenses are related to a lower vulnerability. The indicator is related to the expenses dedicated to health functions, excluding capital investment.	Country
Hospital beds per 100'000 population	The number of hospital beds per 100,000 inhabitants is a measure of the adaptive capacity of a community. A higher value is related to the capability of an area to aid people affected by events; therefore, it is related to a lower vulnerability overall.	NUTS2
Participation in social networks	This indicator transmits a picture of social interaction. Nowadays, interactions in social networks can present one part of social interactions. To bear in mind: it does not replace social interactions with persons.	
Information [Frequency of internet access: once a week (including every day)]	The more people are connected to information services, the better early warning can be disseminated.	
People with tertiary education (levels 5-8)	People with higher levels of education are believed to be less vulnerable due to their degree of knowledge and the ability to react faster in case of an event.	

Table 11 - Indicators of adaptive capacity in the economic dimension, based on the conceptual framework developed by the Joint Research Centre

Indicator	Description	Level
Gross National Saving	The national savings represent the country's economic vulnerability.	Country
GDP per capita	The GDP per capita is a measure of the wealth of the population. The higher the indicator, the less the vulnerability.	
Household income	The household income is calculated as the balance of primary household income calculated in Purchasing Power Standard (PPS, a virtual currency unit to compare the relative purchasing power of different countries). Household income describes a household's possible financial resources, which make it less vulnerable.	NUTS2
Motorways	Access to the major road network describes the connectivity and remoteness of places. The shorter the distance, the lower the vulnerability.	
Railways	Access to major railways describes the connectivity and remoteness of places. The shorter the distance, the lower the vulnerability.	
Employment rate	Higher employment rates present a population with more individuals having financial resource stability for recovery.	
NUTS3 GDP per capita vs country average	The indicator compares the local GDP per capita to the country. It is a measure of the local variability of the vulnerability in terms of economic resources.	NUTS3
Gross Value Added (at basic prices)	Gross Value Added (GVA) is defined as output value at basic prices less intermediate consumption valued at purchasers' prices. GVA is calculated before the consumption of fixed capital. The resources that a city has can be a good indicator of a city's sensitivity in terms of extreme weather events and climate change. If a city has a lower than average GVA, then it may have been more susceptible to damage from all types of extreme weather events. A city with low resources may not be able to adequately address climate change adaptation due to other pressures.	

GDP, the Gross Domestic Product, is the most common measure for the size of an economy. It measures the total value of goods and services produced by that economy during a specific period, typically a year⁵³.

<p>Power plants per 100'000 inhabitants</p>	<p>This indicator shows the power plants per head of population. The more power plants there are, the greater the chance that there may be redundancy. Redundancy is an important concept in resilience. Redundancy demonstrates that there is excess capacity in the given system, which means that during crises, it may still be able to retain functionality. If there are more power plants in a NUTS3 area than the EU average, this may mean that alternative ways of providing energy to a given population may be found.</p>	<p>NUTS3</p>
<p>Patent applications to the EPO</p>	<p>This indicator shows the number of patent applications to the European Patent Office (EPO) per 1000 population. Technology and innovation are important in helping a city to adapt to climate change, for example, investment in new flood technologies or building technologies that can help to mitigate heat. The ability of a country or urban area to invest in technological solutions is considered an indicator of its adaptive capacity. Therefore, the number of patents per year is used as a proxy indicator reflecting this issue.</p>	



Photo by vwalakte, Freepik

Table 12 - Indicators of adaptive capacity in the political dimension, based on the conceptual framework developed by the Joint Research Centre

Indicator	Description	Level
Governmental efficiency	Governmental efficiency is an important indicator for calculating the efficiency at the national level before, during and after a hazard strikes.	Country
National Adaptation Strategies	National Adaptation Strategies can represent the effort and mindset of the national government for Disaster Risk Reduction actions.	

Table 13 - Indicators of adaptive capacity in the environmental dimension, based on the conceptual framework developed by the Joint Research Centre

Indicator	Description	Level
Environmental protection expenditure	<p>It measures the economic resources devoted to the prevention, reduction, and elimination of pollution and any other degradation of the environment. It covers the spending on environmental protection services, e.g., pollution abatement (air, water, soil and noise), waste and wastewater management, protection of biodiversity, as well as related research and development, education and training activities. Higher investments lead to a lower environmental impact from those activities, therefore, to lower pressure.</p> <p>As a result, the ecosystems can increase their resilience against other stressful events (example in Box H).</p>	Country (...)

Box H

The National Expenditure on Environmental Protection (NEEP) in 2022, for several EU countries and the sum of all countries (27 countries in 2022). Data from Eurostat, expressed as a percentage of gross domestic product (GDP) and as million euros⁵⁴.

Country	Percentage GDP	Million €
Belgium	3.4	18 991.2
Austria	3.2	14 280.5
Spain	1.8	24 691.6
Finland	1.8	4 813.4
Portugal	1.7	4 090.1
European Union (27 countries)	2.1	338 126.3

<p>Climate-related economic losses</p>	<p>The economic losses that come from weather and climate-related disasters are a good indicator of the coping capacity of a country. The vulnerability of a country will be higher if it has to dedicate a lot of economic resources to that kind of event.</p>	<p>(...) Country</p>
<p>Production, value added and exports in the environmental goods and services sector (EGSS)</p>	<p>The indicator EGSS provides the quantity of resources that come from products for environmental protection or resource management. They include measures undertaken to restore degraded habitats and ecosystems. Examples are electric vehicles, catalysts and filters to decrease pollutant emissions, wastewater and waste treatment services, or noise insulation works. A country capable of producing more services of this kind can create a less vulnerable environment.</p>	



4

TARGET AREAS

4. Target Areas

Climate-related hazards, such as heatwaves, prolonged droughts and floods, in interaction with non-climatic risk drivers, as pollution, unsustainable agricultural practices, and social inequalities, threaten Europe in many ways. There are various ways to organise climate-related impacts, and the approach followed here incorporates elements from the European Climate Risk Assessment Report¹², with changes to facilitate alignment with the “Adaptation in Sectors” structure, which can be found on the Climate-ADAPT platform. The organisation in target areas simultaneously follows overarching clusters of risk due to climate change and aggregate lines of adaptation to climate change. A target area is a system where climate change has impacts and is simultaneously interconnected with other systems.

Five main target areas were considered: ecosystems, food and water, human health, infrastructure and socio-economics¹² (Figure 6). Depending on their nature, risks in each target area alone have the potential to cause significant environmental degradation, economic damage, social emergencies and political turbulences; their combined effects are even more impactful.

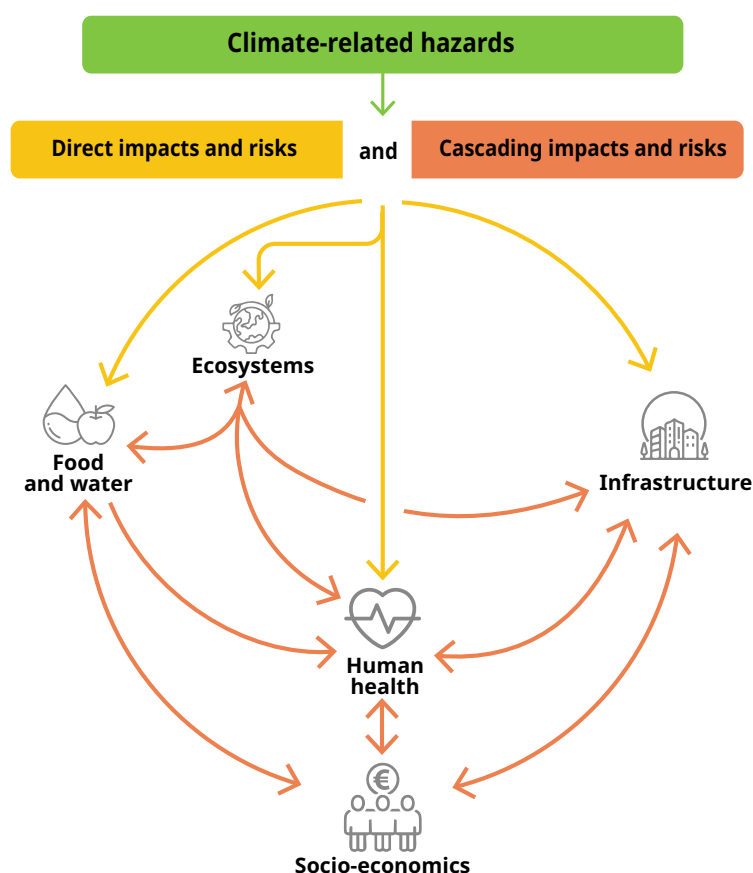


Figure 6 – Interconnections and risk transmission pathways between risk key climate-related hazards and the main target areas. Adapted from EEA (2024)¹².

Climate impacts can cascade from one system or region to another (Figure 6). Cascading climate risks can lead to system-wide challenges affecting whole societies, with vulnerable social groups particularly implicated. For example, climate impacts on human health and well-being, including those of workers, can affect labour productivity and resource needs of the health system, and thus the wider economy. Climate impacts on critical infrastructure, such as energy, water or transport, can affect nearly all aspects of society, from human health to the wider economy and the financial system. Infrastructure assets and networks are often interconnected, so a failure at one point in the network can also cascade to other regions and countries. Awareness of risk cascades is crucial for reducing climate risks, as it offers different possible focus areas for risk reduction strategies. It is often more efficient to address a risk at the beginning of the cascade than where the impacts are felt most strongly.

4.1 Ecosystems

Marine, terrestrial, freshwater and cryosphere ecosystems work in conjunction to sustain life on the planet by controlling flows of energy, producing oxygen, recycling nutrients and regulating climate⁶. Human subsistence and well-being fundamentally depend on the healthy functioning of ecosystems, which deliver essential services such as clean air, freshwater, natural medicines, and food. Important factors to consider when talking about ecosystems are biodiversity loss and ecosystem degradation, which play an important role in climate change mitigation and adaptation⁵⁵. The rate of global change in nature during the past 50 years is unprecedented in human history.



Tracey Jennings / Ocean Image Bank

The direct drivers of change in nature with the largest global impact have been (starting with those with the most impact): changes in land and sea use; direct exploitation of organisms; climate change; pollution; and invasion of alien species⁵⁵. The impacts of climate change on nature are complex and there are considerable variations across regions, ecosystems and species, depending on whether ecosystem function and productivity are precipitation-, radiation- or temperature-limited¹².

4.2 Food and Water Security

Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food required to live a healthy and active life⁵⁶. The food system relies mostly on nature, as it is interconnected and its production depends significantly on the resources and services offered, such as shelter for animals, healthy soils for crop production and others⁵⁷. Similarly, access to drinking water is fundamental for human well-being. Water security is defined as the capacity of a population to safeguard sustainable access to adequate quantities of acceptable-quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability⁵⁸.



4.3 Human Health

Human health is a fundamental component of well-being, influencing all aspects of life and enabling people to live an independent and fulfilling life. Climate change presents a direct threat to human health, as rising temperatures, increased humidity, and extreme weather events, such as floods and heat-waves, can severely impact physical and mental well-being. Herein, it is considered climate-related impacts on human health conditions such as heatstroke,

spread of **vector-borne**, diseases or eco-anxiety. These human health risks vary in severity and distribution depending on the location and local conditions of the population¹². Climate-sensitive health risks are disproportionately felt by the most vulnerable and disadvantaged population groups, including lower-income households, the elderly, children, youth, migrants, outdoor workers, pregnant women and those with pre-existing health conditions⁵⁹.

Vectors are living organisms that can transmit infectious pathogens between humans or from animals to humans. Therefore, **vector-borne** diseases are human illnesses caused by parasites, viruses and bacteria that are transmitted by vectors. Mosquitoes are an example of a vector that can cause vector-borne diseases such as malaria, dengue and yellow fever⁶⁰.

4.4 Infrastructure

The built environment holds a central position in the socio-economic landscape. It corresponds to everything people live in and around, such as housing, transport infrastructure, services networks and public spaces. The built environment includes buildings and civil engineering works. Buildings refer to residential (single and multiple residential dwellings) and non-residential (commercial, institutional and public) buildings. Civil engineering works include critical infrastructure (transport, pipelines, communication and electricity lines, energy and industrial infrastructure) and green and blue infrastructure, such as sports grounds, parks, open-air installations and protection areas (such as coastal zone or riverbank defences, rockfall prevention measures, reforestation or landslide mitigation zones).

Infrastructure provides access to essential services such as water and energy, serving as the foundation for daily life and economic development. The proper functioning and resilience of the built environment (i.e., residential and non-residential buildings) contribute significantly to the well-being and development of communities around the world⁶¹. The impacts of climate change here are mainly focused on the built environment, energy systems and transport.

4.5 Socio-economics

The adequate functioning of ecosystems also plays an important role in the economy and finance, as multiple economic activities, such as tourism, fishing and agriculture, depend on the services provided by nature⁶². Also, cultural heritage holds significant value in the context of climate change adaptation. Preserving ancestral knowledge is essential for adaptation, as it can be used to incorporate traditional practices (e.g., plant crops naturally resilient to drought conditions) into responses to climate change⁶³. The education and communication sectors are crucial due to their vulnerability to the impacts of climate change; nevertheless, enhancing public awareness and community resilience through education and capacity-building initiatives helps foster a culture of preparedness and response at the grassroots level⁶¹. Within the core of climate change adaptation lies social engagement.



5

IMPACTS ON THE TARGET AREAS

5. Impacts on the Target Areas

This section explains how climate change will impact the five target areas: ecosystems, food and water, human health, infrastructure and socio-economics. The description of impacts on the various target areas will focus on the different components or sectors that comprise them (Figure 7). Climate change impacts on ecosystems are described across their various components: terrestrial, freshwater, marine, coastal, and cryosphere ecosystems. These are followed by effects on food and water security, and on human health (including vector-borne, food-borne, and water-borne diseases, as well as mental health). In the area of infrastructure, the focus includes the built environment, energy, and transportation. Finally, the socio-economic area covers impacts on education, cultural heritage, the economy, and finance (Figure 7).

For each target area, an impact chain is presented to provide an overview of how different climate-related hazards lead to impacts in specific areas and pose risks to other interconnected components. In the case of the ecosystems, three separate impact chains are included - one for each selected ecosystem. This approach was taken because the distinct characteristics of each ecosystem type mean they are affected by different hazards and experience different types of impacts.



5.1 Ecosystems

Warming and changes in precipitation affect biodiversity by altering species' timing and cyclic patterns (**phenology**), growth, and fitness. These changes

Phenology is the relationship between biological phenomena that recur periodically (e.g., development stages, migration), especially related to climate and seasonal changes⁴⁵. It focuses on the timing of biological events, seasonal rhythms and life cycles in plants and animals, such as leaf emergence, flowering, insect emergence, and bird migration.

impact the ability of ecological networks and corridors to function effectively, thereby altering interactions between species. Similarly, extreme events such as droughts, floods, and wildfires cause additional **fragmentation of ecosystems**, further reducing habitat connectivity. Such alterations lead to cascading effects on species composition and ecological functions, increasing the risk of species extinctions¹².

Ecosystem fragmentation happens when parts of a habitat are destroyed, leaving behind smaller, unconnected areas. This can occur naturally, as a result of fire or volcanic eruptions, but is normally due to human activity⁶⁴.

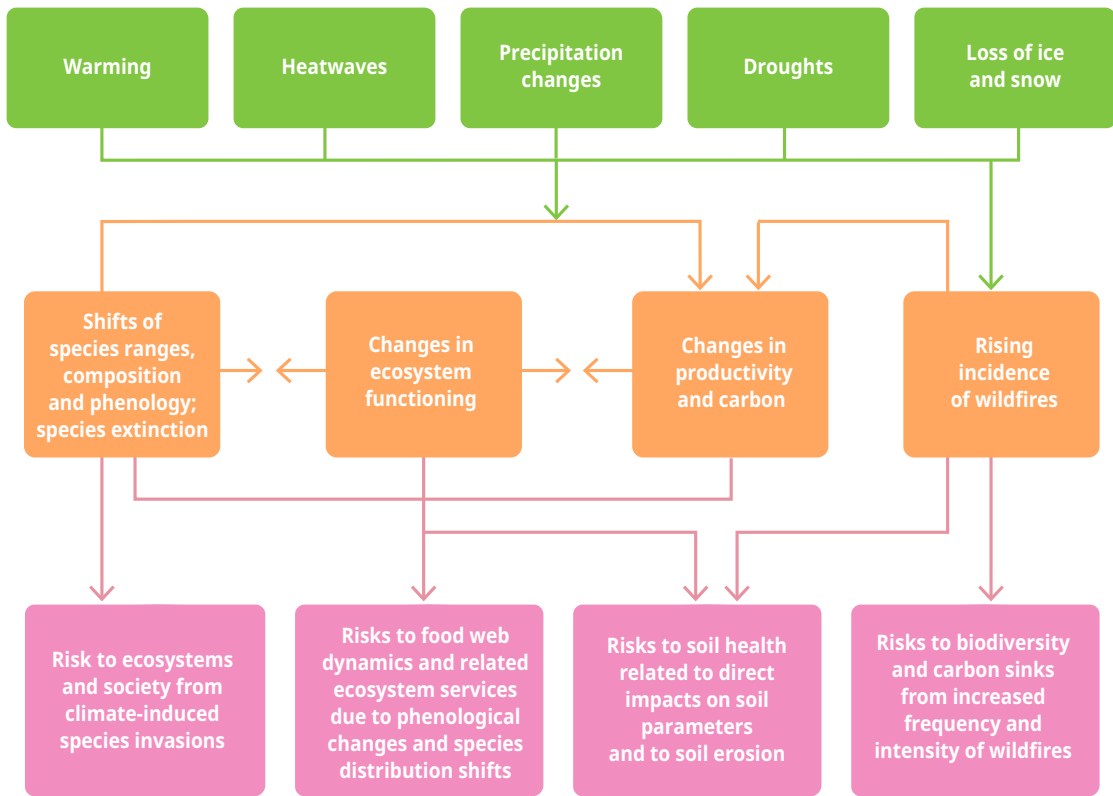


Photo by mebrooks01, Unsplash

In this target area, three global ecosystem types are presented, each with distinct conditions and characteristics, to provide an overview of how they can be affected by climate-related hazards. First, the impacts on terrestrial and freshwater ecosystems are described, with a particular focus on forests and peatlands. This is followed by a description of the impacts on marine and coastal ecosystems, and finally, cryosphere ecosystems are addressed, including glaciers, permafrost, and specific conditions in the Arctic and Antarctic regions.

5.1.1 Terrestrial and freshwater ecosystems

A scheme of the impact chain in terrestrial and freshwater ecosystems from climate-related hazards is presented in Figure 8. There are direct and indirect impacts and interrelations between processes that pose risks to terrestrial and freshwater ecosystems. For instance, droughts and loss of ice and snow can promote an increase in wildfires, which in turn pose a risk to biodiversity. Consequently, the incidence of wildfires exerts indirect impacts, such as changes in forest productivity, thereby constituting a risk to food web dynamics. Further information about the forest, peatlands, permafrost and freshwater bodies is now given.



Terrestrial and freshwater ecosystems



- Climate-related hazard
- Direct or indirect impact
- Major climate risk

Figure 8 – Impact chain in terrestrial and freshwater ecosystems from climate-related hazards. Adapted from EEA (2024)¹².

Concerning **forests**, abiotic (i.e., non-living) factors such as strong winds, snow, and drought have been the drivers of an increase in ecosystem damage. The ongoing trend of increasing drought and heatwave periods has been identified as a key factor contributing to the elevated risk of extensive forest fires and soil moisture droughts. This environmental shift, together with pest outbreaks, has a negative effect on forest productivity and growth.



Photo by wirestock, Freepik

The potential consequences include forests being unable to deliver the current expectations regarding their role in **carbon storage**. Regionally, wildfires,

windstorms and insect outbreaks may turn some forests from **carbon sinks** into sources of GHG emissions. At the same time, the seasonal variability and extreme weather events have negative impacts on pollinators, as high temperature interrupt their hibernation and cause northward migration¹².

Carbon storage is defined as the process by which carbon dioxide (CO₂) is captured and held in natural ecosystems, primarily through biological mechanisms such as photosynthesis in terrestrial plants, algae, and microbial activity in soils, contributing to the reduction of atmospheric CO₂ levels⁶⁵.

Carbon sink refers to any system, natural or artificial, that absorbs more carbon dioxide (CO₂) from the atmosphere than it releases, thereby reducing the concentration of greenhouse gases in the atmosphere. Natural carbon sinks include forests, soils, and oceans, which capture and store carbon through processes like photosynthesis, carbon sequestration in soil, and oceanic absorption. Artificial carbon sinks or industrial removals involve technologies that capture CO₂ from the atmosphere and store it in underground formations or other secure locations⁶⁶.

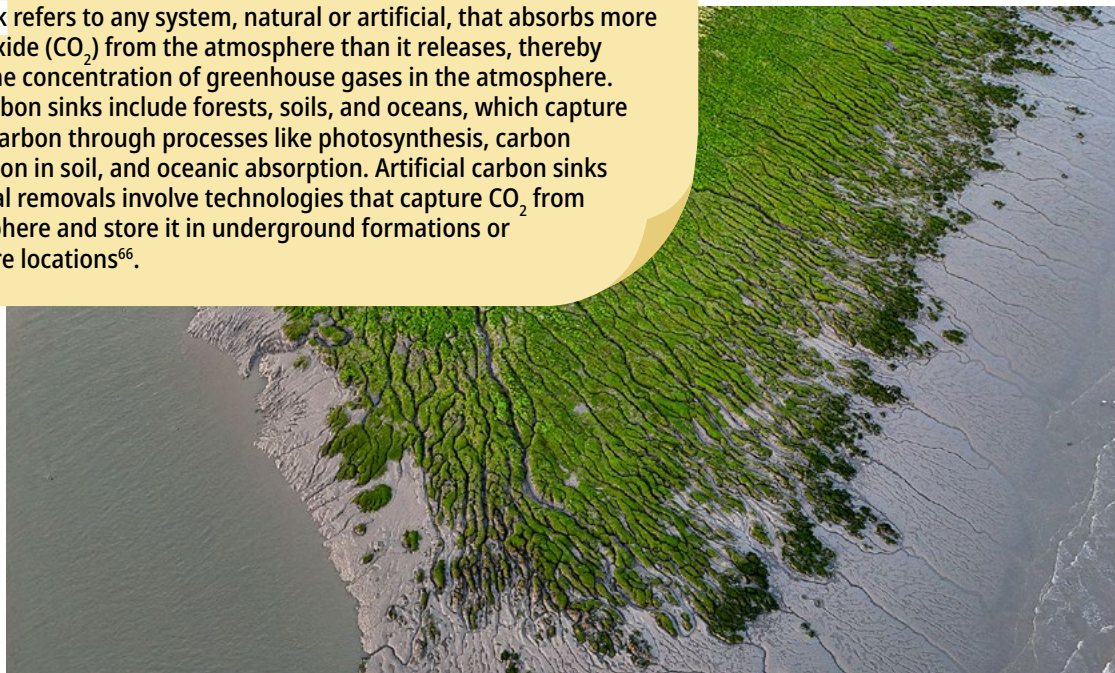


Photo by Mike Erskine on Unsplash

Aerial view of Newport Wetlands National Nature Reserve (Wales, United Kingdom).

Increasing temperatures have caused the drying of **peatlands** and led to **permafrost** thawing, both of which disrupt carbon storage dynamics and make these ecosystems more vulnerable to wildfires. Peatlands are among the most significant terrestrial carbon sinks, but due to climatic pressures, they have increasingly become sources of emissions of CO₂ (carbon dioxide, a greenhouse gas). Changes in precipitation patterns have also created imbalances in water availability within these ecosystems, altering their physical, chemical, and biological processes¹².

Peatlands are wetland ecosystems that form from the accumulation and burial of organic matter derived from plant detritus. They develop under conditions of near continuous soil saturation with water that slows down the decomposition of plant material. Peatlands are usually associated with freshwater and with cool or wet climates, including the high latitudes of the northern hemisphere, oceanic environments, and moist tropical areas⁶⁷. Although these ecosystems only cover about 3% of Earth's land surface, their accumulation of organic matter makes them one of the most important carbon sinks. Peatlands contain approximately 30% of the world's organic soil carbon, storing more than twice the amount of carbon in all the world's forests⁶⁸.

Permafrost is ground that remains frozen under 0°C for a minimum of two consecutive years⁶⁹.

Freshwater ecosystems have been significantly impacted by rising temperatures. Warmer conditions have demonstrated to have a positive correlation with the growth of blue-green algae, which has been linked to the occurrence of **harmful algal blooms (HAB)**. These phenomena have the possibility of resulting in socio-economic impacts and a decrease in the recreational value of freshwater bodies. Another impact caused by higher temperatures is the increased development of horizontal layers of water (**water stratification**) in lakes, which adversely affects the biodiversity of freshwater communities, as only some species can adapt and benefit from warmer conditions¹².

Harmful algal blooms, or HABs, occur when colonies of algae, simple plants that live in the sea and freshwater, grow out of control and produce toxic or harmful effects on people, fish, shellfish, marine mammals and birds⁷⁰.

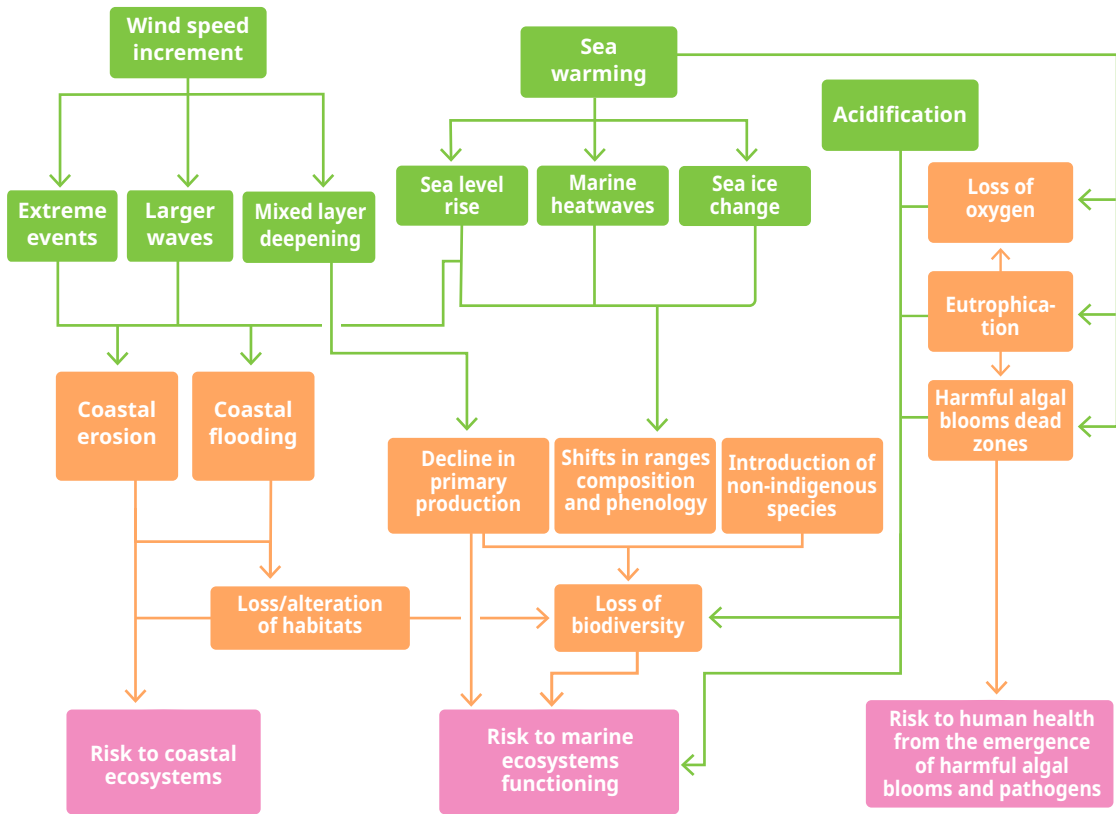
Water stratification is defined as the layering of water bodies with different physical and chemical properties, which occurs in environments such as lakes and the ocean. This can be due to differences in temperature (warm layer overlying a cooler layer), salinity (freshwater overlying saltier water), or both⁷¹.

5.1.2 Marine and coastal ecosystems

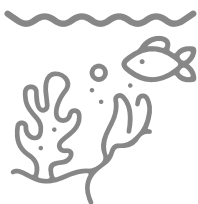
Figure 9 presents the impact chain in coastal and open ocean ecosystems resulting from climate-related hazards. These include acidification, increased wind speeds (which can also lead to other hazards such as extreme events) and sea warming, which contributes to sea level rise, marine heatwaves, and changes in sea ice. These factors have been found to cause significant changes in marine ecosystems, such as **deoxygenation**, altered nutrient availability, and other disruptions⁷². Deoxygenation, in particular, results from sea warming and **eutrophication**, leading to the rise of harmful algal blooms and marine pathogens. These conditions often result in the formation of anoxic (extremely low oxygen concentration) “dead zones”, especially in semi-enclosed seas with limited water exchange, further exacerbating the effects of acidification. As a result, these cascading impacts pose serious risks to human health and the proper functioning of marine ecosystems. The impacts of the previously mentioned climate-related hazards are described in more detail on the next pages.

Deoxygenation is an overall decline in the oxygen content of oceanic and coastal waters. Deoxygenation occurs when oxygen consumption (e.g. from respiration or breathing) is greater than oxygen replenishment through photosynthesis, ventilation, and mixing⁷³.

Eutrophication is a process of pollution that occurs when a lake or stream becomes over-rich in plant nutrients; as a consequence, it becomes overgrown in algae and other aquatic plants. The plants die and decompose. In decomposing, the plants rob the water of oxygen, and the lake, river or stream becomes lifeless. Nitrate fertilisers, which drain from the fields, nutrients from animal wastes and human sewage are the primary causes of eutrophication⁷⁴.



Marine and coastal ecosystems



- Climate-related hazard
- Direct or indirect impact
- Major climate risk

Figure 9 – Impact chain in marine and coastal ecosystems from climate-related hazards. Adapted from EEA (2024)¹².

Coastal ecosystems have been adversely impacted by climate change. Sea-level rise has contributed to exacerbating coastal erosion and coastal flooding. Additionally, sea-level rise has caused saltwater intrusion in aquifers

Coastal erosion is the wearing away and transporting away of sediment particles and rock fragments in the coastal zones. During severe storms, coastal erosion can happen rapidly, potentially causing damage and putting people, properties, and infrastructure in danger. Coastal flooding occurs when dry and low-lying land is submerged by seawater⁷⁵.

(underground bodies of fresh-water), affecting drinking water production. Marine heatwaves have approximately doubled in frequency, leading to mass mortality of marine organisms¹². Heat stress has significantly impacted

multiple species, disrupting their life and distribution patterns. A clear example is coral reefs, which have experienced widespread bleaching due to elevated temperature and **ocean acidification**⁷².

Ocean acidification is the process by which seawater becomes more acidic due to the increased absorption of CO₂ from the atmosphere. When CO₂ dissolves in seawater, it creates a chemical reaction which releases hydrogen and lowers the water pH, increasing its acidity⁷⁶. This alteration has been found to have a significant effect on marine organisms, especially in those that build their shells and skeletons from calcium carbonate, such as corals and oysters. Increasing acidity reduces the availability of carbonate, disrupting the ability of these organisms to grow their structures and dissolve the existing ones⁷⁷.



The Ocean Agency / Ocean Image Bank

Blue fluorescing and bleached reef in New Caledonia (France), in 2016.

Ocean ecosystems have the capacity to store significant amounts of heat, thereby playing an important role in the regulation of Earth's climate. However, changes in heat exchange between the air and the sea surface can shift winds and ocean currents, affect global weather and climate patterns, and have impacts such as hurricanes and storms. Additionally, changes in the water column resulting from rising temperature (i.e., increased upper ocean stratification and deepened **mixed layer**) disrupt the distribution of nutrients, consequently affecting the growth and productivity of **phytoplankton** - the primary producers (organisms in the base of the food chain) - which have consequences in the marine food web¹². A decrease in marine primary production will affect fisheries harvests and, therefore, food availability. Changes in ocean temperature can cause potential shifts in currents' circulation, causing northward migration

The **ocean mixed layer** is the layer of oceanic waters where typically temperature and salinity (and thus density) are fairly uniform⁷⁸. Therefore, the mixed layer depth is the width of the upper ocean that interacts with the atmosphere. It plays a key role not only in climate control but also in the biology of marine organisms.

Phytoplankton are microscopic plants, but they play a huge role in the marine food web. Like plants on land, phytoplankton perform photosynthesis to convert the sun's rays into energy to support themselves, and they take in carbon dioxide and produce oxygen. Because they need the sun's energy, phytoplankton are found near the water's surface⁷⁹.

of tropical species, altering ecosystem dynamics and distribution of fisheries resources⁷².

Semi-enclosed **seas** are particularly vulnerable to the impacts of climate change due to their shallow depths and limited water circulation, which reduce their ability to respond and adapt to changing environmental conditions. This vulnerability is especially evident in parts of the Baltic Sea, the Adriatic Sea, and the North Sea⁸⁰. In addition, areas such as the Mediterranean Sea are especially susceptible to temperature rise and decreasing precipitation. These changes lead to increased evaporation, which in turn causes an increase in salinity levels. This has significant effects on marine ecosystems, causing shifts in species distribution and posing serious threats to species that are unable to adapt to higher salinity conditions^{81, 82}.

5.1.3 Cryosphere Ecosystems

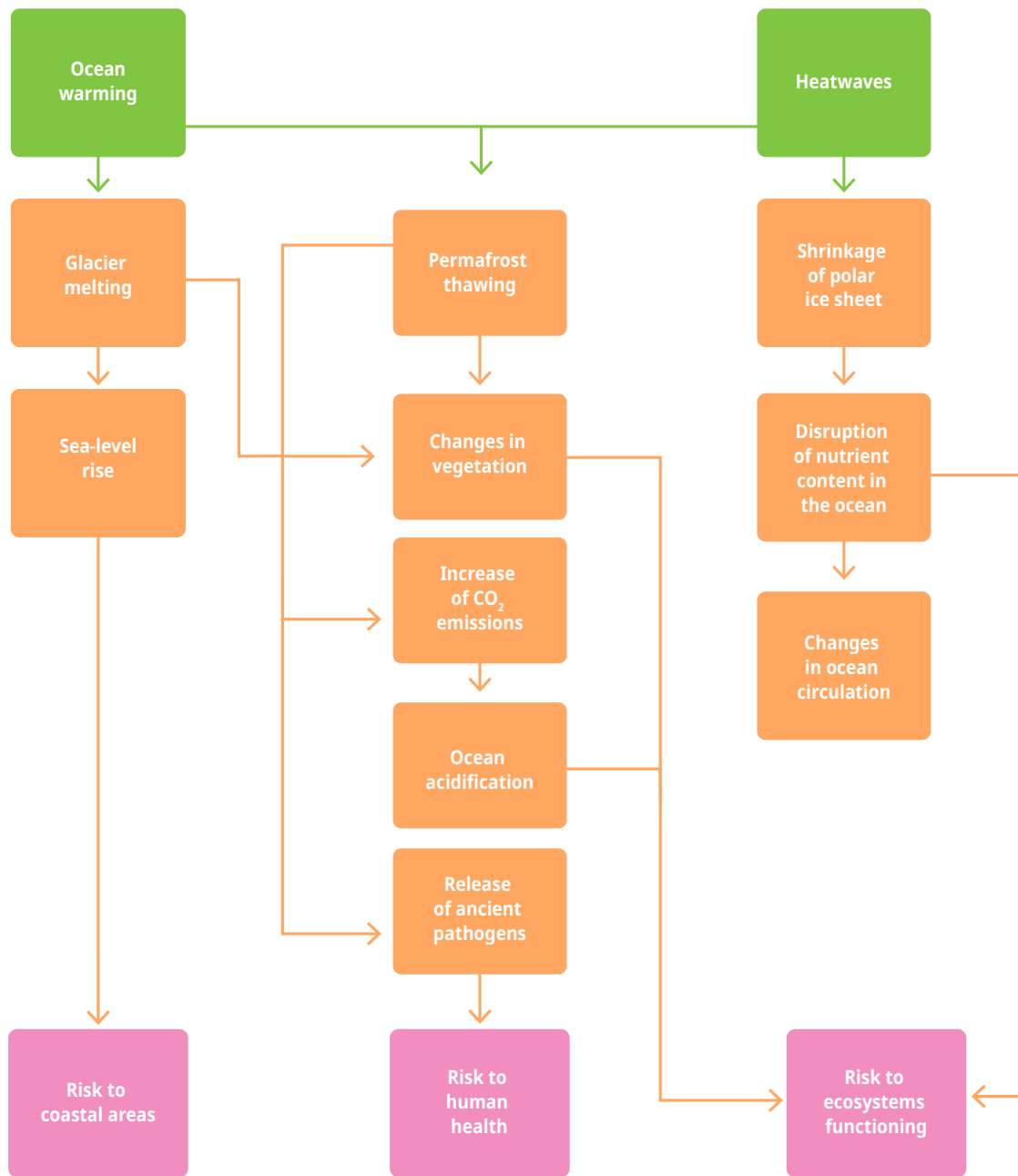
The cryosphere refers to frozen components of the Earth system that are at or

A glacier is an accumulation of ice and snow that slowly flows over land. Alpine glaciers are frozen rivers of ice, slowly flowing under their own weight down mountainsides and into valleys. Ice sheets exist only on Greenland and Antarctica, and they spread out in broad domes in multiple directions. Ice shelves are extensions of ice sheets and glaciers that float in the surrounding ocean^{72,83}.

below the land and ocean surface. These include snow, **glaciers**, ice sheets, ice shelves, icebergs, sea ice, lake ice, river ice, permafrost and seasonally frozen ground⁸³. Snow plays a major role in maintaining high mountain and Arctic ecosystems, affects the Earth's energy budget by reflecting solar radiation (albedo effect), and influences the temperature of underlying permafrost. Currently, around 10% of the Earth's land surface is covered by glacial ice, including glaciers, ice caps, and the vast ice sheets of

Greenland and Antarctica. Figure 10 illustrates how climate-related hazards, specifically ocean warming and marine heatwaves, have affected cryosphere ecosystems.

The cryosphere is experiencing rapid changes due to rising global temperatures. Mountain snow cover, in lower mountain areas (e.g., European Alps), is projected to decline 80% by 2100⁸⁴. Rising temperatures have also accelerated **glacier melting**, with an estimated glacier mass loss rate of approximately 290 gigatonnes (Gt) per year (this is the same as the water consumption of the entire global population in 30 years, assuming 3 litres per person per day). Under pessimistic emission scenarios, many glaciers are projected to disappear by 2100, and even under low-emission scenarios, a loss of up to 60% of glaciers is still expected. This ongoing melting will contribute to sea-level rise and will affect water quality, as it will accelerate the release of pollutants⁸⁴ (Figure 10).



Cryosphere ecosystems



- Climate-related hazard
- Direct or indirect impact
- Major climate risk

Figure 10 - Impact chain in cryosphere ecosystems from climate-related hazards. Based on the processes and described impacts in IPCC (2019)⁷².

There is evidence that **permafrost** temperatures are rising, with some regions experiencing increases of 2 to 3°C since 1988⁷². This sustained warming is leading to the thawing of permafrost, which results in melting ground ice and contributes to permafrost degradation⁸³. The thawing of permafrost, combined with changes in vegetation, is transforming the **tundra ecosystems** from carbon sinks into sources of carbon (example in Box I). At the same time, there are health risks associated with thawing permafrost due to the release of ancient pathogens to which current living beings are not adapted to⁷².

Ocean warming has destabilised ocean currents and weakened ice shelves, further increasing ice loss and causing shifts in marine species distribution and seasonal activities⁷². In the polar regions, **the Arctic** is warming faster than the rest of the planet, which has caused a shrinkage of the polar ice sheet. This disrupts the ocean circulation patterns and nutrient supply, altering salinity levels and impacting native species composition¹². At the same time, these ecosystems are experiencing intensified acidification, as gases like CO₂ are more soluble in colder waters. In **Antarctica**, there has been evidence of accelerating ice loss, which has tripled since 2007. The increasing rate of loss of ice sheets from Greenland and Antarctica has made them the largest contributors to sea-level rise⁷².

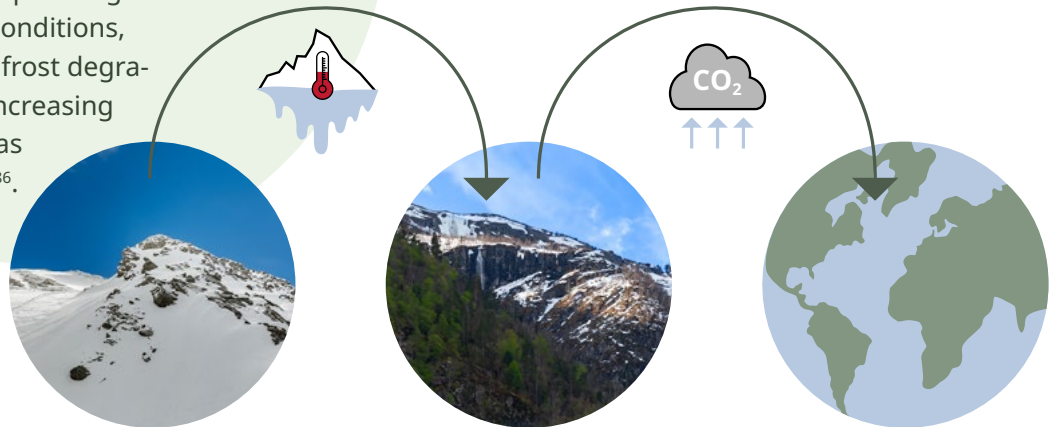
Tundra ecosystems are characteristic of mountainous and polar regions, such as the Arctic. These treeless, frigid landscapes are found in cold, windy environments with scarce rainfall. The temperature during winter is so cold that there is a layer of frozen ground below the surface (permafrost). Vegetation in the tundra has adapted to the cold and short growing season. In the tundra summers, the top layer of soil thaws only a few centimetres down, providing a growing surface for the roots of the low-lying plants⁸⁵.



Tundra in Iceland is an example illustrating these landscapes. Photo by Tomás Mallik on Unsplash

Box I

In northern Scandinavia, rising temperature and reduced snow cover are accelerating the borealisation of Arctic tundra landscapes. Borealisation is a process where boreal species are gradually expanding northward and upward into historically treeless tundra zones. As forest cover increases, the composition of wildlife is changing. There is a decline in cold-adapted vegetation and changes in soil conditions, accelerating permafrost degradation, thereby increasing greenhouse gas emissions⁸⁶.



5.2 Water and Food Security

The second target area is primarily focused on examining how climate-related hazards affect water and food security. It also explores the various factors that pose threats to the availability, quality, and accessibility of food and water resources, as illustrated in the impact chains represented in Figures 11 and 12.

5.2.1 Water security

Water security has been increasingly compromised by the effects of climate change (Figure 11). Droughts and changes in precipitation patterns have disrupted the hydrological cycle, increasing evaporation and evapotranspiration rates, reducing soil moisture (example in Box J) and groundwater levels, and contributing to saltwater intrusion.

The hydrological cycle involves the continuous circulation of water in the Earth-Atmosphere system. At its core, the water cycle is the motion of the water from the ground to the atmosphere and back again⁸⁷.

Saltwater intrusion is a natural process that occurs in virtually all coastal aquifers. It consists of saltwater (from the sea) flowing inland into freshwater aquifers. This behaviour is caused by the fact that seawater has a higher density (which is because it carries more solutes) than freshwater. For example, groundwater pumping can reduce freshwater flow toward coastal areas and cause saltwater to be drawn toward the freshwater zones of the aquifer⁸⁹.

Evaporation is the process that changes liquid water to gaseous water (include land and ocean). Evapotranspiration is the sum of all processes by which water moves from the land surface to the atmosphere via evaporation and transpiration; it includes evaporation from the soil surface, from water bodies on land and plant transpiration⁸⁸.

These impacts also affect water quality, water availability and river flows, compromising the **minimum environmental** flow. This, in turn, places additional stress on irrigated and rainfed agriculture, further contributing to water scarcity¹⁵. Altogether, these changes reduce both the quantity and suitability of raw water sources used for household supply and place additional pressure on water distribution systems⁴⁴. These impacts also threaten the health of aquatic and wetland ecosystems and the services they provide.

The minimum environmental flow is the amount and quality of water necessary to preserve ecological functions and values in watercourses⁹⁰. It is also known as ecological flow. One set of challenges in water resources planning today is to define environmental flow requirements (quantity, timing, and quality on a seasonal basis), integrate them in water allocation policies, achieve consensus on this, and translate and incorporate those requirements into the operating rules for flow regulating structures, such as dams, reservoirs, and diversion schemes.



Agriculture soil exposed to drought conditions. Photo by Md. Asanuzzaman Himel on Unsplash

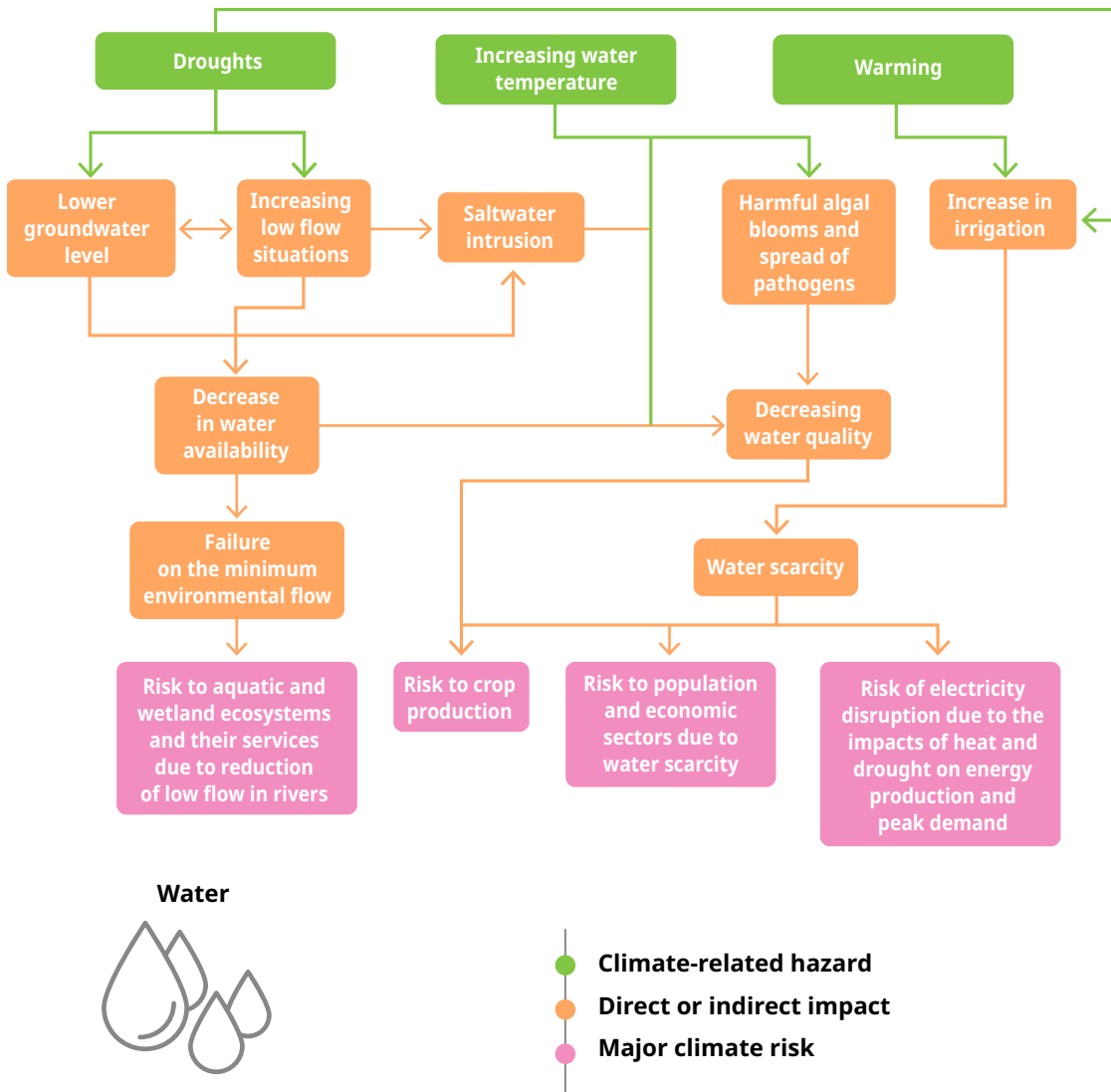
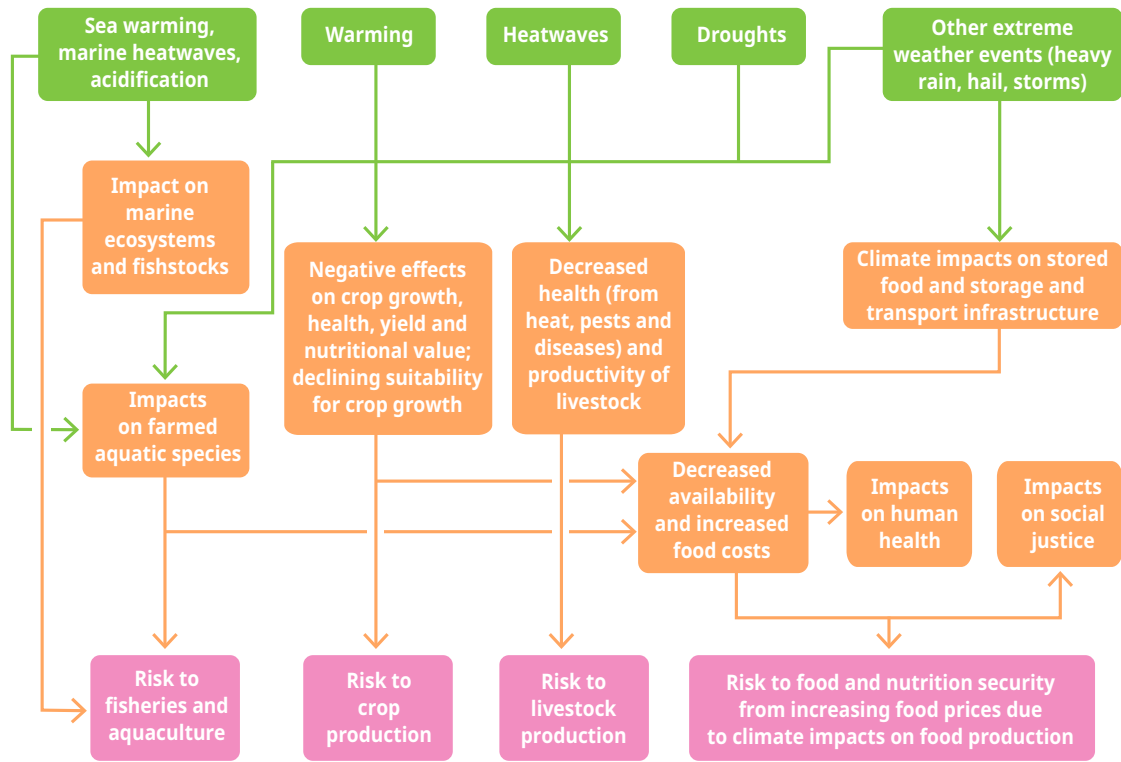


Figure 11 – Impact chain in water security from climate-related hazards. Adapted from EEA (2024)¹².

Floods, resulting from a combination of extreme weather events and land management, pose risks to natural habitats and human assets, such as drinking water supply, sanitation and wastewater systems¹². Despite being beneficial for agriculture when depositing fresh clays, floods might have negative impacts on agriculture and aquaculture, and alter the capacity of soil to retain and infiltrate water. Water temperature have risen by around 1-3°C in major European lakes and rivers over the past century, threatening aquatic ecosystems⁹¹. This is due to a locally specific combination of global warming, discharge of cooling water or effluents from water treatment plants and the alteration of natural ecosystems bordering water bodies, reducing the shade provided. Hydro- and geothermal electricity depend highly on the water regime (i.e., the prevailing pattern of water flow over a given time): the former accounts for a significant portion of renewable electricity in the EU and supports system stability, the latter has seen increased production of almost 40% in the last two decades¹².

5.2.2 Food security

Food production is intricately influenced by numerous climatic factors, and is susceptible to changes in climate such as droughts and heavy rainfall (Figure 12). Climate change reshapes the conditions suitable for crop production; extreme weather events cause crop losses, temperature changes allow the establishment of new pests, and drought conditions have negative effects on crop growth and health. For instance, heatwaves directly affect the health and productivity of livestock and crops, consequently resulting in reduced food availability. This decline in supply leads to increased food prices, which can compromise social equity and strain both agricultural systems and the population’s well-being.



Food security



- Climate-related hazard
- Direct or indirect impact
- Major climate risk

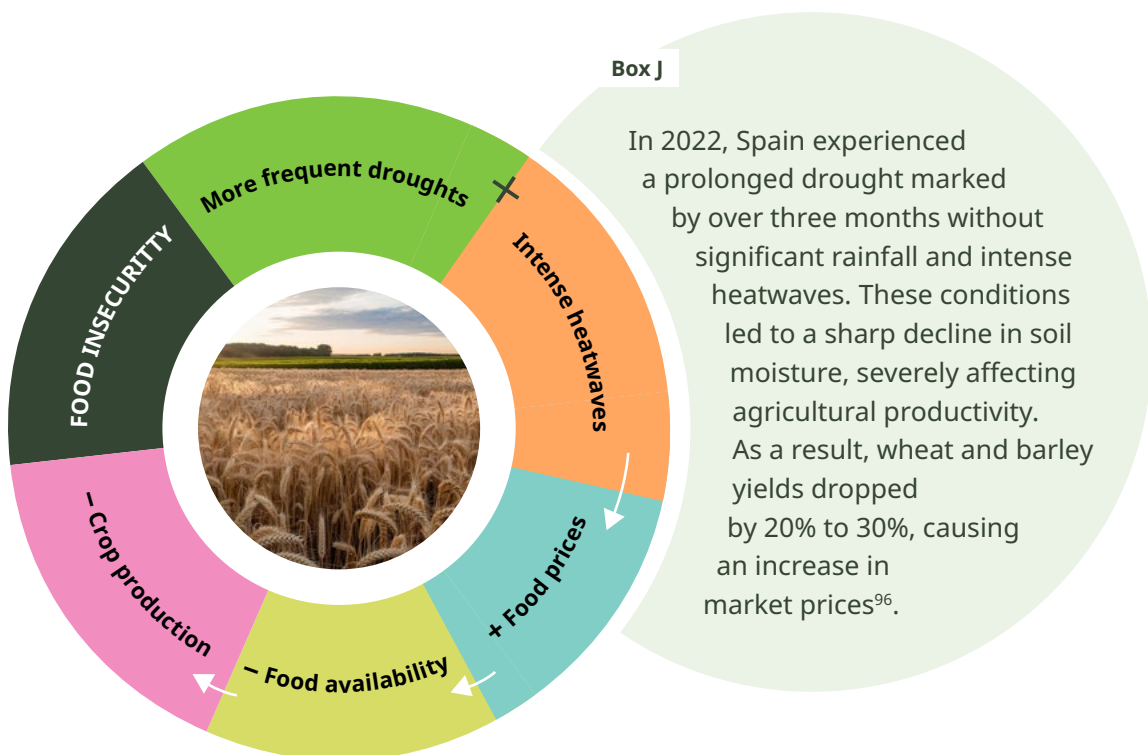
Figure 12 – Impact chain in food security from climate-related hazards. Adapted from EEA (2024)¹².

Ocean warming and acidification affect marine habitats and feed availability, impacting aquaculture and fisheries. Harmful algae bloom due to eutrophication and stimulated by higher temperature cause dead zones and fish kills⁹². Additionally, higher water temperature reduces water quality, threatening the survival and productivity of farmed species in fisheries and aquaculture systems^{12,93}.

Climate change directly affects crop production and shifts suitable regions northwards, with increased associated risks such as late frost events. Heat stress and droughts already negatively affect European crop production compared to their yield potentials, especially in southern Europe (example in Box J). More frequent, severe and complex extreme events reduce crop production and increase its variability. Heavy rainfall exacerbates soil erosion and vegetation loss, resulting in a further decrease in agricultural productivity¹².

Increased temperature and humidity affect animals directly, leading to reduced productivity. Indirectly, the health and productivity of livestock are affected via altered and more variable availability of feed and water and potentially reduced feed quality. Current temperature-humidity stress is a low risk to livestock production in southern Europe⁹⁴; however, substantial, but highly uncertain, novel transmission pathways of complex diseases and increased incidence of (new) diseases may pose a high risk to animals across Europe⁹⁵.

In the food supply chain, climate change hazards (e.g., heat, flooding, storms) can directly disrupt storage, distribution and processing, and transport infrastructure, causing food loss, particularly of highly perishable and nutrition-dense items, reduced food availability and increased costs. Southern European countries are particularly susceptible to shocks in agricultural commodity flows due to their dependence on food imports.



5.3 Human Health

In this section, the impacts of climate-related hazards on human health are described, with particular emphasis on heatwaves, vector-borne diseases, water- and food-borne diseases, and mental health. A significant increase in ill health and premature deaths from climate-sensitive diseases and conditions is projected due to climate change. An excess of 250,000 deaths/year by 2050 attributable to climate change is projected due to heat, undernutrition, malaria and diarrhoeal disease, with more than half of this excess mortality projected for Africa⁵⁹. Figure 13 illustrates the impact chain on human health from the climate-related hazards, including heatwaves, high humidity, warming, wildfires, ocean warming and extreme events. It highlights how these events pose risks to outdoor workers, compromise the built environment, increase the transmission of infectious diseases, place added pressure on healthcare systems, and negatively affect mental health. For example, extreme events, such as floods, can cause sewage system overflows, leading to a rise in waterborne pathogens and diseases, thereby increasing the potential for outbreaks.

Heatwaves affect the ability to regulate body temperature, resulting in heat cramps, exhaustion, heat strokes and worsening of chronic conditions such as cardiovascular, respiratory and cerebrovascular diseases⁵⁹. Workers' safety and health have already been affected by heat stress due to higher exposure to heatwaves, and an increase in heat-related mortality is anticipated among outdoor workers. Simultaneously, elevated temperatures have contributed to the extension of the pollen season and an increase in its concentration. This has caused an increase in the number of patients suffering from allergies¹². These health impacts are further intensified in urban settings, where elevated temperatures, amplified by the urban heat island effect, pose a serious threat, especially during heatwaves⁹³. Among the most affected groups are older adults, who experience significantly increased mortality rates during extreme heat events⁵⁹. Moreover, the increasing frequency and intensity of wildfires, along with the resulting smoke and air pollution, have contributed to rising rates of morbidity and mortality, especially among individuals with pre-existing respiratory and cardiovascular diseases¹².

Vector-borne diseases, which are human illnesses caused by parasites, viruses and bacteria that are transmitted by living organisms, have also been exacerbated due to climate change. Changing weather patterns have accelerated the transmission of infectious diseases and facilitated the distribution of pathogens and their vectors (example in Box K).

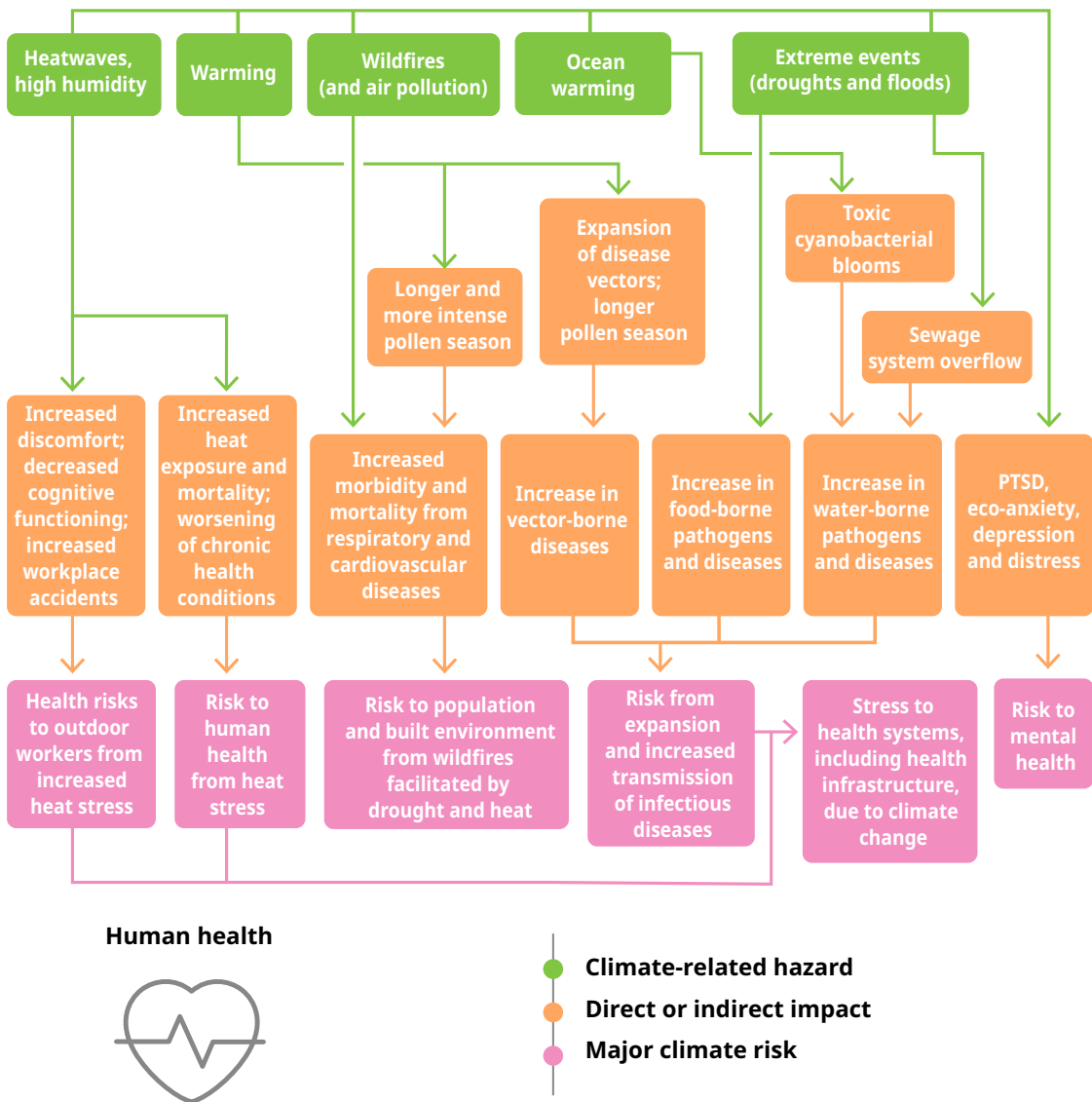
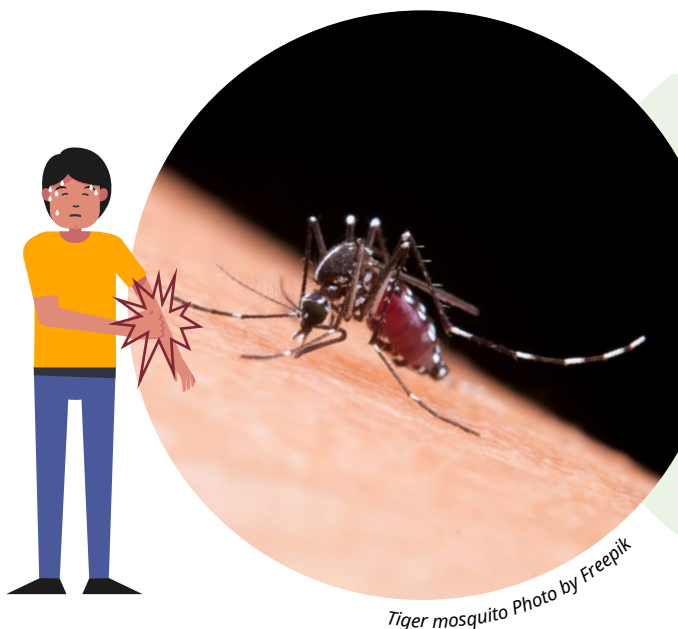


Figure 13 – Impact chain in human health from climate-related hazards. Adapted from EEA (2024)¹².



Box K

In northern Italy, climate change has contributed to the expansion of the tiger mosquito, a known vector of diseases like dengue, chikungunya, and Zika. Warmer temperature and increased summer rainfall have created ideal conditions for these mosquitoes to breed. In 2017, an outbreak of chikungunya occurred in the Lazio region with 436 confirmed cases⁹⁷.

Tiger mosquito Photo by Freepik

Rising temperature and increased precipitation elevate the risk of **water- and food-borne disease** outbreaks. Extreme precipitation events can facilitate the transport of faecal pathogens into water sources, significantly increasing the likelihood of public health emergencies.

Foodborne diseases are diseases caused by contamination of food and occur at any stage of the food production, delivery and consumption chain. They can result from several forms of environmental contamination, including pollution in water, soil or air, as well as unsafe food storage and processing⁹⁸.

Cyanobacteria, also known as blue-green algae, are frequently found in freshwater, estuarine, and marine environments. These microscopic organisms play an important role in supporting various species and food webs. However, when cyanobacteria grow excessively, they can form “blooms” that raise both ecological and human health concerns. Some cyanobacteria are capable of producing highly potent toxins, known as cyanotoxins, which can cause a range of health problems in both humans and aquatic species, including abdominal, neurological, and skin-related issues⁹⁹.

Water-borne diseases are primarily caused by the consumption of contaminated water, and their occurrence is directly linked to higher temperatures, which enhance pathogen survival and reproduction^{12, 59}. Ocean warming also poses a significant threat to human health. As noted in Section 5.1, elevated sea surface temperature promote the development of harmful algal blooms (HABs), including

toxic **cyanobacterial** blooms. These events can lead to serious health effects, such as skin irritation and gastrointestinal illness, when people are exposed to contaminated food or water. In some cases, these algae produce carcinogenic toxins that may increase the risk of cancer^{12, 59}.

Mental health has been both directly and indirectly impacted by climate change. Extreme weather events and the losses associated with them have been related to cases of post-traumatic stress disorder (PTSD), depression and anxiety¹⁰⁰. The ongoing environmental changes and the projected ones have contributed to the rise of eco-anxiety, a persistent fear and distress about the impacts of climate change and concern about the future. High temperatures, resource shortages, and changing livelihoods have been linked to higher rates of suicide, crime, and violence. At a community level, it has been found that cities exposed to high temperatures tend to be more violent and experience more civil disturbances. Similarly, the mental health of indigenous communities has been affected by changes in the ecosystems and resultant shortage of resources, contributing to an increased rate of depression and reports of suicidal contemplation¹⁰⁰.

5.4 Infrastructure

Examining climate-related hazards within the target area of infrastructure, this section highlights the primary impacts on the built environment, energy systems, and transportation networks. The impact chain for infrastructure, illustrated in Figure 14, identifies the main climate-related hazards as warming, heatwaves, droughts, wildfires, extreme events, and sea-level rise. These hazards primarily threaten human well-being, energy infrastructure, buildings, and disrupt the production and distribution of goods. For example, extreme events can lead to damage to transport and energy infrastructure. This results in interruptions in the flow of people, goods, and services, ultimately causing losses across supply chains and leading to significant economic consequences. This section explores how the various impacts are interconnected and how they emerge from the identified climate-related hazards.

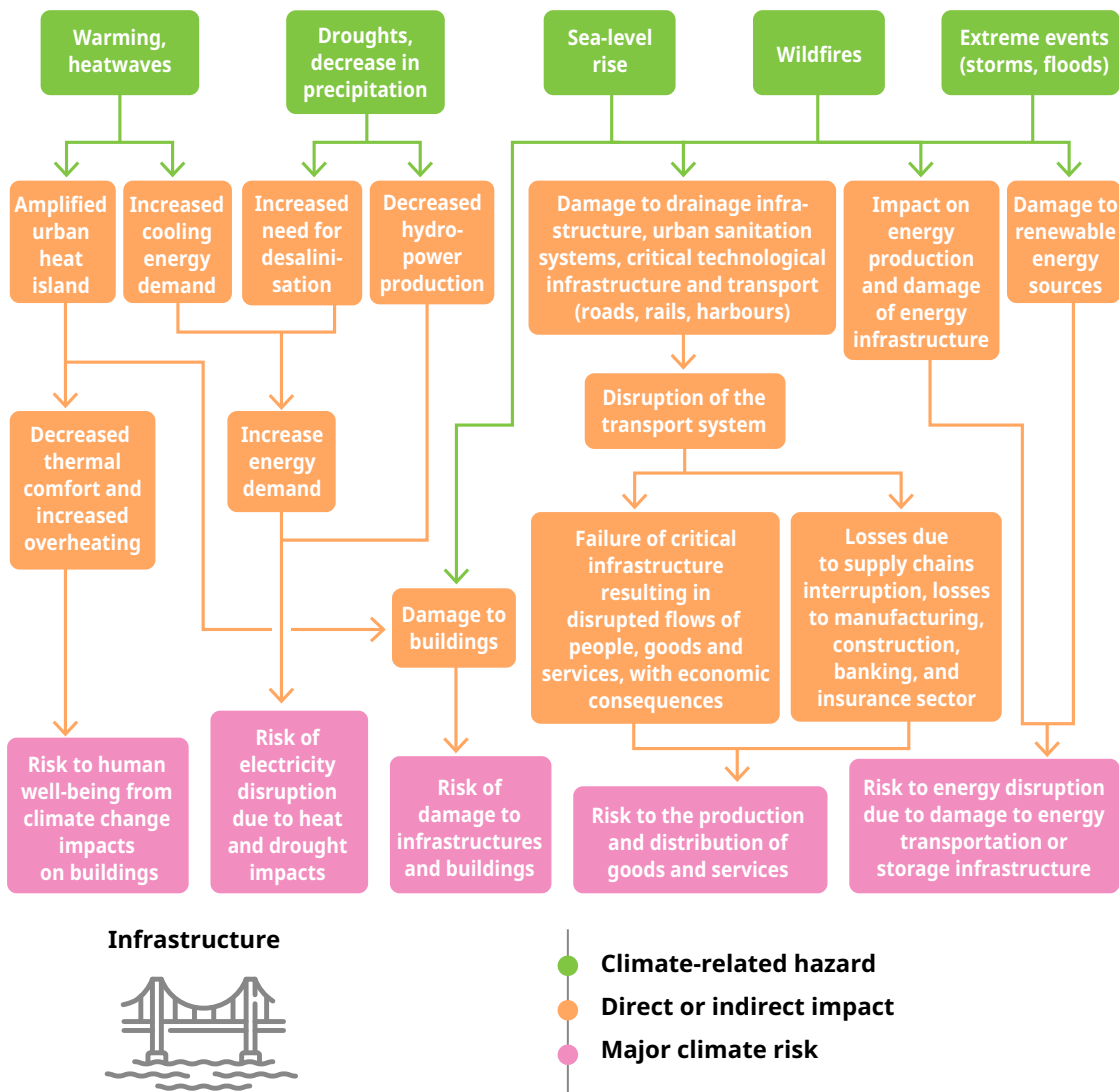


Figure 14 – Impact chain in infrastructures from climate-related hazards. Adapted from EEA (2024)¹².

Network-level effects add a layer of complexity. Infrastructure assets are often part of networks or systems: from rail, road and telecommunications networks to power systems¹². When one or more assets within these networks fail, the effects may cascade, as such infrastructure systems are generally strongly interconnected. Different infrastructure networks also rely on one another, and these interdependencies can lead to disruptions in one system cascading into others. A prime example is power outages, which can quickly affect telecommunications, transport and even water supply and treatment¹².

The **built environment** is increasingly vulnerable to the impacts of climate change. Residential buildings are vulnerable to chronic and acute climate-related hazards, including extreme temperatures, high humidity, heavy rainfall, strong winds and impacts of solid material¹⁰¹. Elevated temperature and humidity accelerate material degradation, particularly by increasing corrosion in building components. Warming and heatwaves, combined with the lack of adequate cooling systems in residential and non-residential buildings, significantly raise the risk of indoor overheating during such events. This poses a serious health threat to vulnerable populations, including the elderly and individuals with pre-existing health conditions¹².

Urbanisation has been shown to intensify temperatures within cities compared to surrounding rural areas (the urban heat island effect (UHI)⁵², described in section 3.2.3). This effect becomes even more pronounced during extreme heat events such as heatwaves, when the air temperature in cities can rise significantly. Higher average temperature is expected to interact more directly with urban infrastructure. This, combined with the widespread use of air conditioning, can further intensify local heating and reinforce the urban heat island effect⁹³.



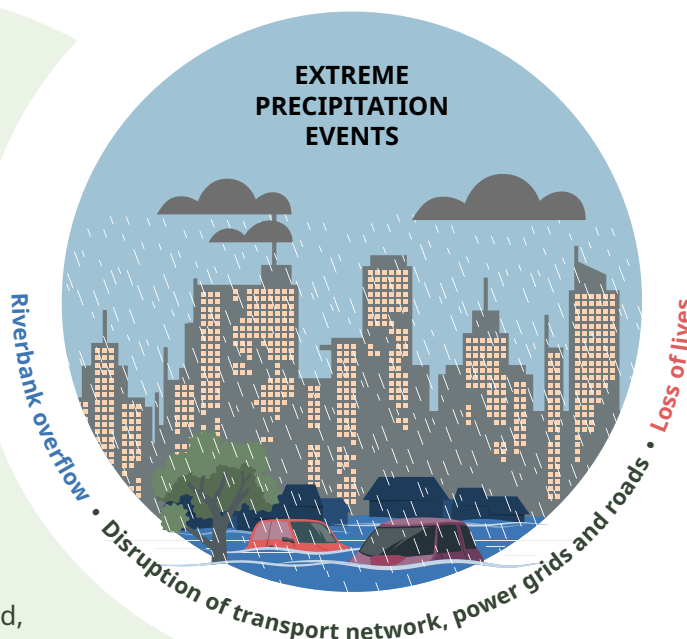
New York (USA) on Freepik

Projections indicate that intense rainfall and more frequent hailstorms will cause an increase in urban landslides (movement of rock, debris or earth down a slope), resulting in structural damage¹² (example in Box L). At the same time, extreme weather events can damage energy supply infrastructure and affect the adequate functioning of energy generation infrastructures, such as wind turbines, which cannot operate in extreme low or high wind conditions. Energy production is affected by high temperatures, as they reduce the efficiency of thermal power plants and, in some cases, force the shutdown of nuclear reactors⁹³.

Climate-related hazards such as changes in precipitation, sea level rise, and flooding pose serious threats to transport infrastructure. Drought conditions can reduce the navigability of rivers and coastal waterways, while wildfire smoke may disrupt airport operations⁹³. Additionally, rising temperatures have led to road surface deformation and melting, further affecting the functionality of transportation networks. These disruptions create cascading impacts, interrupting the flow of goods and services and resulting in significant economic consequences^{12,93}.

Box L

In July 2021, an extreme precipitation event caused severe flooding in western Germany, resulting in the death of more than 180 people. Within 24 hours, some areas received more than double their monthly average rainfall, leading to catastrophic **flash floods**. Infrastructure, including roads, railways, power grids, and water systems, was heavily damaged. Entire sections of the rail network were destroyed, bridges collapsed, and towns were cut off¹⁰².



A flash flood is a flood of short duration with a relatively high peak discharge in which the time interval between the observable causative event and the flood is less than four to six hours¹⁰³. A flash flood is generally characterised by raging torrents after heavy rains, a dam or levee failure or a sudden release of water in a previously stopped passage (i.e., by debris or ice) that rips through riverbeds, urban streets, or mountain canyons, sweeping away everything in its path¹⁰⁴.

Coastal areas face flooding and sea-level rise, impacting buildings, especially in densely populated subsiding regions¹⁰¹. Sea-level rise also severely affects critical infrastructure, including urban sanitation systems and underground networks. These impacts not only compromise infrastructure performance but also contribute to production losses and increased economic costs¹².

5.5 Socio-economics

This section area outlines the impacts of climate-related hazards on the socio-economics. It begins by presenting the effects on the economic sector, then explores the impacts on cultural heritage, implications for education and concludes with social cohesion. In the description of impacts on the other four target areas, many issues with direct or indirect implications on socio-economics have already been addressed, for example, the decreased availability and increased food costs (Target Area Water and Food Security, Figure 12), the water scarcity (Target Area Water and Food Security, Figure 11), increased morbidity and mortality (Target Area – Human Health, Figure 13) or harmful algal blooms (Target Area Ecosystems, Figure 9).



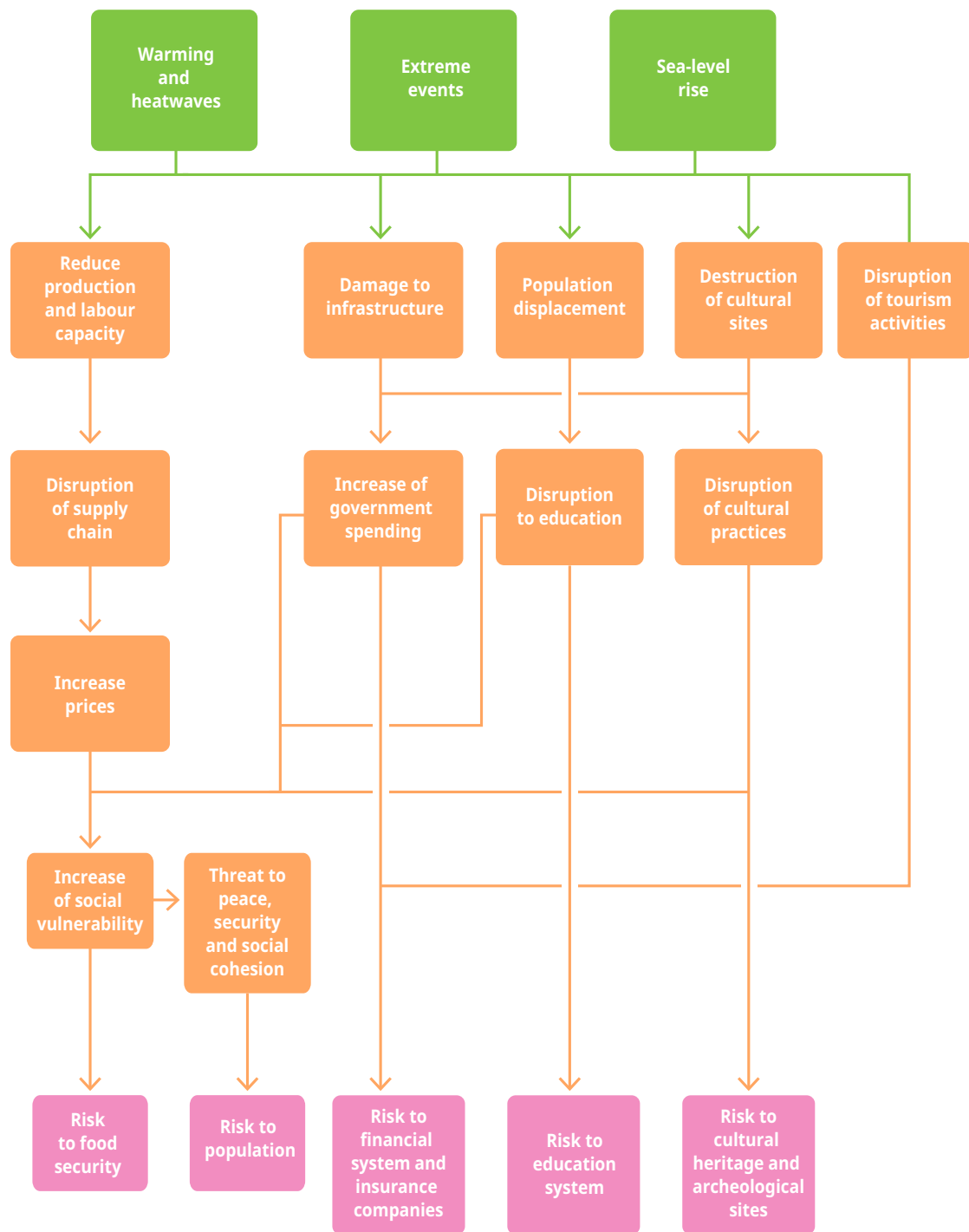
Rafael Marques from Espinho - Aveiro, Portugal

This section focuses on the impacts of three main climate-related hazards, namely warming and heatwaves, extreme events, and sea-level rise, and how these threaten various components of the socio-economic target area, including population well-being, financial systems, cultural heritage, and the education sector (Figure 15). These hazards have interconnected impacts that can be both direct and indirect. For example, extreme events may damage infrastructure (as highlighted in the previous target area), while also reducing labour capacity, destroying cultural heritage (disrupting cultural practices), and displacing populations¹². These disruptions can threaten peace, security, and social cohesion, lead to increased government spending, and limit access to education, particularly in the most vulnerable regions.

The global **economic** sector faces significant risks from the impacts of climate change. These impacts have already led to increased government spending on disaster response and social support programmes¹⁰⁵. Rising temperatures are expected to continue, further reducing productivity across key economic sectors, including agriculture, fisheries, energy, and tourism. Concurrently, disruptions in supply chains are projected to drive up prices, negatively affecting accessibility to essential resources such as food and water¹². Some data show that floods cause the highest direct losses for the manufacturing and utilities sectors¹⁰⁶. Business closures can be influenced by the effects of climate change and the local economy. Indeed, it was estimated that by 2050, the probability of default for firms in regions most exposed to physical risks, may increase by up to four times faster than that of an average firm¹⁰⁷.

Climate-related hazards (particularly extreme events) can have an impact on the information and communication sector, which includes, for example, broadcasting, telecommunications, publishing and information services¹⁰⁸. The telecommunications sector is one of the basic services needed for society to function effectively; the ability to communicate is of paramount importance during emergencies and in subsequent post-disaster stages¹⁰⁸. Indirect effects of climate-hazards, such as service disruption and its impact on factors such as productivity, job losses, lack of comfort and security issues, can be as high as, or substantially higher than, direct effects^{109,110}.

Climate change has directly and indirectly affected **cultural heritage** worldwide. Extreme weather events have led to the destruction of culturally significant sites and elements of identity, while various climate-related hazards pose a threat to archaeological areas. It is estimated that one-third of UNESCO World Heritage properties are at risk from climate change⁶³. Specifically, among World Heritage natural sites, complete glacier extinction is projected by 2100 in 8 to 21 of these sites, under all emission scenarios⁷². The loss of these sites impacts not only local communities but also global heritage, impacting cultural values and traditional practices (Figure 15)⁶³.



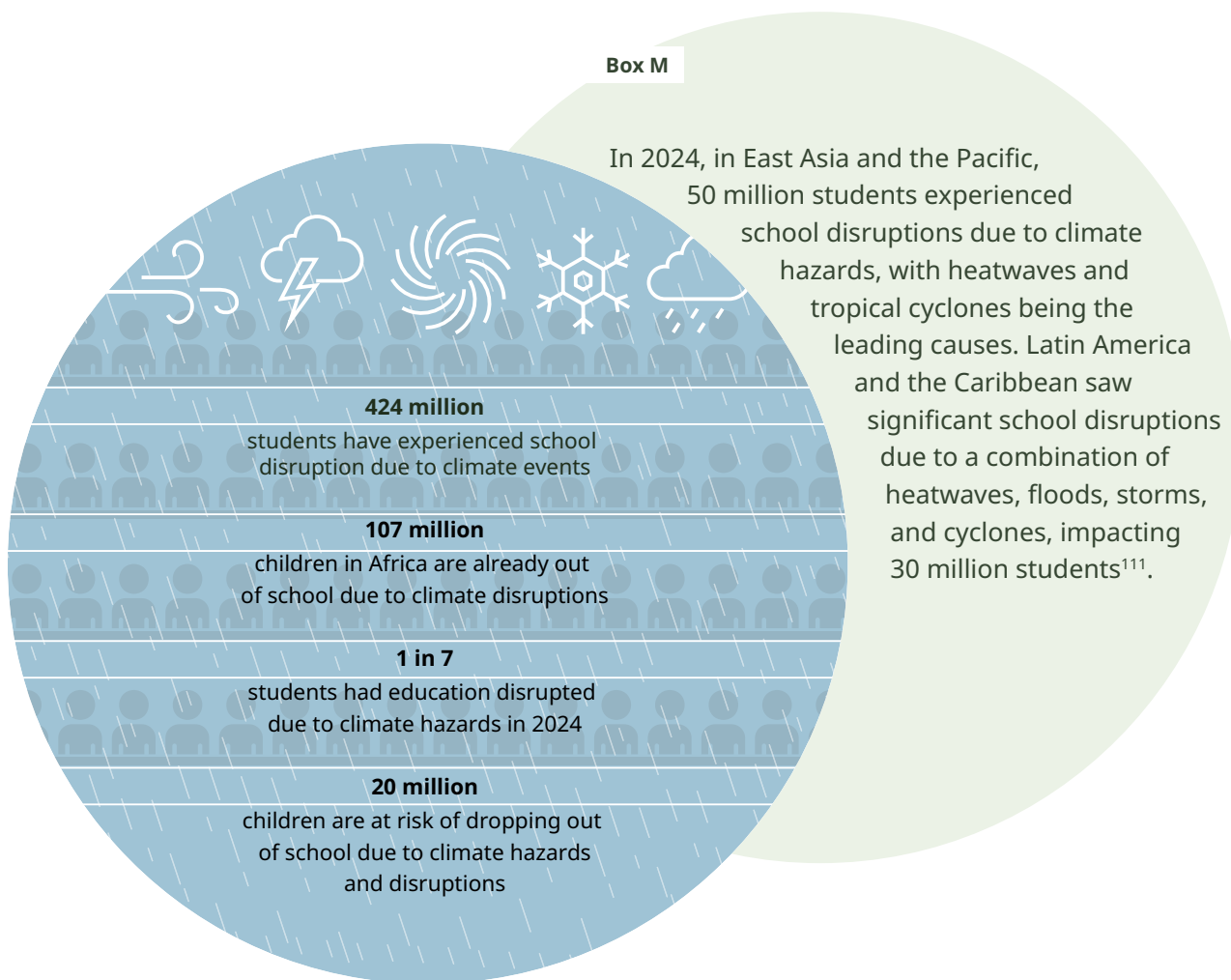
Socio-economics



- Climate-related hazard
- Direct or indirect impact
- Major climate risk

Figure 15 – Impact chain in socio-economics from climate-related hazards. Adapted from EEA (2024)¹².

Climate change has already disrupted the **education sector**, particularly through displacement caused by natural disasters and extreme events. Damaged infrastructure, language barriers faced by displaced populations, and difficulties in the recognition of academic qualifications in host countries have all hindered access to education and learning continuity¹¹¹ (example in Box M). Climate risks affecting educational facilities can exacerbate social inequalities by disproportionately impacting students from marginalised communities who attend schools located in hazard-prone areas¹².



When considering the socio-economic impacts of climate change, social cohesion and the protection of vulnerable people are key. It is crucial to acknowledge that if future climate change under high emissions scenarios continues, without strong adaptation measures, the resulting losses and damages will likely be concentrated among the poorest vulnerable populations¹¹² (example in Box N). Even with moderate climate change, people in vulnerable regions will experience a further erosion of livelihood security, which may interact with humanitarian crises, such as displacement, forced migration, and violent conflict, potentially leading to social tipping points¹¹².

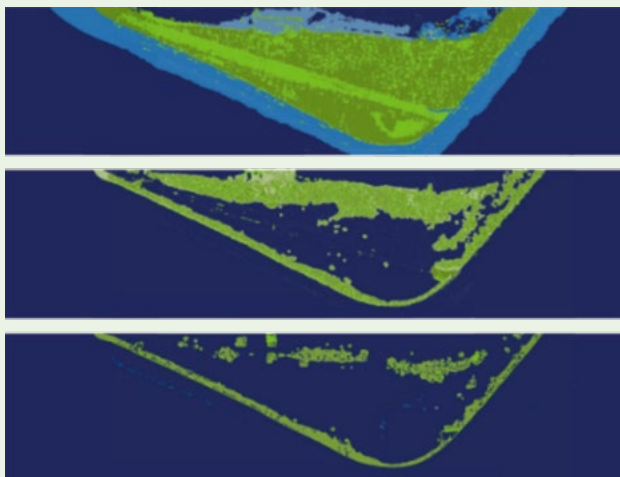
Box N

Tuvalu is a clear example of how climate change is having and will continue to have a significant socio-economic impact. Tuvalu is an island nation and is home to a population of approximately 11,000 people, and it is one of the most vulnerable countries in the world to the impacts of climate change¹¹³. It is expected that by 2050, most of the land will be below water at high tide, leaving the island increasingly vulnerable to episodic flooding¹¹³. Tuvalu boasts a well-established Polynesian culture that promotes a harmonious interaction between people and nature.

Increasing chronic and acute climatic hazards, including coastal inundation, groundwater intrusion and pluvial floods, impact places of cultural significance and heritage, including grave sites, culturally significant community meeting places and related natural assets (e.g. large shade trees, beaches and bathing areas). Net migration of people re-locating from outer islands to Funafuti is expected to compound these issues. This can result in loss of social identity and social cohesion, and a related sense of personal loss and trauma, and risks to intergenerational, loss and trauma, and with negative consequences for mental health and wellbeing for individuals and local communities over intergenerational timescales¹¹⁴.



Nanumea's church, Tuvalu. Photo from UNDP



Note: The top panel shows Funafuti Island (capital of Tuvalu) in 2022. The middle panel shows one-half of the land area expected to be flooded from daily tidal waters by 2050 under the high-emission scenario. The bottom panel shows 95% of land area expected to be flooded from daily tidal waters by 2100 in the same high-emission scenario¹¹⁵.

6



LINES OF ADAPTATION

6. Lines of adaptation for the target areas

Adaptation to climate change in human systems, as previously defined, is the process of adjustment to actual or expected climate and its effects to moderate harm or exploit beneficial opportunities. While uncertainties exist regarding future scenarios, as outlined in section 3, it is essential to proactively prepare for upcoming changes by implementing measures that minimise impacts and promote the development of more resilient communities. Herein, we present lines of adaptation that were defined to raise awareness, facilitate decision-making, and develop scientific research in the five target areas. These adaptation lines were compiled from several documents, namely the national adaptation plans to climate change of Portugal^(116,117,118,119,120), Finland¹²¹, Spain¹²², the European Green Deal¹²³, the European Biodiversity Strategy¹²⁴, and the European Forestry Strategy¹²⁵ and the European Nature Restoration Regulation¹²⁶.

The successful implementation of adaptation strategies is dependent on the active involvement of five key actors: (1) governmental and legislative institutions, (2) resource management entities, (3) research institutions, (4) the private sector, and (5) local communities. Governmental and legislative bodies, such as the European Parliament and the European Commission, are responsible for developing policies, regulations, and national plans. Examples of such policies include the European Climate Law and the European Green Deal, which exert influence on action at both national and international levels. Resource management entities, including national conservation agencies, play a pivotal role in the design of interventions and the execution of specific measures, such as restoration projects, across national and local scales. Research institutions contribute to the global effort by conducting scientific studies that generate knowledge and deepen understanding of climate and environmental issues. These institutions often focus their work on local or regional contexts, as well as international levels, as evidenced by the work of organisations such as the European Space Agency, through their Copernicus Programme for Earth observation. The private sector encompasses all commercial businesses and organisations that are not under governmental control. This includes, for example, agricultural companies, which are considered to be essential partners in the implementation of adaptation measures. Finally, local communities are fundamental to building resilience, fostering social cohesion, and promoting sustainable development; they bring valuable local knowledge and resources, implement tailored solutions, and advocate for their specific needs within the adaptation process.

6.1 Ecosystems



Actors	Ecosystem	Lines of adaptation
Governmental and legislative institutions (...)	Terrestrial and freshwater Marine and coastal	Increase the coverage of protected biodiversity-rich land and sea areas, building on the Natura 2000 network. Member States should also reinforce cross-border cooperation to protect and restore more effectively the areas covered by the Natura 2000 network, integrating the EU Nature Restoration Regulation .
		Integrate management of shared resources between countries to ensure conjunct actions that strengthen ecosystem resilience, implement coordinated adaptive strategies, and reduce cross-border climate-related risks.
		Implement legally binding EU nature restoration targets, to ensure that nature restoration across land and sea, increases the EU's resilience, and contributes to climate change mitigation and adaptation as key Nature-based Solutions (Nbs) .
		Promote the creation of natural parks dedicated to the conservation of natural ecosystems. Incorporate climate change adaptation measures within the context of natural parks.
		Incorporate climate change into national conservation strategies and conservation and recovery plans for endangered species.
		Create national and regional biodiversity monitoring programmes for terrestrial and aquatic species.



European Nature Restoration Regulation: This law sets binding targets to restore degraded ecosystems, in particular those with the most potential to capture and store carbon and to prevent and reduce the impact of natural disasters. It aims to contribute to achieving long-term and sustained recovery of biodiverse and resilient ecosystems through restoration. It establishes that at least 20% of land and sea ecosystems must be restored by 2030, and all the ones in need of restoration by 2025¹²⁶.

Nature-based Solutions (Nbs) are solutions or measures inspired and supported by nature, are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more and more diverse nature and natural features and processes into cities, landscapes and seascapes through locally adapted, resource-efficient and systemic interventions¹²⁷.



Photo by A Rita Carrasco



Actors	Ecosystem	Lines of adaptation
(...) Governmental and legislative institutions	Terrestrial and freshwater	Provide financial support and incentives for agricultural and forestry projects, as well as forest owners, based on the adoption of practices that combat desertification and enhance the quantity and quality of EU forests.
		Promote sustainable forest bioeconomy , including long-lived wood products, non-wood products such as ecotourism, and ensure sustainable use of wood-based resources for bioenergy .
		Integrate land degradation prevention into various land management policies and regulations.
		Implement regulations that make the territory fire-ready, such as fuel management, defence networks, and new landscapes.
	Marine and coastal	Extend Marine Protected Areas (MPA) to improve marine conservation, reduce the effects of human pressures, decrease habitat fragmentation, and enhance ecological connectivity and biodiversity.
		Establish investment funds dedicated to the restoration of marine and coastal ecosystems.



Bioeconomy means using renewable biological resources from land and sea, like crops, forests, fish, animals and microorganisms, to produce food, materials and energy¹²⁸.

Bioenergy is a form of renewable energy that is derived from recently living organic materials known as biomass, which can be used to produce transportation fuels, heat, electricity, and products¹²⁹.

Marine Protected Areas (MPA) are geographically distinct zones for which protection objectives are set. They constitute a globally connected system for safeguarding biodiversity and maintaining marine ecosystem health and the supply of ecosystem services¹³⁰.

Resource management entities (...)	Terrestrial and freshwater Marine and coastal	Apply an ecosystem-based approach in areas where human activities and natural systems coexist. Priority should be given to achieving or maintaining good environmental status in the community's natural environment, to ensure its ongoing protection and preservation, and to prevent further deterioration.
		Integrate restoration of natural ecosystems and management of degraded habitats to improve resilience to climate change.
		Make interventions aimed at maintaining or improving the provision of ecosystem services, mainly regulating ones.
		Minimise, and when possible, eliminate, the introduction and establishment of new invasive alien species and control the spread of already present species.



According to the Convention on Biological Diversity (a part of the UN Environment Programme), ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. Ecosystem-based approaches to adaptation (EBA) uses biodiversity and ecosystem services as part of an overall adaptation strategy to help people and communities adapt to the negative effects of climate change at local, national, regional and global levels. They aim to maintain and increase the resilience and reduce the vulnerability of people and the ecosystems they rely upon in face of adverse effects of climate change¹³¹.

Invasive alien species are animals and plants that are introduced accidentally or deliberately into a natural environment where they are not normally found, with serious negative consequences for their new environment. They are a major threat to native plants and animals and are one of the five major causes of biodiversity loss¹³².



Actors	Ecosystem	Lines of adaptation
(...) Resource management entities	Terrestrial and freshwater	Ensure forest restoration and reinforced sustainable forest management for climate adaptation and forest resilience.
		Conduct regular on-site inspections to verify safety conditions, ensuring the proper maintenance and functioning of wildfire protection and suppression structures, including shelters, refuge infrastructure, and defence networks.
		Implement actions aimed at the recovery of the natural morphology and dynamics of watercourses and the promotion of NbS, including recovering meanders, reconnecting floodplains, renaturalising watercourses, preserving wetlands, eliminating obstacles, promoting continuity, and recovering riverside forests.
	Marine and coastal	Design and implement NbS and hybrid solutions to restore coastal habitats and act as a natural defence against coastal erosion and flooding, including regeneration of dune systems, protection of seagrass beds, restoration of coastal wetlands and marshes, and renaturalisation of degraded areas.
Assess the carrying capacity of natural ecosystems and reduce pressures.		



Research institutions	Terrestrial and freshwater Marine and coastal	Developing science on strategic forest monitoring, reporting, and data collection.
		Develop cutting-edge research and innovation priorities to improve scientific knowledge on natural ecosystems (e.g., automatic remote monitoring).
		Anticipate the impacts of climate change on the distribution of habitat types of community interest.
		Develop and improve predictive models to forecast the effects of climate change on biodiversity, based on habitat evolution, landscape alterations, and detailed regional climate change scenarios, among others.
		Assess the vulnerability of natural habitats at the national level by evaluating their exposure, sensitivity, and adaptive capacity to the effects of climate change.



Carrying capacity is the size of the population or community that can be supported indefinitely upon the available resources and services of that ecosystem¹³³.



Photo by wirestock, Freepik



Actors	Ecosystem	Lines of adaptation
Private sector	Terrestrial and freshwater	Apply appropriate silvicultural treatments to improve the quality and biological diversity of protective forest areas, guarantee their stability, and ensure resistance and functionality under extreme conditions.



Silviculture is the science of controlling the establishment, growth, composition, health, and quality of forests and woodlands to meet the diverse needs and values of landowners and society, such as wildlife habitat, timber, water resources, restoration, and recreation on a sustainable basis¹³⁴.



Photo by Freepik

Apply appropriate silviculture treatments.

Communities	Terrestrial and freshwater Marine and coastal	Implement wildfire education programmes and capacitation in communities to facilitate the modification of behaviour and the adoption of self-protection measures through the active participation of citizens and society itself, which contributes to the incorporation of good practices into their daily lives.
		Integrate collaboration with stakeholders and the community in the planning and implementation of NbS, with the aim of ensuring the fostering and success of climate adaptation measures to prevent coastal flooding and erosion and habitat conservation.
	Marine and coastal	Increase collaboration among stakeholders and raise public awareness in coastal areas to avoid the development of infrastructure in highly exposed areas.



6.2 Food and water



Actors	Resource	Lines of adaptation
Governmental and legislative institutions	Water security	Strengthen regularisation of water availability for agriculture by increasing annual and multi-year storage capacity, water capture, and delivery.
		Control water intake licensing from different economic activities (e.g., agriculture, beverage companies, and the textile industry) to prevent pollution and ensure the good ecological status of water bodies.
	Food security	Integrate sectoral adaptation strategies and technological solutions with compensation mechanisms to reduce impacts on production.



Resource management entities (...)	Water security	Diversify water sources involving multiple sources, and enhance capacity for water transfer between river basins.
		Promote sustainable management of aquifers and the development of a culture of water as a limited resource.
		Implement drought management plans to meet supply requirements by improving storage, diversion, transfer facilities, desalination, and water reuse.
		Promote sustainable management strategies on the demand side, including monitoring scarcity, controlling demand, regulating distribution, using economic instruments, managing land cover, saving water, and efficiency solutions.
		Reinforce wastewater treatment and control of point-source and diffuse pollution, including control of water contamination, improving drainage systems, and wastewater treatment.
		Adapt water treatment technology to cope with variations in raw water quality caused by climate impacts (e.g., floods, droughts, and nutrient leaching).



Point-source and diffuse pollution
 – Point-source pollution refers to contaminants that enter the environment from a single point, such as a factory or sewage treatment plant. Diffuse pollution, on the other hand, involves pollutants being released over a wide area. Runoff from urban and suburban areas is a major origin of non-point source pollution. Discarded trash can become a component of non-point source pollution runoff ¹³⁵.



Actors	Resource	Lines of adaptation
<p>(...) Resource management entities</p>	<p>Food security</p>	<p>Manage animal disease risks, food safety risks, and plant pest risks to ensure food security.</p>
		<p>Assess the vulnerability of the food system to climate change impacts.</p>
		<p>Promote short trade channels and local agriculture, and educate consumers on the real cost of food production, including environmental costs.</p>
		<p>Implement measures to maintain vegetation cover, incorporate pruning remains into the soil in woody crops, and adopt cultivation methods that improve crop reliability.</p>
		<p>Promote the use of native forest crops to replace agricultural crops in flood-prone areas and encourage crop rotation and diversification.</p>



By Gpoint studio on Freepik

Promote short trade channels and local agriculture.

<p>Research institutions</p>	<p>Water security</p>	<p>Monitor and improve understanding of the observable effects of climate change on water bodies and their uses.</p>
		<p>Improve monitoring, forecasting, and warning systems for water resources.</p>
	<p>Food security</p>	<p>Develop research on conservation agriculture techniques and practices to protect the soil, improve irrigation efficiency, and control pests, diseases, and weeds.</p>





Actors	Resource	Lines of adaptation
Private sector	Water security	Promote implementation and improvement of irrigation systems by prioritising water storage during periods of abundance for use in periods of scarcity.
		Promote saving and efficiency measures aimed at reducing net water consumption.
		Use conservation agriculture techniques and practices that protect the soil and improve irrigation efficiency
	Food security	Adapt harvest planning to climate change in terms of changes in infrastructure, resource efficiency, raw materials, logistics, innovation, information, and communication.
		Relocate production areas for some spring/summer crops as part of adaptive strategies.
		Selecting crop varieties or livestock species better adapted to climate change impacts.
		Adjust sowing/planting dates based on the annual thermal regime to extend the production cycle and select better-adapted varieties with greater resistance to thermal and water stress.
		Use protected cultivation methods (e.g., tunnels, greenhouses) as alternatives to open-field farming and strengthen environmental control systems in protected cultivation.



Photo by Freepik

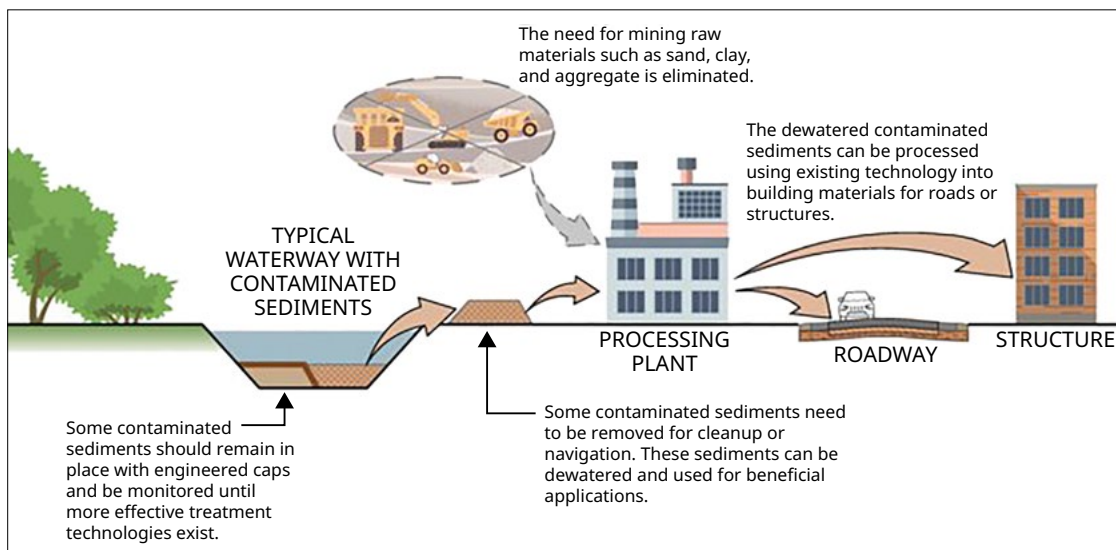
Improve monitoring, forecasting, and warning systems for water resources.



Actors	Resource	Lines of adaptation
Communities	Water security Food security	Participate, collaborate and promote outreach strategies or environmental education for more sustainable use of resources.
	Water security	Promote implementation and improvement of irrigation systems by prioritising water storage during periods of abundance for use in periods of scarcity.
		Integrate NGOs water conservation campaigns as educational tools to educate communities on water-saving and conservation practices.
		Promote saving and efficiency measures aimed at reducing net water consumption.
Food security	Transformation of the food system by moving to healthy diets, reducing food waste, and promoting the bioeconomy and circular economy across all stages.	



According to the European Parliament, the circular economy is a “model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended”¹³⁶. An important aspect of the circular economy is short trade channels, as they benefit the local economy, while contributing to reducing food waste and GHG emission from transportation.



Promote bioeconomy and circular economy. Example of circular economy using contaminated sediments¹³⁷.

6.3 Human health



Actors	Lines of adaptation
Governmental and legislative institutions	Ensure the adequate functioning of essential public services (e.g., water, sanitation, energy, health care, etc.) in the face of climate-related hazards, with a particular focus on maintaining the effective operation of health institutions.
	Establish and update regulatory requirements to ensure the climate resilience of water and sanitation services.
	Strengthen the role for national and regional governments in facilitating knowledge-sharing across scales, allocating financial resources, and creating knowledge and policy programmes on climate and health.
Resource management entities	Integrate early warning systems for climate conditions that pose risks to human health (e.g., heatwaves, storms, extreme precipitation events), in order to enhance preparedness, support timely response by health and emergency services, and reduce impacts on health.
	Facilitate knowledge-sharing across scales with dedicated financial resources and climate-health programmes.
	Implement targeted public information campaigns to mitigate social vulnerabilities associated with the impacts of climate change.
	Implement preventive actions against the effects of excessive temperatures on health. This is based on coordination between meteorological services (which prepare heatwave forecasts), health services (which develop action protocols and recommendations), social services (which provide care to the sectors most vulnerable to the phenomenon) and civil protection authorities (which ensure an adequate response to possible emergencies).
	Develop and update heat health action plans and adapt urban planning to address the impacts of urban heat island effects while reducing overheating of buildings, particularly concerning vulnerable population groups.
	Prepare responses to infectious and parasitic diseases driven by climate change through key elements: epidemiological and microbiological surveillance to detect, diagnose, and treat all patients as quickly as possible; entomological surveillance to detect the presence of the vector; vector management to prevent and control its presence and, if possible, eradicate it; individual protection of the population; training and information and, if necessary, research; as well as coordination and communication between the administrations and agents involved.
	Develop and implement preventive actions against episodes of atmospheric pollution (considering the interaction between temperature and pollution), particularly during periods of extreme heat, and their impact on health.
	Introduce land use restrictions in risk areas, including those prone to forest fires, floods, droughts, heatwaves, and coastal erosion.





Actors	Lines of adaptation
Research institutions	Identify temperature thresholds that trigger heat-related mortality in specific areas as part of the scientific basis for heat-related health measures.
	Support education and training of public health and healthcare professionals on climate change threats.
Private sector	Implement preventive measures to address the effects of climate change on workers' health by incorporating climate-related factors into workplace risk assessments, planning targeted interventions, and promoting dedicated programmes to protect the most vulnerable groups of workers.
Communities	Participate in the development, sharing, and following of protective measures against the impacts of climate change on health, thus increasing readiness and community resilience.
	Identify vulnerable people in the community and develop supporting groups.
	Adapt outdoor activities to weather conditions by avoiding exposure during heatwaves or risks associated with heavy rainfall and icy conditions.



HEAT STROKE

Avoid the sun

The danger of working out in the hot weather

SYMPTOMS

Rapid heartbeat

No sweating hot / red skin

Dizziness & headache

Unconsciousness

Vomiting

PREVENTION

No alcohol

Don't wear the thick clothes

Limit outdoor time

Wear protection

Use sunscreen use umbrella

Drink enough water

Cool showering

Source Freepick

6.4 Infrastructure



Actors	Sector	Lines of adaptation
Governmental and legislative institutions	Built environment	Implement measures to increase readiness for potential impacts, including early warning systems, evacuation protocols, and the introduction of specific construction regulations (e.g., elevation of dwellings, foundation design changes, and protection against humidity).
	Energy	<p>Integrate the National Energy and Climate Plans (NECPs) to deliver a fair, resilient, and climate-neutral transition and to steer investments for the climate and energy transition, helping to mobilise private and public spending.</p> <p>Incorporate analyses of emerging technologies into the energy transition planning process within future NECPs.</p>



The 10-year National Energy and Climate Plans (NECPs) outline how EU countries intend to meet the EU energy and climate targets for 2030. The national plans outline how the EU countries intend to address energy efficiency, renewables, greenhouse gas emissions reductions, interconnections, research and innovation¹³⁸.

Resource management entities (...)	Built environment Energy	Integrate urban green and blue infrastructures into planning, urban NbS, and urban climate mapping to create safe spaces that offer protection from climate-related hazards.
		Identify infrastructures highly vulnerable to extreme events and promote specific adaptation programmes.
		Increase the availability of emergency teams during extreme events to better anticipate and respond to their impacts.



Green and blue infrastructures are strategically planned networks of natural (green for land, blue for water) and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation and climate mitigation and adaptation¹³⁹.

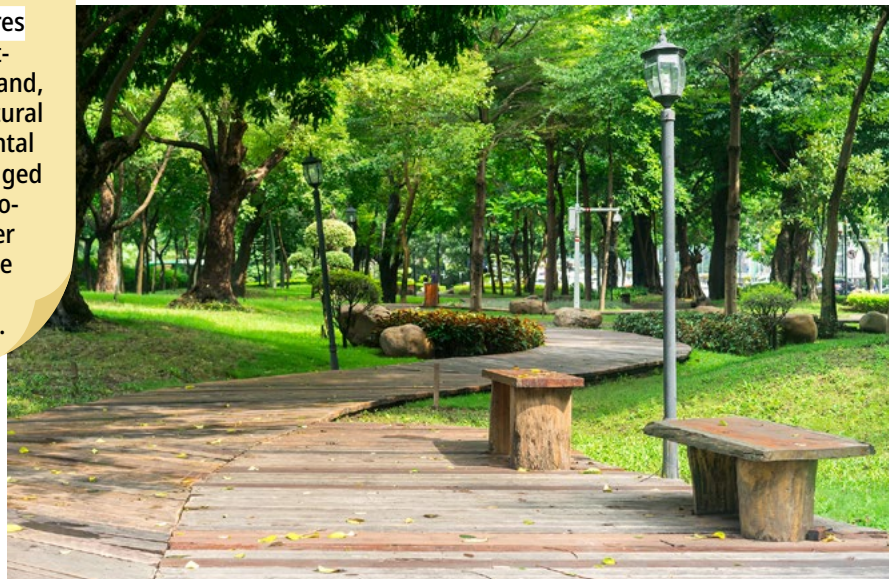


Photo by victor217, Freepik

Integrate urban green infrastructures into planning.



Actors	Sector	Lines of adaptation
(...) Resource management entities	Built environment	Prepare for extreme weather events and floods through land-use planning by locating new construction outside flood-risk areas or ensuring flood-risk management.
		Demolish artificial features that are deteriorated, highly vulnerable, or detrimental to the integrity of the public domain and reduce its adaptive capacity.
		Relocate highly exposed housing and infrastructure to safe areas and enable public acquisition of land on the coastline.
		Integrate the effects of climate change into transport infrastructure design and calculation regulations.
		Implement operational and construction measures to ensure climate-resilient railway infrastructure.
		Prepare road transport infrastructure for flooding to minimise the potential negative impacts of climate change on transportation routes.
	Energy	Promote measures to strengthen self-sufficiency in electricity production and broaden the evaluation of weather dependence in energy production as part of the green energy transition.



Research institutions	Built environment	Research on the areas of urban planning, smart and sustainable building materials, green and blue infrastructure, and urban heat island mitigation.
		Develop research on how to turn cities greener and increase resilience to minimise the impacts of climate-related hazards.
		Research on sea-level rise and flooding scenarios and set recommendations for the lowest permissible construction levels.
		Integrate assessment of climate change impacts on both current and future conditions.
		Conduct stress tests on more vulnerable infrastructures for extreme scenarios (heatwaves, floods, and droughts).
	Energy	Develop projections to assess the availability of water resources and their generation potentials by river basin for various climate change scenarios.
		Improve knowledge on the potential impacts of climate change on the functionality and resilience of energy generation, storage, and distribution systems and specify adaptation measures to avoid or reduce identified risks.

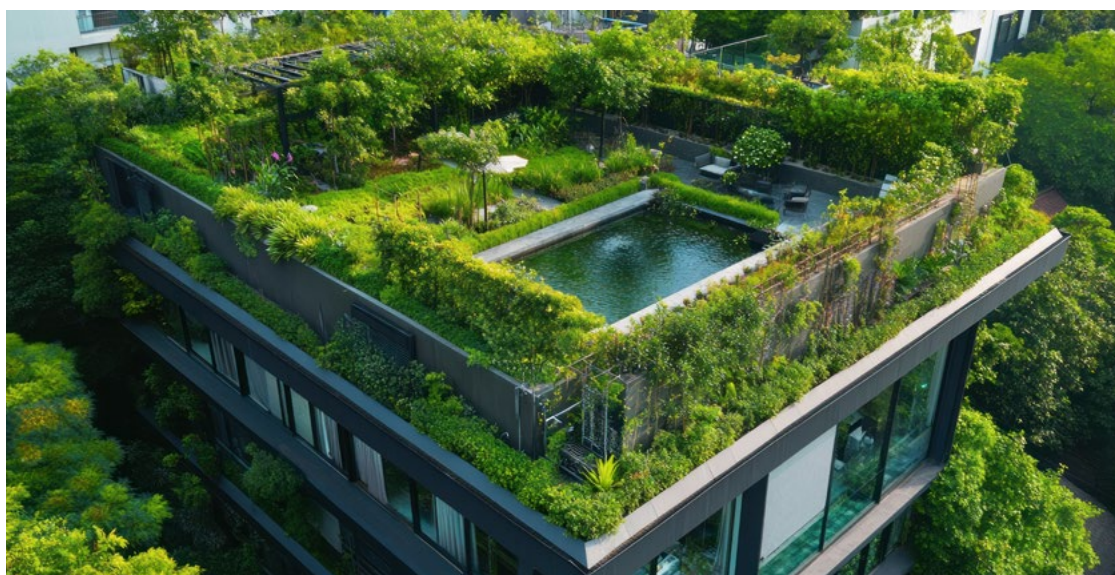




Actors	Sector	Lines of adaptation
Private sector	Built environment Energy	Implement climate-responsive design in buildings and urban settlements, enhancing building efficiency standards, and developing more resilient buildings.
		Implement green roofs, facades, and other vegetated spaces that act as natural sponges, absorbing rainwater and promoting the recovery of rain and greywater.
		Utilise energy-efficient technologies and encourage innovation in materials and building solutions.
	Built environment	Construct climate-proof buildings against excessively high temperatures.
		Adapt airport infrastructure and services to increase climate resilience and to ensure the continuity of supply chains for the business and industry sectors.
		Enhance operational safety in offshore and inshore transport operations by adopting improved personal flotation devices, investing in vessel stability, and performing specific training for safety at sea for operators.
	Energy	Identify and analyse technological improvements to promote more resilient, efficient, and adaptable electricity generation facilities.



Greywater refers to wastewater generated from household activities such as laundry, bathing, handwashing, and the use of sinks, excluding wastewater from toilets (commonly known as blackwater)¹⁴⁰.



Designed by Freepik



Actors	Sector	Lines of adaptation
Community	Built environment	Use elements such as blinds, fans, air conditioning, and other cooling features to help keep the indoor areas of the house cooler.
	Energy	Increase collaboration among stakeholders and local communities to support the transition to local renewable energy sources.
		Engage communities in adapting energy-saving practices and raise awareness about their importance.



Designed by Freepik

Use elements such as blinds, fans, air conditioning, and other cooling features.

6.5 Socio-economics



Actors	Sector	Lines of adaptation
Governmental and legislative institutions	Economy Social cohesion	Implement policies and strategies that restrict access and activities in high-risk areas and ecologically sensitive or endangered ecosystems, including tourism activities.
	Economy	Identify and promote mechanisms to integrate climate change adaptation into the development of policies and strategies within the insurance sector, alongside initiatives aimed at preventing climate-related risks (e.g., carbon market).
	Education	Support the development and implementation of environmental policies aligned with international commitments, making use of environmental education as a key social tool.
	Social cohesion	Integrate climate change adaptation into crisis management systems, considering the threats and challenges climate change poses to national peace and security. Ensure effective and timely responses across all phases, from early warning to emergency response.



North Carolina (USA). Photo by Gene Gallin, Unsplash

Implement policies that restrict access and activities in high-risk areas.

Carbon markets are a form of carbon pricing mechanism that enables governments and non-state actors to trade greenhouse gas (GHG) emission allowances or credits. Each carbon credit represents the right to emit one metric ton of carbon dioxide (CO₂) or its equivalent in other greenhouse gases. By purchasing these credits, entities are paying for the right to emit a specific amount of GHGs¹⁴¹.

Organisations that emit less than their allocated limit can sell their surplus allowances to others that exceed theirs, creating a financial incentive for reducing emissions. This market-based approach encourages emissions reductions where they are most economically viable and directs investment toward sectors or regions with the greatest mitigation potential. The revenue generated through the sale of allowances is often reinvested in low-carbon technologies, renewable energy, and other initiatives aimed at further reducing emissions¹²⁴. A leading example of this mechanism in action is the European Union Emissions Trading System (EU ETS)¹⁴².



Actors	Sector	Lines of adaptation
Resource management entities (...)	Economy	Assess the exposure of national financial systems to climate-related risks as a critical element in shaping resilient business strategies.
		Integrate climate change adaptation into sustainable finance initiatives as a key to respond to climate change, and provide support to companies.
		Identify, plan, and implement adaptation initiatives to protect tourism destinations and resources, while strengthening the resilience of tourism infrastructure and facilities, especially those linked to traditional tourism assets.
		Ensure access to early warning systems and equipment related to climate risks for tourism operators.
	Education	Promote educational activities for teachers and children, including the integration of climate change topics into school curricula.
		Develop and implement communication and educational campaigns that share practical examples of climate change adaptation in action.



Designed by Freepik

Promote educational activities about adaptation to climate change.



Actors	Sector	Lines of adaptation
(...) Resource management entities	Cultural heritage	Identify the main risks and cultural heritage elements most vulnerable to climate change.
		Integrate climate change into preventive conservation plans of artworks and heritage items.
		Use high-quality, acid-free, and mould-resistant storage containers to extend the preservation of artworks and heritage items.
		Upgrade to energy-efficient Heating, Ventilation, and Air Conditioning (HVAC) systems that maintain stable temperature and humidity levels to minimise deterioration of artworks.
		Build digital twins of existing heritage that might be lost in the future to allow its virtual preservation.
		Promote the involvement of multiple sectors and social stakeholders in the cultural transformation required for the ecological and energy transition over the coming decade, through education, communication, training, and environmental participation.
	Social cohesion	Encourage community engagement, citizen participation, and conflict management processes as tools to support peace, security, and social cohesion in response to climate change impacts.
	Prevent potential conflicts through early detection by integrating risk analysis into climate change studies, enabling the identification of scenarios that may threaten peace, security, and social cohesion.	



Research institutions	Economy	Generate knowledge, resources, and tools related to climate change adaptation within the financial system and insurance sector to strengthen institutional capacity and identify opportunities to support adaptation efforts.
	Education	Identify behavioural changes and practical options that create new opportunities for transformation and enhance adaptive responses to climate change.
		Research on climate literacy and pedagogical innovation aimed at educating the public about climate change and appropriate responses during extreme events.
	Cultural heritage	Implement real-time monitoring systems to track temperature, humidity, and ultraviolet radiation levels, enabling rapid adjustments and early detection of potential climate-related hazards.
		Strengthen scientific research on heritage sites at risk in order to generate new knowledge, monitor deterioration processes, and develop innovative conservation methods to ensure long-term protection under changing climate conditions.
	Social cohesion	Advance research into early warning systems to support civil protection services and first responders in implementing timely and effective measures during extreme events





Actors	Sector	Lines of adaptation
Private sector	Economy	Apply weather derivatives as a risk management tool for organisations and individuals seeking protection from the financial impacts of unexpected weather events.
		Find different mechanisms to include climate change adaptation in the design of policies and strategies related to insurance business, as well as the promotion of initiatives to prevent the risks associated with climate change.
		Define more sustainable tourism models that are more resilient to the impacts of climate change.
		Take into account the carrying capacities of destinations and encourage the diversification of economic activities in tourist areas, changing tourist activities (for example, from ski tourism to mountain tourism), redistributing tourist flows to untapped destinations (from coastal areas to inland), decreasing average length of stay and de-seasonalising sun and beach destination.



Weather derivatives are financial instruments that can be used by organisations or individuals as part of risk management strategies to protect themselves from risks caused by unexpected weather changes¹⁴³. These tools work like contracts where one party (the investor) agrees to pay another party (the buyer) if certain weather conditions happen, like a pre-defined amount of rain or temperature. In exchange for this promise, the investor gets an upfront payment. Weather derivatives are based on a specific “weather” trigger (e.g. heating degree days) rather than proof of loss (for instance, temperature over a specified threshold and period) and therefore are simpler (and cheaper) to administer than other alternative options. For example, farmers can use weather derivatives to hedge against poor harvests caused by, for example, a lack of rain during the growing period or excessive rain during harvesting.



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Actors	Sector	Lines of adaptation
Communities	Economy	Use Economic Incentives for Behavioural Change (EPIs) , as they can spur behavioural change through incentives or disincentives and change conditions to enable economic transactions or reduce risk.
	Cultural heritage	Identify good practices in the use of technologies and indigenous knowledge for adjusting to climate conditions.
		Use interpretative media associated with cultural heritage as a vehicle for climate awareness and the communication of climate actions, including generating visibility of good practices.
	Education	Promote resilient and climate-adapted lifestyles, with responsible consumption and habits that contribute to adapting to climate change.
	Social cohesion	Increase awareness on how to deal with climate change and participate in civil protection demonstrations.



Economic Incentives for Behavioural Change (EPIs) are incentives aimed at adapting individuals' decisions to collectively agreed goals, by incentivising behavioural changes that lead to adaptation. They are classified in: pricing, environmental taxes, subsidies, trading and voluntary agreements¹⁴⁴.



by Global Environmental Facility

Education to promote climate-adapted lifestyles.



7

GLOSSARY

7. Glossary

Abiotic factors: non-living part of an ecosystem that shapes its environment. In a terrestrial ecosystem, examples might include temperature, light, and water. In a marine ecosystem, abiotic factors would include salinity and ocean currents.

Adaptation: in human systems, is the process of adjustment to actual or expected climate and its effects, to moderate harm or exploit beneficial opportunities.

Adaptive capacity: is the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities or to respond to consequences.

Albedo: measure of the percentage of sunlight that a surface reflects away. Bright snow and ice have a high albedo, meaning they reflect solar radiation back into space, while green areas like forests and fields have a much lower albedo.

Aquaculture: breeding, rearing, and harvesting of fish, shellfish, algae, and other organisms in all types of water environments.

Aquifer: layers of rock, sand or gravel that can absorb water and allow it to flow. An aquifer acts as a groundwater reservoir when the underlying rock is impermeable.

Billion: 1.000.000.000.

Biodiversity: variability among living organisms from all sources including, among other things, terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.

Bioeconomy: use of renewable biological resources from land and sea, like crops, forests, fish, animals and micro-organisms to produce food, materials and energy.

Bioenergy: a form of renewable energy that is derived from recently living organic materials known as biomass, which can be used to produce transportation fuels, heat, electricity, and products.

Carbon capture: a process by which carbon dioxide (CO₂) is removed from the atmosphere and stored in natural systems. This can occur in multiple terrestrial, freshwater, and marine ecosystems, where CO₂ is absorbed, either through biological processes, such as photosynthesis, or physical processes, such as direct dissolution of CO₂ into the ocean surface.

Carbon markets: a form of carbon pricing mechanism that enables governments and non-state actors to trade greenhouse gas (GHG) emission allowances or credits. Each carbon credit represents the right to emit one metric ton of carbon dioxide (CO₂) or its equivalent in other greenhouse gases. By purchasing these credits, entities are paying for the right to emit a specific amount of GHGs.

Carbon sink: any system, natural or artificial, that absorbs more carbon dioxide (CO₂) from the atmosphere than it releases, thereby reducing the concentration of greenhouse gases in the atmosphere.

Carbon storage: a process by which carbon dioxide (CO₂) is captured and held in natural ecosystems, primarily through biological mechanisms such as photosynthesis in terrestrial plants, algae, and microbial activity in soils, contributing to the reduction of atmospheric CO₂ levels.

Carrying capacity: the size of the population or community that can be supported indefinitely upon the available resources and services of that ecosystem.

Circular economy: a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended.

Coastal erosion: the wearing away and transporting away of sediment particles and rock fragments in the coastal zones.

Coastal flooding: occurs when dry and low-lying land is submerged by seawater.

Coral reef: An underwater ecosystem characterised by structure-building stony corals. Warm-water coral reefs occur in shallow seas, mostly in the tropics, with the corals (animals) containing algae (plants). Cold-water coral reefs occur throughout the world, mostly at water depths of 50–500 m. In both kinds of reef, living corals frequently grow on older, dead material, predominantly made of calcium carbonate (CaCO₃).

Cryosphere: frozen components of the Earth system that are at or below the land and ocean surface. These include snow, glaciers, ice sheets, ice shelves, icebergs, sea ice, lake ice, river ice, permafrost and seasonally frozen ground and solid precipitation.

Cultural heritage: artefacts, monuments, a group of buildings and sites, museums that have a diversity of values including symbolic, historic, artistic, aesthetic, ethnological or anthropological, scientific and social significance. It includes tangible heritage (movable, immobile and underwater), intangible cultural heritage (ICH) embedded into cultural, and natural heritage artefacts, sites or monuments. The definition excludes ICH related to other cultural domains such as festivals, celebration etc. It covers industrial heritage and cave paintings.

Cyanobacteria: also known as blue-green algae, are frequently found in freshwater, estuarine, and marine environments. These microscopic organisms play an important role in supporting various species and food webs. However, when cyanobacteria grow excessively, they can form “blooms” that raise both ecological and human health concerns.

Cyclone: strong, cyclonic-scale disturbance that originates over tropical oceans. Distinguished from weaker systems (often named tropical disturbances or depressions) by exceeding a threshold wind speed. Beyond 32 m/s, a tropical cyclone is called a hurricane, typhoon or cyclone, depending on geographic location.

Deoxygenation: overall decline in the oxygen content of oceanic and coastal waters. Deoxygenation occurs when oxygen consumption (e.g. from respiration or breathing) is greater than oxygen replenishment through photosynthesis, ventilation, and mixing.

Diffuse pollution: pollutants being released over a wide area.

Driver (of change): any natural or human-induced factor that directly or indirectly causes a change in a system.

Early warning system: set of technical and institutional capacities to forecast, predict, and communicate timely and meaningful warning information to enable individuals, communities, managed ecosystems, and organisations threatened by a hazard to prepare to act promptly and appropriately to reduce the possibility of harm or loss.

Eco-anxiety: chronic fear of environmental cataclysm that comes from observing the seemingly irrevocable impact of climate change and the associated concern for one's future and that of next generations.

Ecological niches: characteristics of an environment that provides all the essential food and protection for the continued survival of a particular species of flora or fauna. In addition to food and shelter, there is no long-term threat to existence in that place from potential predators, parasites and competitors.

Economic incentives for behavioural change (EPIs): are incentives aimed at adapting individuals' decisions to collectively agreed goals, by incentivising behavioural changes that lead to adaptation. They are classified into: pricing, environmental taxes, subsidies, trading and voluntary agreements.

Ecosystem: A functional unit consisting of living organisms, their non-living environment and the interactions within and between them.

Ecosystem fragmentation: happens when parts of a habitat are destroyed, leaving behind smaller, unconnected areas. This can occur naturally, as a result of fire or volcanic eruptions, but is normally due to human activity.

Ecosystem services: Ecological processes or functions having monetary or non-monetary value to individuals or society at large. These are frequently classified as (1) supporting services such as productivity or biodiversity maintenance, (2) provisioning services such as food or fibre, (3) regulating services such as climate regulation or carbon sequestration, and (4) cultural services such as tourism or spiritual and aesthetic appreciation.

Ecosystem-based approach: strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. It uses biodiversity and ecosystem services as part of an overall adaptation strategy to help people and communities adapt to the negative effects of climate change at local, national, regional and global levels.

Ecotourism: responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and creates knowledge and understanding through interpretation and education of all involved: visitors, staff and the visited.

Environmental flow: amount and quality of water necessary to preserve ecological functions and values in watercourses.

Eutrophication: process of pollution that occurs when a lake or stream becomes over-rich in plant nutrients; as a consequence, it becomes overgrown with algae and other aquatic plants. The plants die and decompose. In decomposing, the plants rob the water of oxygen, and the lake, river or stream becomes lifeless. Nitrate fertilisers, which drain from the fields, nutrients from animal wastes and human sewage are the primary causes of eutrophication.

Evaporation: process that changes liquid water to gaseous water (include land and ocean).

Evapotranspiration: sum of all processes by which water moves from the land surface to the atmosphere via evaporation and transpiration; it includes evaporation from the soil surface, from water bodies on land and plant transpiration.

Exposure: the presence of people, livelihoods, species or ecosystems, environmental functions, services and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

Financial system: institutional units (e.g., household, corporation, or government agency) and markets that interact, typically in a complex manner, for the purpose of mobilizing funds for investment and providing facilities, including payment systems, for the financing of commercial activity.

Firm default: occurs when scheduled payments of interest or principal on a debt are not made according to the agreed terms.

Flash flood: a flood of short duration with a relatively high peak discharge in which the time interval between the observable causative event and the flood is less than four to six hours. A flash flood is generally characterised by raging torrents after heavy rains, a dam or levee failure or a sudden release of water in a previously stopped passage that rips through riverbeds, urban streets, or mountain canyons, sweeping away everything in its path.

Food chain: describes how energy and nutrients move through an ecosystem. At the basic level there are plants that produce the energy, then it moves up to higher-level organisms like herbivores. After that when carnivores eat the herbivores, energy is transferred from one to the other.

Foodborne diseases: diseases caused by contamination of food and occur at any stage of the food production, delivery and consumption chain. They can result from several forms of environmental contamination, including pollution in water, soil or air, as well as unsafe food storage and processing.

Fossil fuel: carbon-based fuels from fossil hydrocarbon deposits, including coal, oil and natural gas.

Geothermal energy: accessible thermal energy stored in the Earth's interior, in both rock and trapped steam or liquid water (hydrothermal resources), which may be used to generate electric energy in a thermal power plant, or to supply heat to any process requiring it.

Gini coefficient: measures the extent to which the distribution of income within a country deviates from a perfectly equal distribution. A coefficient of 0 expresses perfect equality, where everyone has the same income, while a coefficient of 100 expresses full inequality, where only one person has all the income.

Glacier: an accumulation of ice and snow that slowly flows over land. Alpine glaciers are frozen rivers of ice, slowly flowing under their own weight down mountainsides and into valleys.

Green and blue infrastructures: strategically planned networks of natural (green for land, blue for water) and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation and climate mitigation and adaptation.

Greenhouse gases: gases in the atmosphere that have the property of being mostly transparent to visible sunlight but not to infrared radiation (primarily associated with heat) emitted by the Earth's surface. These gases (including water vapour, carbon dioxide, methane and nitrous oxide) trap the infrared energy and send a part of it back to the surface, thus warming the lower atmosphere and the planet's surface. This phenomenon is known as the greenhouse effect.

Greywater: wastewater generated from household activities such as laundry, bathing, handwashing, and the use of sinks, excluding wastewater from toilets (commonly known as blackwater).

Gross Domestic Product: the most common measure for the size of an economy. It measures the total value of goods and services produced by that economy during a specific period, typically a year.

Harmful algal blooms: occur when colonies of algae grow out of control and produce toxic or harmful effects on people, fish, shellfish, marine mammals and birds.

Hazard: a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation.

Heritage sites (UNESCO): designation for places on Earth that are of outstanding universal value to humanity and as such, have been inscribed on the World Heritage List to be protected for future generations to appreciate and enjoy.

Hurricane: tropical cyclone formed over the Atlantic and East Pacific.

Hydrological cycle: continuous circulation of water in the Earth-Atmosphere system. At its core, the water cycle is the motion of the water from the ground to the atmosphere and back again.

Invasive alien species: animals and plants that are introduced accidentally or deliberately into a natural environment where they are not normally found, with serious negative consequences for their new environment.

Marine Protected Areas: geographically distinct zones for which protection objectives are set. They constitute a globally connected system for safeguarding biodiversity and maintaining marine ecosystem health and the supply of ecosystem services.

Minimum environmental flow: the amount and quality of water necessary to preserve ecological functions and values in watercourses. It is also known as ecological flow. One set of challenges in water resources planning today is to define environment flow requirements (quantity, timing, and quality on a seasonal basis), integrate them in water allocation policies and achieve consensus on this, and translate and incorporate those requirements into the operating rules for flow regulating structures, such as dams, reservoirs, and diversion schemes.

Mitigation (of climate change): a human intervention to reduce emissions or enhance the sinks of greenhouse gases.

Mixed layer: mixing layer of oceanic waters where typically temperature and salinity (and thus density) are fairly uniform.

Monitoring: mechanisms put in place to respectively monitor and evaluate efforts to reduce greenhouse gas emissions and/or adapt to the impacts of climate change with the aim of systematically identifying, characterising and assessing progress over time.

Morbidity: state of being symptomatic or unhealthy for a disease or condition.

Natura 2000: the largest coordinated network of protected areas covering the most valuable and threatened species and habitats.

Nature-based Solutions: solutions inspired and supported by nature that are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience.

Ocean acidification: the process by which seawater becomes more acidic due to the increased absorption of CO₂ from the atmosphere. When CO₂ dissolves in seawater, it creates a chemical reaction which releases hydrogen and lowers the water pH, increasing its acidity.

Ocean mixed layer: layer of oceanic waters where typically temperature and salinity (and thus density) are fairly uniform. Therefore, the mixed layer depth is the width of the upper ocean that interacts with the atmosphere. It plays a key role not only in climate control but also in the biology of marine organisms.

Organic matter: Plant and animal residue that decomposes and becomes a part of the soil.

Peatlands: wetland ecosystems that form from the accumulation and burial of organic matter derived from plant detritus. They develop under conditions of near continuous soil saturation with water that slows down the decomposition of plant material. Peatlands are usually associated with freshwater and with cool or wet climates, including the high latitudes of the northern hemisphere, oceanic environments, and moist tropical areas.

Permafrost: ground that remains frozen under 0°C for a minimum of two consecutive years.

Phenology: relationship between biological phenomena that recur periodically (e.g., development stages, migration), especially related to climate and seasonal changes. It focuses on the timing of biological events, seasonal rhythms and life cycles in plants and animals, such as leaf emergence, flowering, insect emergence, and bird migration.

Photosynthesis: the process by which a plant uses carbon dioxide from the air, water from the ground, and the energy from the light of the sun to produce its own food and oxygen.

Phytoplankton: microscopic plants that play a huge role in the marine food web. Like plants on land, phytoplankton perform photosynthesis to convert the sun's rays into energy to support themselves, and they take in carbon dioxide and produce oxygen. Because they need the sun's energy, phytoplankton are found near the water's surface.

Point-source pollution: contaminants that enter the environment from a single point, such as a factory or sewage treatment plant.

Pollinators: something, such as an insect, that carries pollen from one plant or part of a plant to another.

Power plant: facility that generates electricity from primary energy such as coal, natural gas and nuclear energy.

Primary producers: organisms, such as plants and phytoplankton, that can produce their own food through photosynthesis or chemosynthesis.

Renewable energy: any form of energy that is replenished by natural processes at a rate that equals or exceeds its rate of use.

Return period: estimate of the average time interval between occurrences of an event (e.g., flood or extreme rainfall) of (or below/above) a defined size or intensity.

Risk: the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems.

Run-off (superficial): fraction of precipitation that does not infiltrate at the land surface and may be retained at the surface or result in overland flow toward depressions, streams and other surface water bodies.

Saltwater intrusion: a natural process that occurs in virtually all coastal aquifers. It consists of saltwater (from the sea) flowing inland into freshwater aquifers.

Silviculture: the science of controlling the establishment, growth, composition, health, and quality of forests and woodlands to meet the diverse needs and values of landowners and society, such as wildlife habitat, timber, water resources, restoration, and recreation on a sustainable basis.

Sink of greenhouse gases: a natural or artificial reservoir that absorbs and stores these gases from the atmosphere by chemical, physical and biological mechanisms. Examples include oceans, forests, and soils.

Snow water equivalent: depth of water that would cover the ground if the snow cover were in a liquid state. It is the depth of water that would be formed if all the snow on the ground were to melt uniformly and spread over the area.

Social cohesion: extent of connectedness and solidarity among groups in society. It identifies two main dimensions: the sense of belonging of a community and the relationships among members within the community itself.

Social equity: fair access to livelihood, education, and resources; full participation in the political and cultural life of the community; and self-determination in meeting fundamental needs.

Soil moisture: water stored in the soil in liquid or frozen form.

Stakeholder: all those with interests in an organization; for example, as shareholders, employees, suppliers, customers, or members of the wider community (who could be affected by environmental consequences of an organization's activities).

Storm surge: rise in seawater level during a storm, measured as the height of the water above the normal predicted tide. The surge is caused primarily by strong winds pushing water onshore.

Supply chain: the system of people and things that are involved in getting a product from the place where it is made to the person who buys it.

Surveillance (epidemiological, entomological, microbiological): continuous, systematic collection, analysis and interpretation of health data (epidemiological), vector data (entomological) or microorganisms data (microbiological).

Threshold (climate): a limit within the climate system (or its forcing) beyond which the behaviour of the system is qualitatively changed.

Tundra ecosystems: ecosystems characteristic of mountainous and polar regions, such as the Arctic. These treeless, frigid landscapes are found in cold, windy environments with scarce rainfall.

Urban heat island: warming effect that occurs because cities receive and retain more heat than the surrounding countryside areas and because natural cooling processes are weakened in cities compared to rural areas.

Vector: living organisms that can transmit infectious pathogens between humans or from animals to humans.

Vector-borne disease: human illnesses caused by parasites, viruses and bacteria that are transmitted by vectors.

Vulnerability: propensity or predisposition to be adversely affected, encapsulating concepts such as sensitivity, susceptibility and lack of capacity to cope.

Water stratification: layering of water bodies with different physical and chemical properties, which occurs in environments such as lakes and oceans. This can be due to differences in temperature (warm layer overlying a cooler layer), salinity (freshwater overlying saltier water), or both.

Abbreviations and acronyms

List of abbreviations and acronyms used in the document and/or related to the subject.

AMAP	Arctic Monitoring and Assessment Programme
AR6	Sixth Assessment Report
CBA	Community-based Adaptation
CO₂	Carbon Dioxide
COP	Conference of the Parties (UNFCCC)
DRR	Disaster Risk Reduction
EBA	Ecosystem-based Approach
EC	European Commission
EEA	European Environment Agency
EGSS	Environmental Goods and Services Sector
EPIs	Economic Incentives for Behavioural Change
EPO	European Patent Office
EQI	Regional Quality of Government Index
ETC-CCA	European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation
EU ETS	European Union Emissions Trading System
EU	European Union
EWS	Early Warning Systems
FAO	Food and Agriculture Organization of the United Nations
GCF	Green Climate Fund
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GMST	Global Mean Surface Temperature
GVA	Gross Value Added
HAB	Harmful Algal Blooms
HVAC	Heating, Ventilation, and Air Conditioning
IPBES	Intergovernmental Platform on Biodiversity & Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
MPA	Marine Protected Area
LDC	Least Developed Countries
NAP	National Adaptation Plan
NASA	National Aeronautics and Space Administration
NBS	Nature-based Solutions
NECPs	National Energy and Climate Plans
NEEP	National Expenditure on Environmental Protection
NGO	Non-Governmental Organisation
NOAA	National Oceanic and Atmospheric Administration,

NUTS	Nomenclature of Territorial Units for Statistics
OECD	Organisation for Economic Co-operation and Development
PM	Particulate Matter
PPS	Purchasing Power Standard
pSCI	Sites of Community Importance
PTSD	Post-Traumatic Stress Disorder
RCPS	Representative Concentration Pathways
SAC	Special Areas of Conservation
SDG	Sustainable Development Goals
SIDS	Small Island Developing States
SPA	Special Protection Areas
SPI-3	Standardised Precipitation Index
SRES	Special Report on Emissions Scenarios
SSP	Socio-economic Pathways
UHI	Urban Heat Island
UN	United Nations
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Survey
WB/WBG	World Bank (Group)
WG	Working Group (IPCC)
WGI	Worldwide Governance Indicators
WHO	World Health Organization
WMO	World Meteorological Organisation
WRI	World Resources Institute
IS92	1992 IPCC Emission Scenarios

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