European Environment Agency

# European Climate Risk Assessment

EEA Report 01/2024

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# Part A Setting the scene

# 1 Introduction

**About this report**

- This report presents the first European Climate Risk Assessment (EUCRA) as announced in the 2021 EU strategy on adaptation to climate change. It contributes to the European Green Deal.
- The report was produced by the European Environment Agency (EEA) together with many partner organisations, supported by a wide range of stakeholders and experts.
- EUCRA aims to support the identification of policy priorities related to climate change adaptation and policy development in climate-sensitive sectors during the next EU policy cycle (following elections to the European Parliament in 2024), both at the European and the national level.
- It focuses on risks for Europe caused or aggravated by human-caused climate change, but also considers non-climate risk drivers and the policy context.
- The first EUCRA is a fast-track assessment, which builds mainly on existing knowledge sources. It combines both quantitative and qualitative lines of evidence.
- Major climate risks for Europe are presented in 'thematic factsheets' and in cross-cutting 'risk storylines'.
- The report comprises an assessment of major climate risks and of the policy context, including a coarse evaluation of risk ownership and policy readiness.
- 36 major climate risks for Europe are identified. The urgency of addressing these risks is evaluated using a structured framework, which considers both the severity of risks over time and policy characteristics.
- EUCRA identifies priorities for EU policy action, considering the outcomes of the structured risk evaluation jointly with qualitative aspects, such as considerations of social justice.



## 1.1 EUCRA purpose and governance

### *1.1.1 EUCRA purpose and target audience*

This first European Climate Risk Assessment (EUCRA) intends to support the identification of adaptation-related policy priorities in Europe and policy development in climate-sensitive sectors during the next EU policy cycle, following the elections to the European Parliament (EP) in 2024. It may also be relevant for identifying priorities for future investments, but no cost-benefit analysis of specific adaptation measures has been conducted. This report is targeted primarily at policymakers at the European level, in particular the European Commission (EC), the

EP and the Council of the EU, and at relevant advisory bodies, such as the European Committee of the Regions (CoR).

This report is also intended to provide an EU-wide point of reference for conducting and updating national or subnational climate risk assessments, including in relation to the EU Mission on Adaptation to Climate Change, in support of policymakers and planners addressing climate-related risk at the national or subnational level.

Finally, the EUCRA report and the supplementary material made available online aims at providing relevant information and data to societal stakeholders, the scientific community and the general public with an interest in understanding climate risks and building climate resilience.

This first EUCRA report was conducted within a short period of time, which placed some constraints on the assessment approach (see Section 1.3 for further information). A future EUCRA may wish to cover additional topics or address further decisionmakers and stakeholders. Its development should be preceded by a discussion about the most suitable assessment approach, and the institutional and resource context, to achieve the stated objectives.

### 1.1.2 EUCRA scope and mandate

The EU adaptation strategy adopted in 2021 (EC, 2021b) states under No. 14: '*Building on its overview of natural and man-made disaster risks the European Union may face, relevant research projects, its series of PESETA reports, and taking into account existing sector regulations, the Commission will draw up an EU-wide climate risk assessment*'. In September 2022, the EP adopted a resolution on the '*consequences of drought, fire, and other extreme weather phenomena: increasing EU's efforts to fight climate change*' (EP, 2022). Under No. 12, this resolution '*calls on the Commission to urgently draw up a comprehensive EU-wide climate risk assessment paying special attention to the risks of droughts, forest fires, health threats, ecosystem vulnerabilities and the effect on critical infrastructures and network hotspots in order to guide and prioritise short-, medium- and long-term adaptation and resilience efforts …*'

Against this policy background, the European Environment Agency (EEA) has produced this EUCRA report in response to a request from the EC. The scope was further clarified in discussions between the EC's Directorate-General for Climate Action (DG CLIMA) and the EEA, which considered the time and resource constraints for producing the first EUCRA as well as the valuable input obtained from the EUCRA Community of Practice (see Section 1.1.3).

This EUCRA report has the following scope and focus:

- The report focuses on those climate-sensitive risks that may require action at the European or transnational level to avoid major impacts on Europe's citizens, economy or ecosystems of international importance, or the overall functioning of the EU.
- EUCRA focuses on those climate-sensitive risks where changes in climatic hazards are a major contributor to current and future risk levels, while acknowledging the importance of non-climatic risk drivers.
- Particular attention is paid to 'complex' climate risks, including risks caused by the combination of various climatic and/or non-climatic hazards ('compound hazards'), risks cascading through systems and sectors ('cascading risks'), and risks impacting Europe from outside Europe ('cross-border risks'). It is acknowledged that standard quantitative risk assessment approaches may be difficult to apply to some of these complex risks and risk pathways.
- The social justice implications of climate risks and climate risk management are addressed. This includes, in particular, identifying the European regions most affected by and the population groups most vulnerable to the major climate risks assessed in this report.

- EUCRA goes beyond framing scientific evidence by also addressing how climate risks can impact on specific policy areas. This includes identification of EU policies exposed to climate risks and those that can increase resilience to these risks, encompassing both financial aspects and non-financial policies.
- Priorities for further action are identified for integrating risks in relevant policy areas. Identification of these priorities is based on a transparent assessment of risk severity and urgency, using quantitative information where available. The assessment of risk urgency also considers the timing of risks, risk ownership and the relevant policy context.
- The report pinpoints possible synergies and trade-offs between increasing climate resilience and other policy objectives, such as climate change mitigation and nature protection, based on the available evidence.
- Climate risks in all EEA member and cooperating countries, including non-EU countries, are assessed, based on the available evidence. However, the policy analysis and identification of priorities for action focus on the EU.

The following aspects are *not* covered in this EUCRA:

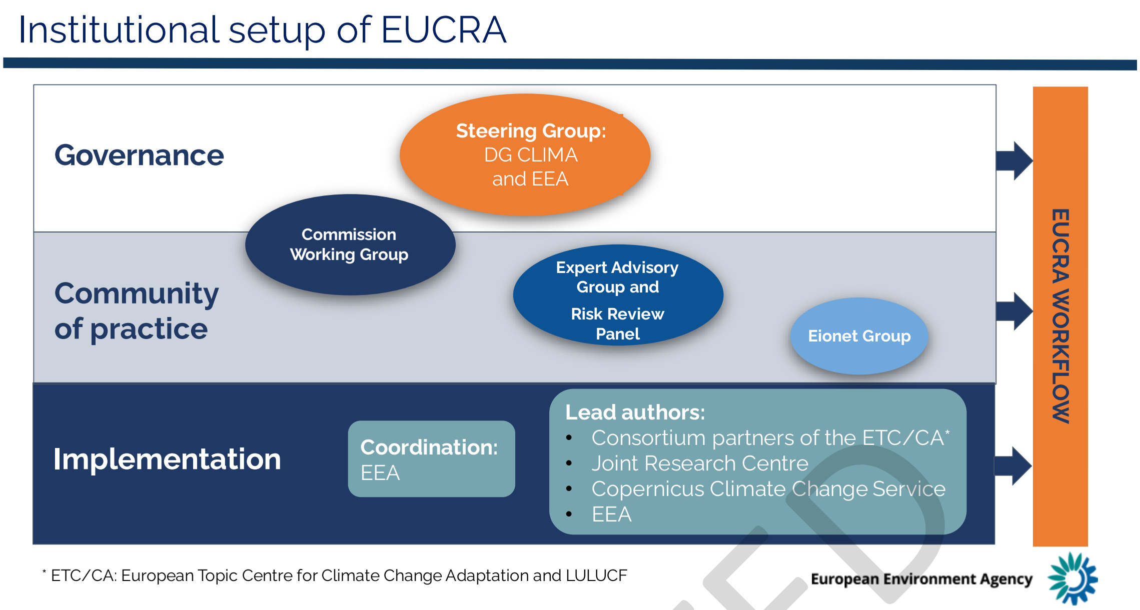
- climate-related risks linked to the EU's common foreign and security policy, including risks of uncontrolled mass migration and geopolitical risks;
- the global adaptation framework, with the exception of selected climate risks outside Europe that affect Europe;
- climate change adaptation policies and actions in individual European countries;
- specific adaptation solutions, including their benefits and costs;
- opportunities presented by climate change, where these may occur;
- risks related to the transition to a low-carbon economy ('transition risks').

### 1.1.3 EUCRA governance and implementation

The first EUCRA was prepared through the collaboration of a wide range of organisations and experts under the joint leadership of the EC (represented by DG CLIMA) and the EEA, together forming the EUCRA Steering Group. The report's preparation was further supported by a Community of Practice, which involved many external experts, policymakers and other stakeholders through the following groups (see Figure 1.1):

- EC Working Group on EUCRA (managed by DG CLIMA);
- EUCRA Expert Advisory Group (managed by the EEA);
- EUCRA Risk Review Panel (managed by the EEA);
- Eionet Group on Climate Change Impacts, Vulnerability and Adaptation (managed by the EEA).

**Figure 1.1 Institutional setup of EUCRA**




**Source:** EEA.

For a list of the individual experts and their host organisations who have contributed to EUCRA as authors or members of the Community of Practice, please see the Acknowledgements section.

## 1.2 EUCRA context

### *1.2.1 Climatic context*

This EUCRA report has been prepared against the backdrop of countless long-term climate records being shattered worldwide and in Europe in recent years. The planet's 10 warmest years on record have all occurred since 2000. Global mean temperature has already increased by about 1.2°C above pre-industrial levels (based on 10-year averages), whereas the mean temperature over European land areas has risen even faster, by about 2.1°C (EEA, 2023h). Globally, 2023 was the hottest year on record, close to 1.5°C above pre-industrial levels, and most likely the hottest year in more than 100,000 years. July and August 2023 were the two hottest months on record, and each month from June 2023 to January 2024 was warmer than the corresponding month in any previous year (C3S, 2023g).

Many extreme climate events in Europe have had wide-ranging impacts on ecosystems and ecosystem services, people and the economy. 2022 saw the hottest summer on record in Europe, and the years 2018, 2019, 2021, 2022 and 2023 all experienced record-breaking heatwaves, often combined with extreme droughts. The extreme heatwaves of 2022 have been associated with 60,000-70,000 excess deaths in Europe (Ballester et al., 2023a, 2023e). Heatwaves in combination with increasingly severe droughts have also facilitated the weather conditions for huge and destructive forest fires, as witnessed in 2022 and again in 2023. Finally, the heat and drought conditions in 2022 interacted with environmental risk factors (in particular, discharges of wastewater with a high salt content from mining activities) to create an ecological disaster along the Oder river in the German-Polish border region in summer 2022 (EC, 2023a).

Rising temperatures over land and sea have increased the risk of torrential rainfall. Sea surface temperatures reached record-warm levels during summer 2023, both globally and in Europe.

Marine heatwaves in the Mediterranean Sea have created the conditions for Mediterranean cyclones. For example, Storm/Cyclone Daniel in September 2023 brought torrential rain to parts of south-east Europe, where some areas of Greece received around 80cm of rain within a single day, leading to large-scale flooding. Various other regions in Europe have experienced extreme flooding as well. In August 2023, flash floods submerged large parts of Slovenia, causing an estimated EUR 10 billion of damage, which corresponds to 16% of national GDP (EBRD, 2023; Bezak et al., 2023a). Two years earlier, flooding following torrential rainfall in July 2021 led to more than 200 fatalities and estimated damage of EUR 44 billion in parts of Germany, Belgium and the Netherlands (Mohr et al., 2022b; EEA, 2023d). Extreme climate events in recent years have also had substantial impacts on many economic sectors in Europe, including agriculture, forestry, energy supply, transport and tourism.

Extreme event attribution, a relatively new branch of climate science, has shown that many of these extreme events would have been less severe, less likely, or – in the case of some heatwaves – virtually impossible in the absence of anthropogenic climate change (Robinson et al., 2021; Pearce et al., 2022; World Weather Attribution, 2023). Further information on past and future changes in climate hazards is provided in Chapter 2.

### *1.2.2 European policy context*

In the European Green Deal (EC, 2019b), the EC has committed to tackle climate and environment-related challenges as a top priority. The European Climate Law adopted in 2021 (EU, 2021), a key initiative of the Green Deal, provides the legal framework for the EU's policies and measures on adaptation to climate change. Article 5 requires the EU and its Member States to ensure continuous progress in enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change. It further obliges the Commission to adopt a Union strategy on adaptation to climate change in line with the Paris Agreement and to establish a regular review process to assess progress, while Member States must adopt and implement national adaptation strategies and plans, taking into consideration the Union strategy.

In 2021, the Commission adopted a new, more ambitious EU strategy on adaptation to climate change (EC, 2021b). This was welcomed by the Council of the EU, which also explicitly endorsed its long-term vision (Council of the EU, 2021, 2022a). The strategy sets out how the EU should adapt to the unavoidable impacts of climate change and become climate resilient by 2050. It commits the EC to 48 actions grouped under the four core objectives of facilitating smarter, faster, more systemic and global adaptation to the threats of climate change. The strategy proposes to step up adaptation planning and risk assessments as one of the key steps towards achieving these objectives.

Adaptation to observed and anticipated climate change is a cross-cutting policy issue with relevance for many sectoral policies (EEA, 2023a). Close links exist with, for instance, disaster prevention and preparedness, which is addressed at the EU level through the Union Civil Protection Mechanism (EU, 2013a, 2019). In a bid to accelerate EU adaptation efforts, the EC launched the Mission on Adaptation to Climate Change to galvanise actions across hundreds of EU regions, cities and local authorities to build resilience against adverse climate impacts (EC, 2022g; EC and EEA, 2023b). The LIFE programme has been another important source of funding for climate change adaptation and other environmental objectives in the EU (EC, 2021i).

Furthermore, through the Technical Support Instrument (TSI), the Commission is providing technical support to reforms in EU Member States, including for the development of climate change adaptation strategies and improving resilience to climate-related hazards (EC, 2021s). For example, the TSI has provided Member States with expertise to improve management of rural wildfires, flood risks and heatwaves. Finally, the EU sustainable finance framework aims to mobilise private finance to mitigate climate risks, adapt to climate change, and reduce associated risks in the financial sector (EC, 2023i).

On the knowledge side, the EC is funding the Copernicus Climate Change Service (C3S) and other relevant services under Copernicus, the Earth observation component of the EU Space programme. C3S' mission is to support society by providing authoritative information about the past, present and future climate in Europe and the rest of the world through publications, data and tools (C3S, 2023b). The EC has also launched the Destination Earth (DestinE) initiative to develop highly accurate digital twins (DTs) of the Earth on a global scale (EC, 2023n). This will contribute to achieving the objectives of the twin green and digital transition, as part of the Commission's Green Deal and digital strategy. DestinE's DT on climate change adaptation will provide simulations of climate scenarios from global to regional and national levels at a multi-decadal timescale, including uncertainty quantification (ECMWF, 2023). These initiatives and the wider policy context related to managing climate risks are reviewed in Chapter 20 and other parts of this report.

EU Member States and EEA member countries are also adapting to climate change, and every second year EU Member States report on national adaptation actions under the Regulation on the Governance of the Energy Union and Climate Action, (EU) 2018/1999 (EU, 2018). The results of their reporting are summarised in regular EEA reports (EEA, 2022a, 2023k), which provide important input for assessments of national measures and of Union progress and measures required under the European Climate Law (EC, 2023b, 2023g, 2023d).

The CoR estimates that local and regional authorities implement 90% of climate change adaptation policies in Europe (CoR, 2020). Against this background, in October 2023, the Commission adopted the Communication on Enhancing the European Administrative Space (EC, 2023j). The aim is to strengthen the capacity of public administrations in EU Member States in several crucial areas, with Pillar 3 focusing specifically on their ability to lead the green transition and build resilience.

### *1.2.3 Environmental and socio-political context*

EUCRA focuses on those risks that are either caused or are considerably aggravated by human-caused climate change. However, climate change has close links to other global environmental problems, as exemplified by the concepts of the 'triple planetary crisis' (UNFCCC, 2022) and the nine 'planetary boundaries' (Richardson et al., 2023). Hence, policies to reduce the risks from climate change need to consider synergies as well as trade-offs with environmental and other policy objectives.

The multiple challenges facing the EU since the COVID-19 pandemic and Russia's war of aggression against Ukraine have often been described as 'multiple crises' or 'poly-crisis' (EEA, 2022j; EC, 2023q). These unprecedented, non-climatic shocks have led to the development of new policy priorities and instruments at both the EU and Member State level, as discussed in the most recent EU Strategic Foresight Report (EC, 2023y).

In response to the COVID-19 pandemic, the EU has significantly increased collaboration in various policy areas, as exemplified by the common procurement of vaccines, the establishment of the Health Emergency Preparedness and Response Authority, and the creation of NextGenerationEU, an unprecedented post-pandemic recovery plan (EC, 2021k; Council of the EU, 2023). The pandemic has also showcased the interaction between climatic and non-climatic risk factors, such as heatwaves disproportionally impacting health personnel wearing personal protective clothing, or the limited capacity of emergency services already stressed by the pandemic during climatic disasters.

The disruption of supply chains due to the pandemic and Russia's war of aggression against Ukraine are key factors behind rapidly rising inflation in Europe, with particularly strong price increases for energy supply. Rising geopolitical tensions in Europe and beyond have also led to rapidly increasing public expenditure on defence and military support in Europe. At a global level, the combined impact of the COVID-19 pandemic's economic repercussions, limited grain exports from Ukraine and extreme climatic events, such as multi-year droughts affecting the Horn of Africa, have led to an unprecedented rise in the number of people facing acute food insecurity (WFP and FAO, 2022).

According to the latest Eurobarometer survey on climate change, about 80% of EU inhabitants believe that climate change is a very serious issue, and more than half see the EU as having a leading role in tackling this issue (EC, 2023c). At the same time, various European countries are experiencing political polarisation, which might create barriers for collaboration across the political spectrum and thus undermine the sustainability of adaptation policies. Furthermore, citizen movements in different EU countries have highlighted the importance of social justice issues in environmental and climate policies. In response, considerations of social justice and fairness have found their way into several recent EU policies, such as the Just Transition Mechanism (EC, 2021t), Council recommendations on ensuring a fair transition towards climate neutrality (Council of the EU, 2022b) and the Social Climate Fund (EU, 2023b). They also figure prominently in various EEA publications in the context of the transition to a climate-resilient society (EEA, 2019i, 2022k).

The above-mentioned environmental and socio-political challenges are not the focus of EUCRA, but they provide an important context for the climate risk assessment. In particular, various risk storylines explore further the interaction between climatic and non-climatic risk drivers, considering recent experiences.



## 1.3 Assessment approach

This section presents the report's knowledge context and analytical approach. The choices presented here take into account the fact that the first EUCRA is a fast-track assessment, which was conducted in about 18 months.

### *1.3.1 Knowledge context*

This report builds largely on the available scientific knowledge base, thereby integrating various lines of evidence, including quantitative and qualitative knowledge sources. Key information sources considered on climate change, associated impacts and adaptation in Europe include:

- reports and data from C3S;
- the review of scientific literature in the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6) (IPCC AR6; IPCC, 2021c, 2022e);
- publications from research projects funded under Horizon 2020 and Horizon Europe (see EC, 2022l);
- other relevant academic publications;
- reports and knowledge sources produced by the EC, including but not limited to:
    - *Overview of natural and man-made disaster risks the European Union may face* (EC, 2021l);
    - the series of PESETA projects undertaken by the Joint Research Centre (EC, 2022i);
- other products developed and managed by the EEA, including:
    - the Climate-ADAPT portal (EC and EEA, 2023a);
    - *Is Europe on track towards climate resilience?* (EEA, 2023k).

### *1.3.2 A policy-focused assessment*

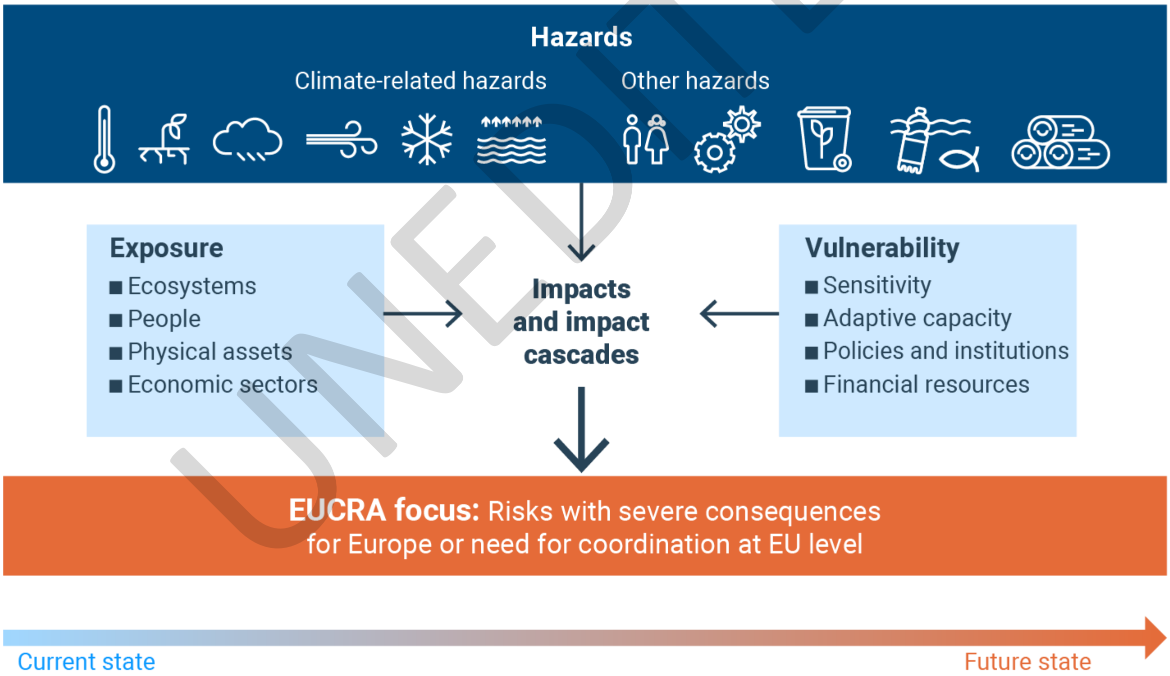
EUCRA has incorporated the following innovative elements intended to maximise its relevance for policymakers and other stakeholders in Europe:

- involving a wide range of stakeholders from the outset of the assessment process (see Section 1.1.3);
- presenting complex climate-related risks (i.e. compound, cascading, cross-sectoral and cross-border risks) through risk storylines (see Part C);
- identifying 36 major climate risks for Europe and three additional climate risks for EU Outermost Regions, compared to four key risks (with various sub-risks) in the IPCC AR6 chapter on Europe (Bednar-Friedl et al., 2022b);
- assessing those major climate risks according to their severity over time and confidence, complemented by an initial assessment of the policy horizon, risk ownership and EU policy readiness, supported by an external risk review panel;
- determining risk urgency for those major climate risks in a structured way based on the outcomes of the risk and policy evaluation;
- providing supplementary information online.

In this context, it is also important to stress the limitations of the first EUCRA, as outlined in Section 1.1.2 above.

### *1.3.3 Analytical approach and risk terminology*

**Figure 1.2 Methodological framework of EUCRA**




**Source:** EEA.

Figure 1.2 presents the methodological framework of EUCRA, including key terms.

EUCRA follows the risk concept of the IPCC AR6, according to which (climate) '*risk is defined as the potential for adverse consequences for human or ecological systems … Relevant adverse consequences include those on lives, livelihoods, health and well-being, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species'* (IPCC, 2022e, Glossary).

Risk drivers are broadly distinguished into climate-related hazards and non-climatic risk drivers. **Climate-related hazards** comprise both chronic and acute changes in climate conditions that can cause risks to human or ecological systems. Largely synonymous terms include climate hazards, climatic hazards, climate change hazards, climatic impact drivers and climatic risk drivers. **Non-climatic risk drivers** comprise those processes and conditions that determine how certain climate-related hazards, individually or in combination, affect a human or ecological system. They include environmental stressors, such as pollution or ecosystem fragmentation; technical factors, like the design standards of critical infrastructure; socio-economic factors, such as access to flood insurance and universal healthcare; and policy aspects, like the designation of flood risk areas and the enforcement of construction bans within them.

The risk assessment approach in EUCRA follows the ISO 31000 standard on risk management and ISO 14091 on adaptation to climate change with its phases of risk identification, risk analysis and risk evaluation (ISO, 2018, 2021b). However, simplifications were required due to the fast-track nature of this first EUCRA. Other approaches for assessing climate-related risks are being applied by private companies and regulators, e.g. in the financial sector.

EUCRA is building directly on the IPCC AR6's Europe chapter (Bednar-Friedl et al., 2022b). The IPCC AR6 assessment contains various new elements compared to the Fifth Assessment Report. This includes the attribution of observed climate impacts to human-caused climate change and the improved consideration of non-climatic conditions in climate risk assessment, of compound, cascading, cross-sectoral and cross-border risks, and of distributional justice dimensions of climate impacts and adaptation. It also identifies key risks for Europe, including eight economic risks, and provides sectoral key risk tables for Europe as a whole and four sub-European regions for three levels of global warming.

EUCRA extends and modifies the IPCC AR6's findings in several ways. First, it identifies 36 major climate risks for Europe, compared to four key risks (with several sub-risks) in the IPCC AR6 chapter on Europe. Second, EUCRA assesses the overall severity of climate-related risks, rather than only the magnitude attributable to recent and projected climate change. Third, it complements the risk analysis with an initial assessment of policy characteristics, such as the policy horizon, risk ownership and policy readiness, to evaluate the urgency of risk reducing measures. Within EUCRA, the policy context of major climate risks comprises relevant EU policies that may be adversely affected by climate risks or which can mitigate specific risks.



### 1.3.4 *Structured risk assessment of major climate risks*

A structured risk selection, analysis and evaluation was conducted for EUCRA. The risk selection identified major climate risks for Europe based on common criteria. The risk analysis classified these risks according to their severity over time, based on their potential for severe consequences for Europe. The risk evaluation phase evaluated the urgency for EU action considering risk severity over time, confidence in the risk severity assessment and the temporal aspects of potential adaptation actions jointly with risk ownership, policy readiness and the policy horizon.

The structured risk evaluation involved both the author teams of the relevant chapters and an independent risk review panel. The objectives were:

- ensuring the comparability of the risk evaluation for major climate risks for Europe within and across EUCRA factsheets and storylines;
- ensuring the legitimacy of the risk evaluation by drawing on the competence of a large group of experts with cross-cutting expertise in climate risk assessment;

- supporting the identification of priorities for action by combining the risk assessment with relevant policy characteristics.

Further information on the structured risk evaluation is available in 'Annex 2: Method for structured risk assessment'. The outcome of the evaluation, including the urgency to act for all major climate risks identified in EUCRA, is presented in Chapter 18.

## 1.4 Outline

The overall structure of the report is presented below:

- **Thematic factsheets** (part B) focus on major climate risks for eight selected systems and sectors.
- **Risk storylines** (part C) complement the factsheets by a more detailed analysis of selected compound climate risks across sectors and systems.
- **The concluding chapters** (part D) summarize the findings of the factsheet and storylines, present an overview of the 36 major climate risks for Europe identified therein, discuss the relevant EU policy context, and suggest priorities for action.

# 2 Europe in times of change and extremes

## 2.1 Key messages

- Human-induced climate change has manifested itself in unprecedented levels of warming and many other phenomena, including extreme events. Globally, 2023 was the warmest year on record, at 1.48°C above pre-industrial levels, and Europe is the fastest warming continent, at about twice the rate of the global average.
- Heatwaves are getting worse in Europe: more frequent, longer and hotter. Many European countries have experienced their warmest ever temperatures in recent years.
- Precipitation patterns in Europe are changing, with downpours and other precipitation extremes increasing in magnitude. Recent years have seen catastrophic floods in various regions, while southern Europe can expect considerable declines in overall rainfall. Accelerating sea levels are threatening coastal cities and communities.
- Europe's climate will continue to change in the future, but the rate of change depends on how quickly global greenhouse gas emissions are reduced.
- Climatic hazards can interact with environmental and social risk drivers to create cascading and compound impacts on the economy, ecosystems, equity and human health.
- Projections of both climate and non-climate impact drivers can increase confidence in anticipating future risk and better underpin adaptation policies. 'Wildcards' – unexpected climatic and geophysical, political and social events – should also be considered when planning for future scenarios.

## 2.2 Introduction

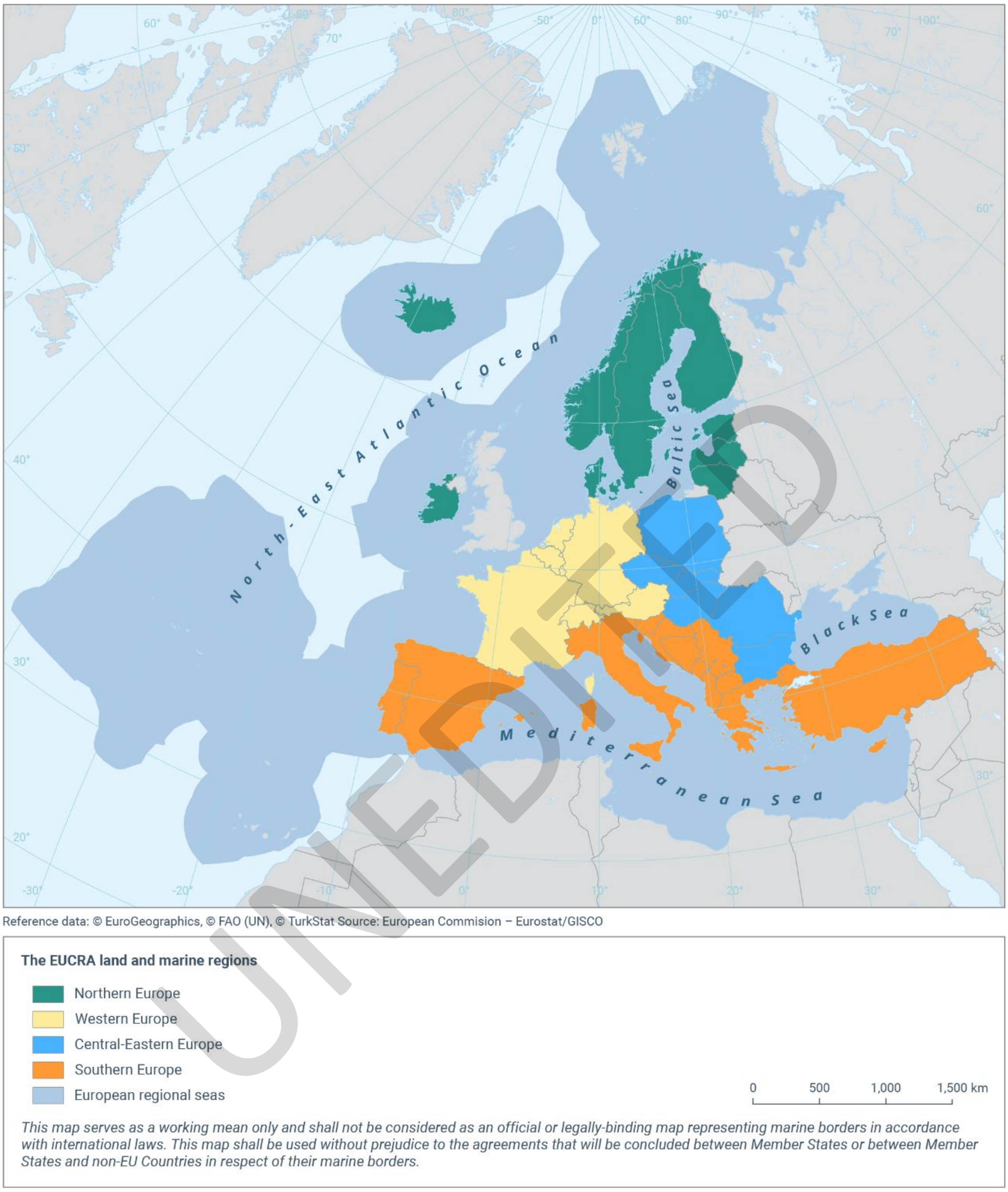
Recent increases in heatwaves, floods, wildfires and droughts, among other hazards, indicate that Europe is facing worse-than-anticipated climatic extreme events. These recent extreme events need to be understood in the context of gradual socio-economic developments that have affected Europeans' quality of life, including their exposure and vulnerability to such hazards. Moreover, risks have been compounded by concurrent, emergent and unexpected events such as the COVID-19 pandemic, Russia's war of aggression against Ukraine and related geopolitical tensions. Such interactions between climatic and societal changes have highlighted the systemic nature of multi-hazard risks confronting European policymakers addressing the need for climate change adaptation (Schweizer, 2021).

Climate changes of relevance for risks in Europe are expressed through observed and projected changes in climatic impact drivers (CIDs), which vary across the continent in their direction, magnitude and rate. A heterogenous landscape of climate change impacts is an outcome of the interaction of these drivers with levels of exposure, adaptive capacity and vulnerability affected by non-climatic impact drivers (NCIDs) that describe societal trends. Though there are regional exceptions, overall adaptive capacity is high in many parts of Europe, and the European population's current vulnerability to natural disasters is mostly low to moderate (IPCC, 2022a). However, the increased frequency and intensity of extreme climate events in Europe, such as the Slovenian floods of 2023, which caused an estimated EUR 10 billion in damage (Bezak et al., 2023b), require an updated understanding of adaptive capacity and risk. For example, the more than 200 deaths and about EUR 44 billion damage from the July 2021 floods affecting countries with ostensibly high adaptive capacity – Germany, Belgium and the Netherlands (EEA, 2023d) – suggest deficiencies of adaptation that may reflect, in part, our limited knowledge of how to prepare for the potentially non-linear, multiplier effects of systemic risks.

Confronted by these challenges, a climate change risk assessment typically constructs scenarios for representing a credible range of alternative future developments of CIDs and NCIDs, based on the best available knowledge, that can help to define and delimit future risks. In addition, it can be both instructive and prudent to make provision for other types of surprise, or wildcard events, that might alter scenario trajectories, potentially compounding risks and leading to further impacts that would not otherwise be considered in the assessment. The present assessment follows this dual approach for characterising future drivers of climate change risks in Europe: complementing a small set of scenarios with selected wildcards.

Section 2.3 provides an overview of the recent changes in CIDs and NCIDs. Drivers are analysed over four EUCRA land regions and four marine regions (see Figure 2.1). Section 2.4 presents the concepts of scenarios and wildcards. Finally, Section 2.5 covers the CIDs and NCIDs in the near-, medium- and long-term future under two illustrative scenarios.

## Figure 2.1 The EUCRA land and marine regions






**Note**: Spatially aggregated regions for four subcontinental land regions and four marine regions. For a list of countries included in the different regions, see Annex 2.

**Source**: based on UN Geoscheme for Europe.

## 2.3 Recent changes: how Europe has arrived at its present condition

### 2.3.1 Climate impact drivers

CIDs are the climatic and related physical factors that are driving impacts of climate change ([1]). They are combined here into five groups that are related to temperature (heat and cold), the availability of water (wet and dry), wind (wind), freezing conditions (snow and ice), and the aquatic environment (marine, coastal and lakes).

**Table 2.1 Categories of climatic and non-climatic impact drivers discussed in this chapter and illustrative impacts or risks associated with them**

| Impact driver | Illustrative impacts or risks |
|---|---|
| **Climate impact drivers** | |
| ***Heat and cold*** | Temperature effects on vegetation zones, growing season, energy demand for air conditioning and space heating; heat stress for human health, crops, ecosystems and infrastructure |
| ***Wet and dry*** | Pluvial and fluvial flooding with risks to infrastructure, economy, mental health; drought effects on fire risk, crop yields and pest outbreaks; water resource risks for hydropower, irrigation and domestic water supply |
| ***Wind*** | Risks to infrastructure, forests and energy production |
| ***Snow and ice*** | Risks to infrastructure and transport, winter recreation and tourism, and slipping injuries |
| ***Marine and coastal*** | Water quality (e.g. toxins, acidity and temperature) impacts on marine ecology, fisheries distribution and abundance, algal formation and recreation; sea level rise risks to coastal flooding and erosion, and salinisation |
| **Compound events ([2])** | *Preconditioning* (e.g. flooding due to heavy precipitation on already saturated soil; land use change amplifying heat/flood risk); *multivariate* (e.g. fluvial flooding and coastal storm surge; flooding and landslides due to heavy rain and snowmelt); *temporally compounding* (e.g. cumulative impacts of consecutive storms; heat- and wind-related fire risk); *spatially compounding* (e.g. upstream precipitation leading to downstream flooding) |
| **Non-climate impact drivers** | |
| ***Exposure*** | Population at risk of heat stress, flooding, landslides, water shortage and quality, coastal erosion and infrastructure failure; land use impacts on urban heat island; soil nutrients; green spaces; confounding environmental hazards ([3]) such as sea level rise and water quality (see climate impact drivers above), atmospheric composition (e.g. risks of surface ozone, $NO_x$, $SO_2$, dust and pollen to human health and plant growth) and atmospheric $CO_2$ concentration (e.g. impacts on growth/water use of forests and crops) |
| ***Vulnerability*** | Income and wealth affects quality of life; health status; residence; service provision; educational status related to awareness and preparedness; inequality may compromise access to services; influence and voice; health status affects susceptibility to heat and cold extremes and allergies |
| ***Adaptive capacity*** | Indicators act in reverse sense to exposure and vulnerability (not identified explicitly in this chapter) |

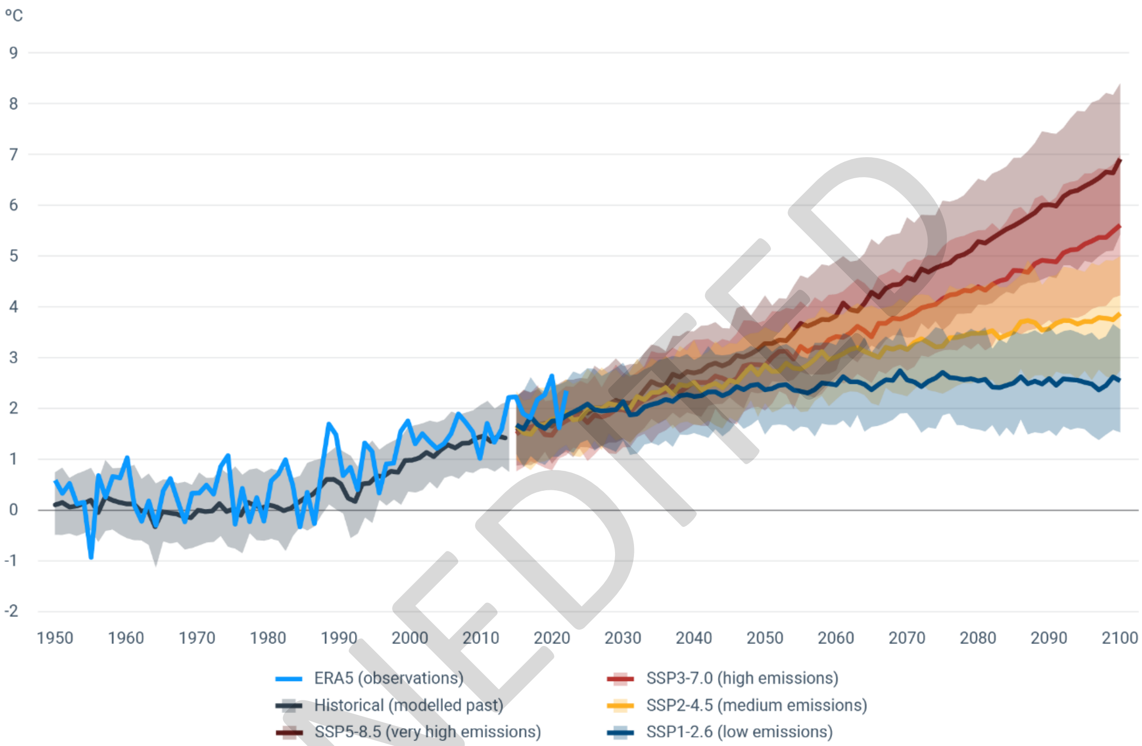


([1]) This chapter uses the term impact drivers to identify the constituent elements affecting climate change-related impacts/risks. Hence, climate impact drivers include climate-related variables (indicators) affecting the (aggregate) hazard of importance for impact/risk. That terminology is also used to distinguish them from non-climatic impact drivers, which embrace socio-economic and related indicators affecting exposure and vulnerability, also of importance for impact/risk.
([2]) Based on (Zscheischler et al., 2020)
([3]) Some may also be classified as climate impact drivers

### *Heat and cold*

Temperatures for Europe show continuing long-term warming trends for both annual and seasonal averages. The warming trend over the last 30 years is larger than over the last 70 years, which highlights that Europe's rate of warming has increased in recent decades (see Figure 2.2). For the annual mean and for the extremes, the strongest increase in recent decades is in central-eastern and southern Europe (see Table 2.2).

**Figure 2.2 Observed and projected increase of European temperature compared to the pre-industrial level**






**Note**: Observed (ERA5) and projected near-surface temperature for different Shared Socioeconomic Pathways (SSPs) across the 21st century relative to pre-industrial levels for the EEA-38. The two scenarios assessed are SSP1-2.6: low warming, and SSP3-7.0: high warming.

**Source**: Copernicus Climate Change Service, C3S.

**Table 2.2 Observed trends over the EUCRA land and marine regions**

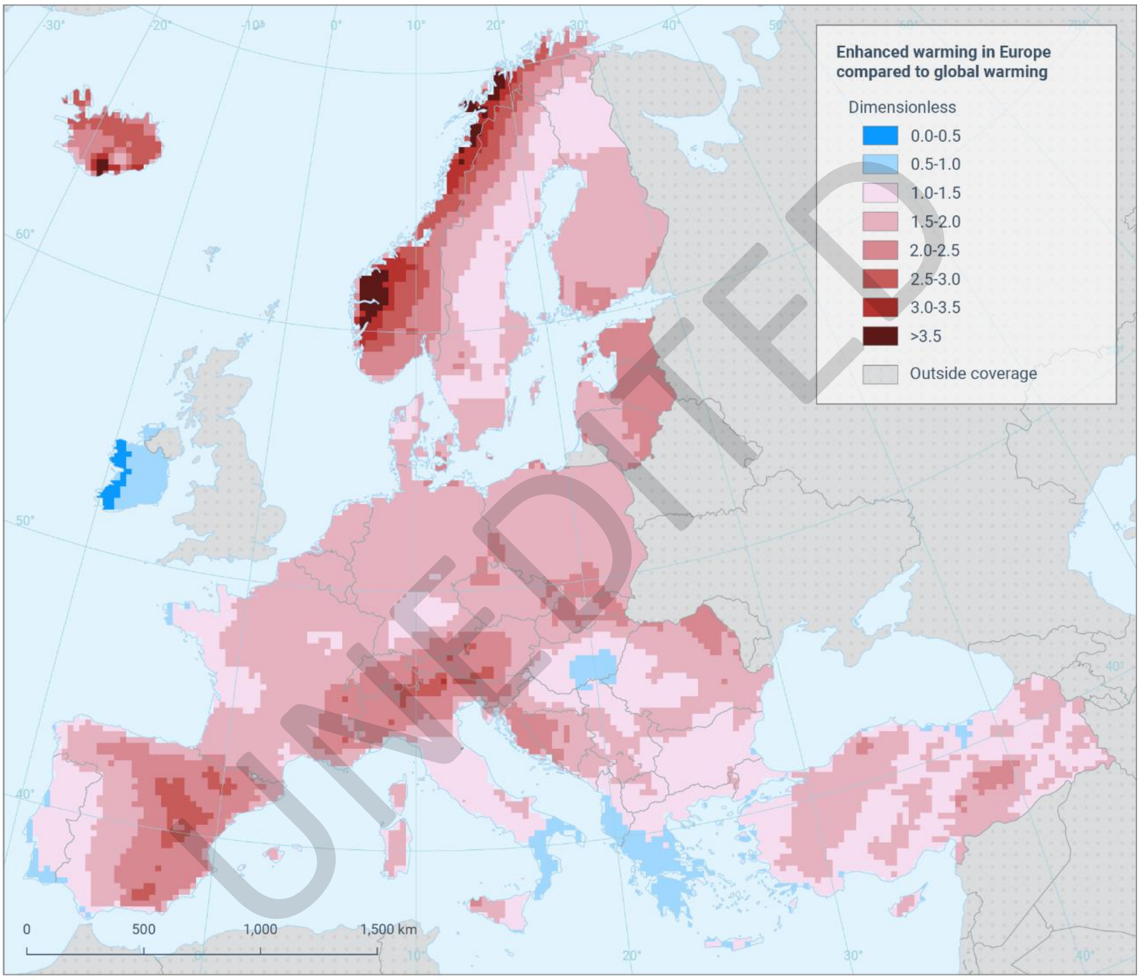
| | | | | Northern Europe | | | | Western Europe | | | | Central-Eastern Europe | | | | Southern Europe | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1952-2021 | | 1992-2021 | | 1952-2021 | | 1992-2021 | | 1952-2021 | | 1992-2021 | | 1952-2021 | 1992-2021 |
| | | | | ERA5 | E-OBS | ERA5 | E-OBS | ERA5 | E-OBS | ERA5 | E-OBS | ERA5 | E-OBS | ERA5 | E-OBS | ERA5 | ERA5 |
| Heat and Cold | T | Trend in mean temperature | °C per decade | 0.33 | 0.28 | 0.4 | 0.4 | 0.27 | 0.29 | 0.37 | 0.35 | 0.28 | 0.2 | 0.52 | 0.52 | 0.25 | 0.47 |
| | CD | Trend in cooling degree days | °C day per decade | 1.3 | 1.4 | 2.1 | 2.4 | 8.9 | 9.7 | 11.8 | 13.4 | 11.2 | 11.4 | 17.7 | 19.6 | 18.5 | 32.6 |
| | HD | Trend in heating degree days | °C day per decade | -110 | -97 | -134 | -135 | -70 | -73 | -93 | -83 | -71 | -59 | -140 | -142 | -53 | -109 |
| | FD | Trend in frost days | days per decade | -4.56 | -4.35 | -8.08 | -9.07 | -3.53 | -3.41 | -4.46 | -3.12 | -3.6 | -3.38 | -9.62 | -9.18 | -2.15 | -5.92 |
| | TN | Trend in minimum temperature | °C per decade | 0.3 | 0.33 | 0.47 | 0.41 | 0.23 | 0.24 | 0.25 | 0.18 | 0.21 | 0.23 | 0.43 | 0.45 | 0.2 | 0.41 |
| | TNN | Trend in minimum of minimum temperature | °C per decade | 0.51 | 0.67 | 0.85 | 0.8 | 0.54 | 0.57 | 0.86 | 0.8 | 0.43 | 0.35 | 1.03 | 0.93 | 0.27 | 0.37 |
| | TX | Trend in maximum temperature | °C per decade | 0.34 | 0.28 | 0.37 | 0.39 | 0.34 | 0.32 | 0.49 | 0.47 | 0.34 | 0.47 | 0.64 | 0.86 | 0.31 | 0.58 |
| | TXX | Trend in maximum of maximum temperature | °C per decade | 0.27 | 0.18 | 0.44 | 0.54 | 0.55 | 0.5 | 0.83 | 0.8 | 0.4 | 0.59 | 0.2 | 0.77 | 0.32 | 0.55 |
| | TX35 | Trend in days with max. temperature above 35 °C | days per decade | 0 | 0 | 0 | 0 | 0.15 | 0.22 | 0.33 | 0.49 | 0.24 | 0.26 | 0.26 | 0.39 | 0.88 | 1.7 |
| | TX40 | Trend in days with max. temperature above 40 °C | days per decade | 0 | 0 | 0 | 0 | 0.003 | 0.006 | 0.012 | 0.013 | 0.006 | 0.005 | -0.003 | -0.003 | 0.065 | 0.156 |
| Wet and Dry | PR | Relative trend in total precipitation | % per decade | 1.92 | 2.24 | 2.95 | 0.58 | 0.82 | 0.36 | -1.25 | -4.33 | 0.58 | -0.19 | 0.67 | -1.26 | -0.55 | 2.22 |
| | RX1DAY | Relative trend in maximum 1-day precipitation | % per decade | 1.23 | 2.25 | 1.86 | -0.17 | 1.14 | 2.65 | 0.27 | -0.9 | 1.25 | 1.87 | 0.23 | -0.24 | 0.75 | 2.72 |
| | RX5DAY | Relative trend in maximum 5-day precipitation | % per decade | 1.13 | 1.73 | 0.51 | -0.96 | 0.9 | 1.51 | -0.39 | -2.13 | 1.29 | 1.15 | 0.91 | -0.62 | 0.11 | 2.27 |
| | CDD | Trend in annual maximum consecutive dry days | days per decade | -0.17 | -0.32 | -0.51 | -0.41 | -0.15 | -0.2 | -0.08 | 0.39 | -0.06 | 0.01 | 0.51 | 0.4 | -0.5 | -0.11 |
| | SPI6 | Trend in standardized precipitation index for 6 months cumulation period | st.dev. per decade | 0.1 | 0.1 | 0.16 | 0.02 | 0.05 | 0.01 | -0.05 | -0.17 | 0.04 | -0.01 | 0.03 | -0.07 | -0.02 | 0.07 |
| | SPEI6 | Trend in standardized precipitation evapo-transpiration index for 6 months cumulation period | st.dev. per decade | -0.26 | | -0.22 | | -0.29 | | -0.43 | | -0.29 | | -0.47 | | -0.28 | -0.51 |
| Wind | SFCWIND | Relative trend in surface wind speed | % per decade | 0.37 | | -0.3 | | 0.08 | | -1.31 | | -0.02 | | -1.29 | | 0.04 | 0.47 |
| Snow and ice | PRSN | Trend in daily snowfall | mm/day per decade | -0.003 | | -0.027 | | -0.011 | | -0.002 | | -0.013 | | -0.024 | | -0.009 | -0.015 |
| | | | | Black Sea | | | | Mediterranean Sea | | | | North-east Atlantic Ocean | | | | Baltic Sea | |
| | | | | 1952-2021 | | 1992-2021 | | 1952-2021 | | 1992-2021 | | 1952-2021 | | 1992-2021 | | 1952-2021 | 1992-2021 |
| Coastal and Oceanic (ERA5) | SICONC | Trend in sea area covered by ice (ERA5) | % per decade | 0.005 | | 0.02 | | 0 | | 0 | | -0.798 | | -1.179 | | -0.401 | -1.312 |
| | SST | Trend in sea surface temperature (ERA5) | °C per decade | 0.101 | | 0.684 | | 0.125 | | 0.358 | | 0.128 | | 0.232 | | 0.328 | 0.473 |
| | SLA | Trend in sea level anomaly (CMEMS; 1993-2021) | m per decade | 0.016 | | | | 0.026 | | | | 0.031 | | | | 0.043 | |

**Note**: Trends for two periods, 1952-2021 and 1992-2021. Trends are estimated using linear ordinary least squares and calculated with annual regional means.

**Sources**: ERA5 (Hersbach et al., 2020), E-OBS (Cornes et al., 2018) and Copernicus Marine Service (CMEMS).

The observed rate of increase of annual mean temperature for specific regions in Europe is more than 2.5 times the global mean temperature increase (see Figure 2.3). There is enhanced warming in northern Europe, mainly due to warming in winter. Enhanced warming over the Pyrenees, the Scandinavian Mountains (see Figure 2.3) and the Swiss Alps affects both snow depth and permafrost (Rottler et al., 2019).

### Figure 2.3 Enhanced warming in Europe compared to global warming




Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO

**Note**: European annual mean air temperature trend (temperature regressed on time as the independent variable) expressed as multiples of the annual mean global temperature trend ([4]) between 1950 and 2023.

**Source**: ERA5 (Hersbach et al., 2020).

The 10 warmest years on record in Europe have all occurred since 2000, and the five warmest since 2014. The average temperature for Europe for the period 2018-2022 was around 2.2°C warmer than the pre-industrial level (1850-1990) (C3S, 2023d). The average global temperature for the same period was 1.2°C above the pre-industrial level (C3S, 2023h), but 2023 witnessed exceptional anomalies. Every month from June 2023 to January 2024 saw record-breaking global average temperatures in comparison to the corresponding month in any previous year (C3S,

[4] Grid-point level annual mean temperature trend divided by global annual mean temperature trend.

2024b, 2024c). 2023 has been confirmed as the warmest year on record, with the global near-surface annual mean temperature at 1.48°C above the pre-industrial level (C3S, 2024a). The average global temperature in the 12-month period between February 2023 and January 2024 exceeded pre-industrial levels by 1.5°C (C3S, 2024c). A critical driver of the unusual air temperatures experienced throughout 2023 was the unprecedented high surface temperatures in the ocean. The global average sea surface temperatures (SSTs) for the period between April and December were the highest for the time of year in the ERA5 dataset. However, the transition to El Niño alone does not explain all of the increase in ocean surface temperatures at a global scale in 2023; high SSTs outside of the equatorial Pacific also played an important role in the record-breaking global sea surface temperatures. This is particularly true in the North Atlantic, which saw exceptional SSTs throughout June to December, with monthly anomalies well above average for the time of year and daily SST records broken (C3S, 2024a).

In Europe, every summer since 2015 has been warmer than the 1991-2020 average, with 2022 experiencing the warmest summer on record by a large margin at 1.4°C above average and 0.3-0.4°C above the previous warmest summer, which occurred in 2021 (C3S, 2023d). Likewise, seven of the eight autumn and winter seasons since 2015 have been warmer than average. The six spring seasons from 2015 to 2020 were all warmer than average, with spring 2021 and 2022 slightly cooler than average (C3S, 2023d). The frequency of heatwaves observed in Europe has increased in recent decades, with extreme heatwaves across Europe in 2018, 2019, 2021 and 2022 (C3S, 2020a, 2021, 2022, 2023d; Di Napoli, 2023). The trend of increasing heat extremes across Europe is larger than the trend simulated by climate models (Vautard et al., 2023). This indicates that the uncertainty of climate projections is larger than might be inferred from the spread in CMIP6 models (i.e. models from the Sixth Phase of the Coupled Model Intercomparison Project, CMIP), and that they might severely underestimate the induced hazards and associated risks of certain CIDs (see also Box 2.3). Heat stress has increased in summer over all European regions, with cities particularly sensitive to enhanced heat stress and exceedance of critical heat stress thresholds for outdoor activities (IPCC, 2021a). The number of days in summer with strong or very strong heat stress ([5]) has increased across Europe and, in southern Europe, the number of days with extreme heat stress has also risen (C3S, 2023d). The 10 years with the highest number of days with very strong heat stress in southern Europe have all occurred since 2010, apart from 2003, which ranks fifth after 2022, 2017, 2012 and 2021 (Di Napoli et al., 2021b). 2022 saw the warmest summer on record, with an unparalleled number of days with very strong or extreme heat stress and up to 30% more warm days than average in south-western and western areas (C3S, 2023b). While 2023 witnessed a summer of contrasts across Europe, southern Europe experienced a record number of days with extreme heat stress, although confined to localised areas (C3S, 2023f). Some regions, such as southern Spain, saw up to 60 days of very strong heat stress and, locally, up to 5 days of extreme heat stress. In 2021, a new temperature high was set for Europe, at 48.8°C in Sicily (WMO, 2023b).

While recent years have been characterised by more warm than cold events, notable cold spells occurred in 2018, 2021 and 2022 (C3S, 2023d). In February and March 2018, extremely cold air caused below-average temperatures, which resulted in above-average frost days for western Europe and above-average ice days in northern Europe (C3S, 2019a). Cold records were also broken in April 2021 for much of Europe (C3S, 2022). Although it has been hypothesised in the literature that the cold spells were induced by Arctic warming, the Intergovernmental Panel on



([5]) Based on the indicator Universal Thermal Climate Index (UTCI). The UTCI is based on temperature, humidity, wind speed, sunshine and heat emitted by the surroundings, and how the human body responds to different thermal environments. A UTCI between 32°C and 38°C corresponds to strong heat stress, between 38°C and 46°C to very strong heat stress and above 46°C corresponds to extreme heat stress (Di Napoli et al., 2021a).

Climate Change's Sixth Assessment Report (IPCC AR6) concluded, by assessing all available literature, that there is low confidence in this hypothesis.

*Wet and dry*

Overall, Europe is seeing an increase in precipitation, but the change in precipitation varies by region (IPCC, 2021; Table 2.2). Northern Europe is becoming wetter and southern Europe drier, especially in winter. Although during winter northern Europe is getting wetter, it is becoming drier in summer. These changes are also simulated by global and regional climate models and have been attributed to climate change (IPCC, 2021a). Heavy precipitation frequency trends have been detected in northern, western and central-eastern Europe, with observed increases in pluvial flooding in northern Europe (IPCC, 2021a). Mountains are particularly prone to extreme precipitation events due to orographic effects (caused by moist air moving over elevated terrain), with the potential cascading consequences of floods, landslides and lake outbursts. There is an increasing trend of river floods in western and central-eastern Europe and a decrease in northern and southern Europe (see also Box 2.2). Coastal floods are affecting cities and other settlements in particular. Compound flooding due to simultaneous storm surges and high river flows are increasingly frequent in several cities and/or low-lying areas in Europe (Bevacqua et al., 2019a; Ganguli and Merz, 2019).

Due to enhanced evaporation, a drying trend in Europe as a whole has accelerated during recent decades, which is strongest in southern and central-eastern Europe (SPEI6 in Table 2.2). This drying due to enhanced evaporation occurs even in regions with an increase in annual precipitation. It has resulted in summer drying in western and northern Europe. Severe droughts with large economic losses occurred in 2018 and 2023 in western and northern Europe (see also Box 2.1). Due to the drying, there has also been a negative trend in soil moisture since around 2000, and 7 of the 8 years since 2015 have seen below-average soil moisture, with 1 year slightly above average. 2022 saw the second lowest soil moisture for Europe in the last 50 years (C3S, 2023d). Hydrological droughts have increased in southern Europe and in spring and summer for western and northern Europe. Agricultural and ecological droughts have increased in Europe, too. In northern and western Europe, summer droughts have increased despite no change or an increase in annual precipitation. These droughts have been attributed to human influence. The combination of reduced soil moisture and heavy precipitation enhances the possibility of floods, because parched soils repel water rather than allowing it to soak in (Yin et al., 2023).

Since 2015, 7 out of 8 years have seen below-average river flow for Europe as a whole, with only 2016 slightly above average (C3S, 2023d). 2022 was the sixth consecutive year of below-average flows, with the second-lowest average river flow in records dating back to 1991. However, 2022 was also the driest year on record in terms of the areas affected, with 63% of Europe's rivers seeing below-average flow.

Above average temperatures and drought conditions in 2021 and 2022 led to extreme fire danger and the spread of wildfires, with 2022 seeing the second-largest burnt area on record across the EU (C3S, 2023d). 2023 also witnessed several large wildfires in southern Europe.

**Box 2.1 Recent drought events**

Much of Europe has experienced drought conditions in recent years. In 2022, a persistent lack of precipitation affected large parts of Europe from winter to summer, which, together with higher-than-average temperatures, triggered a severe-to-extreme drought. At its peak, the drought affected just over one third of Europe. In 2021, large parts of the central Mediterranean region were affected by droughts of exceptional magnitude, with some areas seeing soil moisture values among the lowest 10% of the last 40 years. In 2018, northern Europe experienced drought conditions that at the time were the most severe since 1976, while in 2017 drought conditions in some areas of south-western Europe persisted for up to a year (C3S, 2023d; Toreti et al., 2023c).

**Box 2.2 Recent flood events**

A number of flood and flash flood events have occurred across Europe in recent years. At least 12 countries were affected by flood events in the first half of 2023. The same year, major flood events hit Italy (in May), Norway and Sweden (August), Slovenia (August), Greece (September) and the UK and Ireland (November). North-western Europe was affected by above-average precipitation and flooding during October to December 2023 due to increased storm activity. Europe also saw numerous more localised flood and flash flood events in 2023. In July 2021, a slow-moving low-pressure system travelled across Europe, contributing to higher-than-average, and in some locations record-breaking, precipitation and extreme flooding, affecting parts of Belgium, Germany and surrounding countries. Precipitation amounts in parts of the region were 'by far the largest' in the ERA5 record dating back to 1950 (C3S, 2022). River flows in the Meuse and Rhine catchments were the highest since the start of the European Flood Awareness System records in 1991 (C3S, 2022). In October 2020, Storm Alex (/Brigitte/Aiden) brought unusually pronounced rainfall in a short period of time, leading to above-average river flows over much of western Europe and devastating landslides and flooding in some regions of France, Italy and central Europe (C3S, 2022). One year before, in October 2019, areas of France, Italy and Spain were also impacted by heavy precipitation, resulting in flooding and landslides, as part of a wetter-than-average end to the year for much of western and southern Europe. Several countries saw their wettest November on record at the time, with precipitation amounts two to four times larger than average (C3S, 2020a).



### *Wind*

During the 2021/2022 winter, wind speeds were higher than average in most of central and eastern Europe, except France and Spain. The season was dominated by stormy conditions in February 2022, when three storms impacted north-western Europe within a single week, causing widespread power outages, extensive damage and loss of life (C3S, 2023d). In 2021, north-western Europe experienced annual wind speeds well below average, reaching record or near-record lows in some countries (C3S, 2022).

The 1950-2022 data record highlights large year-to-year variability, and significant decadal variability, in wind speeds across Europe (based on estimates of wind speed at 100 metres above the surface (Table 2.2). The 1990s and 2000s saw generally above-average wind speeds, while the 2010s and 2020s saw both large positive and negative anomalies, indicating no clear current trend in annual average European wind speeds, despite the high-impact events in 2022 that cannot be related to climate change (C3S, 2023d).

### *Snow and ice*

Since the early 1980s, in snow-dominant areas the length of the snowfall season has reduced with regional warming, and the melt onset dates have advanced. Widespread and accelerated declines in snow depth and snow water equivalent have been observed in Europe. During the last 20 years, high regional mass loss rates of glaciers were observed in central Europe. Rapid retreat of glaciers and downwasting (glacier thinning) throughout the European Alps in the early 21st century has been reported. At the end of winter 2022/2023, the snow water equivalent in the Alps was more than 50% below the historical average. Due to this, the contribution of snowmelt to river flows in the perialpine region throughout spring and early summer 2023 was significantly reduced (Toreti et al., 2023c). In recent decades, permafrost (for Europe in the high mountains and Scandinavia) has been notably diminished and accelerated warming at high altitudes and latitudes has favoured an increase of permafrost temperatures. Rain-on-snow events are decreasing in northern regions (IPCC, 2021a).

In 2022, much of central and south-eastern Europe saw far fewer winter snow days than average (C3S, 2023b): up to 30 fewer days across many areas, and in some locations up to or more than 50 days fewer. Combined with the warm temperature anomalies and heatwaves throughout the year, this likely contributed to the severe drought. Snow is also an important factor influencing glacier melt. In Europe, glaciers accumulate snow during winter and spring, and snow cover can delay melting in spring and summer. In 2022, the Alpine glaciers received very little winter snow and experienced an unusually warm summer, leading to record ice loss from glaciers in the Alps, equivalent to a loss of ice more than 3.5m thick on average, or a total of around 5km$^3$ of ice (C3S, 2023d). Heavy snow and ice storms, hail, snow avalanches and frost are currently impacting the service life of buildings and safety requirements. These events can compromise buildings due to storm damage, subsidence, water encroachment, soil degradation and erosion (EC, 2023p).

*Marine, coastal and lakes*

Sea surface temperatures, both globally and across Europe, have risen since records began in 1850. For the latest 5-year averages (2018-2022), the SST increase since 1980 is around 0.5°C globally and around 1.1°C for Europe (C3S, 2023c) and in 2023 it reached unprecedented levels. This warming has accelerated at a different pace in different regions during the last three decades, with the largest increase of about 2°C in the Black Sea (Table 2.2).

Apart from 2003, the 10 warmest years on record for European seas have all occurred since 2014. 2022 was the warmest, with anomalies of up to 4.6°C in July in some regions of the Mediterranean (C3S, 2023d). Marine heatwaves have also been reported around Europe in recent years, with severe marine heatwaves across the Mediterranean in 2022 and across the North Atlantic, around the UK and Ireland, and in the Mediterranean in 2023 (C3S, 2023j). The Barents Sea has experienced accelerated warming and several marine heatwaves in recent decades (Mohamed et al., 2022).

Lake surface water temperatures, both globally and across Europe, have risen since the start of the data record in 1995. Across Europe, they are warming at a rate of 0.33°C per decade, which is faster than the global rate of 0.23°C per decade. The four warmest years for lake surface water temperatures in Europe have occurred since 2010, with the warmest in 2018. Globally, 2022 saw the warmest lake surface temperatures on record (C3S, 2023d).

Global mean sea level rose faster in the 20th century than in any prior century over the last three millennia, with a 0.20-m rise over the period 1901-2018, and it has accelerated since the late 1960s. Most coastal regions in Europe have experienced an increase in sea level relative to land since 1900, except for the northern Baltic Sea coast, where the land is still rising due to global isostatic adjustment (Oelsmann et al., 2024).

With the rising $CO_2$ concentration, ocean surface acidity has increased globally over the past four decades (IPCC, 2021a).

*Compound events*

Although past research has been focused on individual hazards, recent understanding has made clear that many of the most severe impacts are due to compound events. These may involve climate impact drivers alone or interactions between climate and non-climate impact drivers (see Section 2.3.2). Different types of compound events have been identified (Zscheischler et al., 2020): *preconditioned* (e.g. heavy precipitation on saturated soil; rain on snow; heatwave occurrence during holidays or strikes with reduced social cover), *multivariate* (e.g. flooding due to combined coastal storm surge and heavy precipitation; fire risk due to combined drought, heat and wind; human health risks of combined heat, high humidity and air pollution), *temporally compounding* (e.g. clustering of consecutive precipitation or storm events), and *spatially compounding* (e.g. headwater precipitation extremes leading to downstream flooding; remote, teleconnected climate extremes linked to continental-scale circulation regimes).

The probability of compound events has increased due to human-induced climate change (IPCC, 2021a). A typical event observed in Europe is compound coastal flooding due to the combination of extreme sea levels induced by storms and extreme precipitation associated with high levels of run-off. Sea level rise is projected to enhance the probability of compound flooding. In the present climate, Mediterranean coasts are exposed to a higher probability of this type of compound flooding event (Bevacqua et al., 2019a).

For river floods, the distance over which multiple rivers flood near-synchronously varies strongly across Europe, and these distances have grown by about 50% over the period 1960-2010, thus the size of the flooded areas has increased (Berghuijs et al., 2019). Compound events of dry and hot summers have increased; their probability has risen across much of Europe between the periods 1950-1979 and 1984-2013, notably in southern, central-eastern and western Europe (Manning et al., 2019).

### 2.3.2 Non-climate impact drivers

The level of climate change risk is commonly defined according to the magnitude of a climate hazard combined with the levels of exposure and vulnerability of a system to that hazard. There have been increasing efforts to quantify historical trends in exposure and vulnerability that can help explain the magnitude and pattern of climate impacts occurring in the past. An alternative approach is to seek metrics that capture society's capacities and evolving ability to offset risks through adaptation. The concept of climate resilience is sometimes used interchangeably with adaptive capacity, though in the context of climate risk it more commonly embraces adaptation and mitigation as well as transformation, as a means for securing a safe climate (IPCC, 2022a).

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' (IPCC, 2022a). Popular metrics applied to define aspects of exposure include population indicators that describe who is exposed to a given hazard in a particular place; the value of assets at risk; emergency preparedness and support services; and infrastructure robustness.

Vulnerability is a term that is used in various ways in the literature, but in the context of risk as defined by the IPCC it refers to 'the propensity or predisposition to be adversely affected', encapsulating concepts such as sensitivity, susceptibility and lack of capacity to cope (IPCC, 2022a). In a social and economic context, this draws attention to inequalities in society that render some populations, individuals or sectors more susceptible to climate impacts than others.

Many of the same indicators used to describe exposure and vulnerability are also applied in an opposite sense to characterise aspects of adaptation potential for ameliorating risk (Andrijevic et al., 2023). Adaptive capacity is defined by the IPCC as 'the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities or to respond to consequences' (IPCC, 2022a).

All three terms – exposure, vulnerability and adaptive capacity – are typically described by NCIDs, including a diverse range of socio-economic and environmental factors. However, while there are comprehensive spatially gridded time series of historical data available to characterise numerous CIDs across Europe, the same cannot be said about many NCIDs, for which there are several challenges to overcome.

One challenge concerns the identification of indicators. The key drivers of exposure, vulnerability and adaptive capacity may differ greatly according to the types and characteristics of impacts being considered. Identifying appropriate metrics (e.g. as single variable indicators or as compound indices) can be demanding enough for individual cases, given that causal mechanisms linking drivers to impacts may not be well understood. It is particularly challenging to identify appropriate metrics of NCIDs that can be applied to a wide range of sectors, scales and circumstances, as aimed for in EUCRA. 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 (Paprotny et al., 2018a). Furthermore, it is necessary to account for ongoing adaptation, for which indicators are often even more poorly quantified and difficult to define.

Information exists and some datasets are available, especially for the more common demographic and economic variables monitored in all countries, and for well-being and social capital variables from the biennial European Social Survey, pertaining to Europeans' attitudes and behaviour (ESS, 2024). However, much more work is still required to compile, quality check and archive data for a wider range of relevant but hitherto less accessible variables. These data should be in a form that is of sufficiently comprehensive coverage and fine spatial resolution to be appropriate for climate change analysis (Hewitson et al., 2014).

This section we provide examples of historical changes in indicators of NCIDs in Europe that may have had a bearing on the frequency and magnitude of observed climate-related impacts (Table 2.1). Indicators of exposure and vulnerability have been separated, though for some the distinction may not be clear cut. This overlap becomes more apparent when applying many of the same indicators in an opposite sense, for defining adaptive capacity.

### *Indicators of exposure*

#### Population change

Demographic indicators of exposure include population totals and distribution that change over time. Europe's population has more than doubled since the end of the 19th century, with the urban population increasing more than 10-fold (Paprotny et al., 2018a). In 2021, 74.8% of Europe's population was estimated to live in urban areas (EUROSTAT, 2022). While regional patterns of population change over a centennial timescale are also instructive for thinking about future trends, they differ quite substantially in some regions from recent decadal trends (e.g. many rural areas of Europe were developing during the early part of the period and birth rates were much higher than today). Population in Europe has stagnated since 2001 and is even in decline in some regions in eastern and southern Europe (EUROSTAT, 2023b).

Europe's population is ageing in all four EUCRA regions, with the proportion of people aged 65 and above increasing on average across EU countries by 3% from 2012 to 2022 (EUROSTAT, 2023b). The areas of rural decline tend to be those experiencing a flight of younger people, which accentuates the trend towards an ageing population in many rural areas (EUROSTAT, 2023b).

#### Populations and assets at risk

The exposure of European populations and their assets to climate-related hazards is defined according to the type of hazard. This can be illustrated for one type of hazard: flooding. Exposure to flooding relates to locations adjacent to rivers and/or on the coast (the locations of pluvial floods due to intense precipitation events are less predictable). The exposure of European populations and their assets to floods is high. Between 2012 and 2018, urban residential expansion took place on nearly 234km² of floodplains across the EU-27 and the UK. In addition, nearly 1,128km² of floodplains in the EU-27 and the UK were subject to expansion of economic sites and infrastructure (EEA, 2019g). The condition of assets at risk can also affect exposure, for example related to the quality of maintenance and depreciation of infrastructure with age, as well as capacities to keep pace with changing risks in developing, implementing and enforcing building regulations (e.g. (EC, 2023p)).

**Land use change**

Land use is a predisposing factor for exposure – climate hazards are location-specific and the exposure of populations and assets, such as buildings, crops or forests, to these hazards is an outcome of land use decisions. The type of land use can also modify local climates, such as through urban enhancement of extreme temperatures. Land management and planning also play a vital role in the cycling of carbon and nutrients, as well as being an important feedback to the climate (IPCC, 2021a). The rate of land use change in Europe varies by region and country but, overall, there has been a trend towards urbanisation and agricultural intensification in recent years. Artificial surfaces in Europe increased by 7.1% between 2000 and 2018; land taken at the expense of arable land, permanent crops and pastures, and mosaic farmlands. Despite significant changes in some regions, forested areas remained relatively stable during this period (EEA, 2019g). The urban population did not grow much in Europe between 1990 and 2015, whereas the built-up areas increased by 18% during that period. This implies that an increasing amount of built-up area is being used per capita in urban areas (Melchiorri et al., 2018).

**Confounding environmental hazards**

Aside from changes in socio-economic indicators, climate change risks can also be confounded by other environmental trends, such as environmental pollution. For example, exposure to air pollution is known to exact a high toll on human health, and this can have a multiplier effect when combined with the effects of extreme weather such as heatwaves and prolonged cold spells (see also Chapters 7 and 11). Pollutants like ozone and particulate matter are monitored closely in Europe (EEA, 2018b). Note that some of these indicators may also be classified as CIDs.

*Indicators of vulnerability*

**Economic growth and inequality**

The economic metric most often used to describe relative wealth is gross domestic product (GDP) per capita. This divides the value of production by population and, to allow for international comparison, this is commonly adjusted according to the cost of living of a country to obtain purchasing power parity. Greater personal wealth would normally be associated with lower social vulnerability or higher adaptive capacity (e.g.(Marzi et al., 2018)). GDP per capita varies across regions in Europe, with higher values in western, northern and central Europe compared to eastern and southern Europe, as well as disparities between rural and urban centres in most countries. Moreover, large disparities occur at even finer scales, such as within large urban areas (EUROSTAT, 2023b).

Income inequality metrics, for example, have been poorly covered for Europe in the IPCC AR6 but metrics such as the Gini coefficient are starting to be acknowledged for their role in accounting for inequalities, which in turn affect vulnerability, adaptative capacity and residual risk across regions (Sheng et al., 2023; Cevik and Jalles, 2023; Andrijevic et al., 2020). Income inequality has grown since the 1980s in Europe, when the average income of the richest 10% was seven times higher than that of the poorest 10%. Today, it is around nine times higher, due in particular to changes in labour markets and redistribution. Despite economic recoveries following deep economic crises, inequalities have persisted and even increased, with the younger population and families with children being most affected by this widening divide. The welfare system, that is, taxes and transfer policies in European countries, has helped reduce market income inequalities, although with mixed results (Förster et al., 2017).

**Health status**

Life expectancy at birth is a useful indicator for the overall health status of the population. At a more local scale, it can provide a quite detailed spatial view of inequality (e.g. (Redondo-Sánchez et al., 2022; Woods, 2005)), often correlating with other indicators of deprivation or privilege that may become evident in extreme situations, such as health effects of severe heatwaves. Life expectancy for females exceeds that for males by about 3-10 years, depending on the region (EUROSTAT, 2023). For both sexes, life expectancy had been increasing steadily over time until interrupted by the COVID-19 pandemic (EUROSTAT, 2023b), though trends are expected to return to positive in most regions (Schöley et al., 2022). It should be noted that, for the economic indicators above, a wide range of factors affect vulnerability regionally, besides life expectancy, such as the proportion of elderly and urban vs rural population, prevalence of diseases and educational attainment.

*Indicators of adaptive capacity*

Many of the indicators characterising exposure and vulnerability can be used in a reverse sense to describe adaptive capacity, to understand how well society can adapt. Adapting to risks is not only about coping with the risks reactively, but also about creating the conditions for societal actors and systems to handle them, prepare and learn. Discussing challenges to adaptation goes hand in hand with the capacities of our institutions for good governance. Constraints that hamper national, regional or local governments in planning and implementing adaptation vary depending on context and actor (Moser and Ekstrom, 2010; Biesbroek et al., 2013), but effective institutions and good governance are an essential factor to address inequalities and consequently risk (Andrijevic et al., 2020, 2023). This chapter does not delve into which indicators of governance would be more suitable to capture adaptive capacity, or the lack of it, since governance can be conceptualised in many different ways. The Worldwide Governance Indicators provide a reasonable starting point in terms of categories that constitute good governance (Andrijevic et al., 2020). These categories are voice and accountability, political stability, government effectiveness, regulatory quality, rule of law and control of corruption. Measures including policies to support adaptive capacity in Europe include the Covenant of Mayors (EC, 2023k), the EU Mission on Adaptation to Climate Change (EC DG CLIMA, 2023a) and the Disaster Risk Management Knowledge Centre's Risk Data Hub (EC JRC, 2023).

## 2.4 Exploring the future

### *2.4.1 Scenario approach*

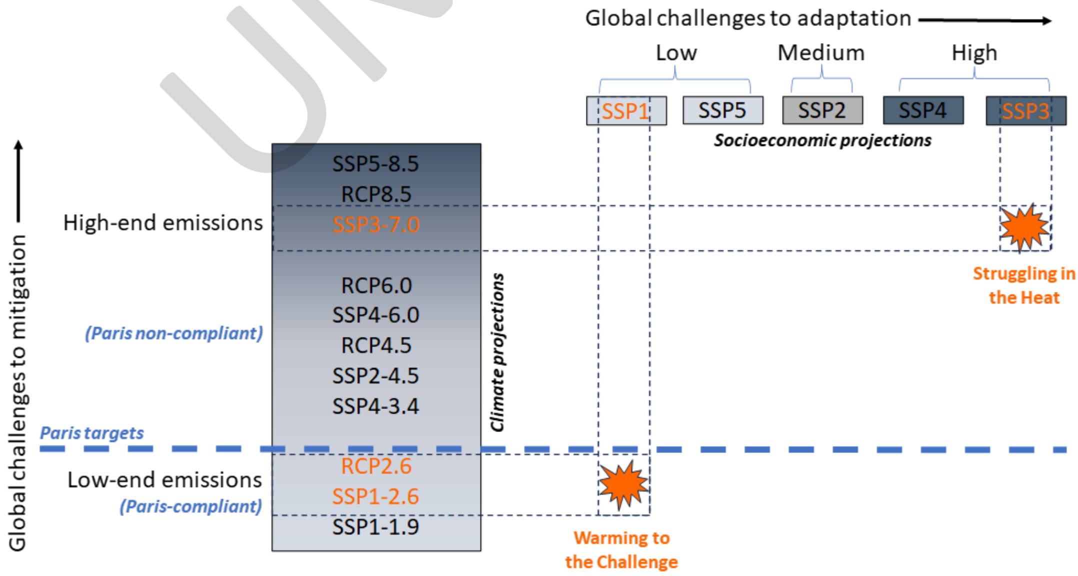
To assess risk, it is fundamental to consider how the key driving factors determining potential impacts that were described in Section 2.3 will evolve into the future. There are several approaches available to project the drivers, each approach having various uncertainties (see Box 2.3), and examples of these are referred to in this assessment. However, since all projections are conditional on assumptions made about future human behaviour and decisions (e.g. concerning greenhouse gas mitigation, technological development and international relations), it is important to capture some of these overarching assumptions in the assessment. This can be done using scenarios. A scenario can be defined as 'a plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces ... and relationships' (IPCC, 2022a).

This chapter makes use of an existing global scenario framework that was developed for climate change research and is widely adopted in the assessment of climate change impacts, mitigation and adaptation: Shared Socioeconomic Pathways (SSPs). These comprise five contrasting narrative storylines and an associated set of quantified measures of development that focus on key socio-economic drivers of change extending to 2100 (O'Neill et al., 2017; Riahi et al., 2017). SSPs are designed to be used in conjunction with specifications of future climate trajectories under different greenhouse gas and atmospheric aerosol emission assumptions, the Representative Concentration Pathways (RCPs) (Van Vuuren et al., 2011). Basic SSP assumptions relevant for challenges to adaptation are combined with emission pathways represented by SSP-based RCPs to characterise alternative future developments that are readily applicable for estimates of physical climate change and risk analysis. These SSP-based RCPs are used as input for the climate models in the 6th Climate Model Intercomparison Project (CMIP6 (Tebaldi et al., 2021). In summary, this chapter uses scenarios as projections of what can happen, considering climate change risks across alternative projections of future climate and in the context of alternative specifications of future socio-economic development.

This chapter presents two cornerstone scenarios to provide illustrative bounds on climate and socio-economic projections for Europe. The first scenario combination describes a *Paris-compliant emissions* trajectory, with climate projections assuming SSP1-2.6 forcing trajectories by 2100 (Tebaldi et al., 2021), combined with modest challenges to adaptation under the SSP1 socio-economic projections (further referred to as the 'Warming to the Challenge scenario', see Figure 2.4). The second scenario combination describes a *Paris non-compliant* trajectory with climate projections assuming SSP3-7.0 forcing trajectories by 2100, combined with high challenges to adaptation under the SSP3 socio-economic projections (further referred to as the 'Struggling in the Heat' scenario, Figure 2.4).

The extreme range of scenarios is not used for the cornerstones described in this chapter for two reasons. First, projections for the highest forcing (8.5 W/m$^2$ by 2100), while still plausible, are increasingly regarded as low likelihood given recent shifts in energy production, although conceivably stronger carbon cycle feedbacks for lower emissions could lead to similar outcomes (CarbonBrief, 2019). Second, far fewer climate model projections covering Europe are available for the lowest emissions case (SSP1-1.9) than for 2.6 W/m$^2$ forcing. These are scenarios that are plausible and hence, by definition, do not have probabilities assigned to them.

**Figure 2.4 EUCRA cornerstone scenarios**




**Note**: EUCRA 'cornerstone' scenarios 'Warming to the Challenge' and 'Struggling in the Heat' combine future climate projections under high- and low-end emissions trajectories with future socio-economic developments that entail high challenges (a struggle) or low challenges (a challenge that is tractable) for adapting to climate change. These are positioned alongside other climate and socio-economic projections that may have been used in published studies.

**Source**: EEA-ETC.

Even though the two scenarios used are not representative of the whole range of uncertainty and extremes, they do provide sufficiently diverging trends (visualised as cornerstone scenarios in Figure 2.4) in both CIDs and NCIDs.

The rationale of using “cornerstones” is reflected in the structured risk assessment conducted in the thematic factsheets (Chapters 3 to 10) and risk storylines (Chapters 11 to 17), and summarized in Chapter 18, which assesses the severity of major climate risks for Europe semi-quantitatively for two warming scenarios (in the long-term future): low warming and high warming (see Annex 2 for further information). The choice of specific “cornerstone” scenarios varies throughout the rest of the EUCRA report and depends on: (1) the time of the century (near-term; mid-term; long-term) when impacts take place, in a specific context; (2) the relative influence of NCIDs in the interaction with specific CIDs, which is very contextual to the sector and scale of analysis; and (3) highly uncertain earth system responses due to surprises and tipping points (see also Box 2.3). Most of the climate projections used in the EUCRA chapters are derived from simulations in the CMIP6 and earlier phase 5 (CMIP5, (Taylor et al., 2012)). Earlier CMIP5 projections were conducted before quantified SSPs were available, instead applying idealised RCPs to achieve different levels of climate forcing (Figure 2.4). Additionally, some EUCRA chapters may have used earlier climate projections based on slightly different trajectories for the same forcing, such as RCP2.6. However, the results illustrated in this chapter offer some guidance not only on uncertainties in the joint evolution of climatic and non-climatic futures, but also on where these might be influenced by policy decisions, acting on the level of forcing (through mitigation) and on the socioeconomic determinants of exposure and vulnerability, through adaptation.

The specific projections are presented using fixed time periods in the future, which is relevant for understanding the rate of climate change and its impacts, and hence the urgency for adaptation. Future changes are discussed for three periods: current/near term (2021-2040), mid-term (2041-2060) and long term (2081-2100). Using fixed time periods, it is easier to identify the role of key risk drivers to explore, based on rates of historical developments and the range of future trends. Special attention is paid to the mid-term future, as this is the time-frame for guiding many adaptation policies to reduce risks associated with climate change. Scenario uncertainties grow as one proceeds into the long-term future.

### Box 2.3 Uncertainty in climate and non-climate impact drivers

Climate uncertainty refers to the incomplete knowledge about future climate and related non-climatic conditions. It is a challenge for decision-making and adaptation planning because waiting for uncertainties to be resolved may leave little or no time for effective action.

Projecting CIDs and NCIDs over time horizons of multiple decades into the future is a formidable challenge, especially at the fine temporal and spatial resolution commonly required for risk analysis. Projections of CIDs are typically obtained using global Earth system models (ESMs), also known as climate models. ESMs are skilful at reproducing historical climate changes at global and large scales in response to observed emissions, but much less so at regional and local scales, even when deploying finer resolution regional models and/or related statistical methods. The ability of models to simulate future climate is conditional on the trajectories of greenhouse gas concentrations for the future, which largely depend on human decisions or scenarios (here labelled scenario uncertainty).

For CIDs, they include structural variability (due to the limitations in climate models that reduce their ability to accurately simulate some relevant climate processes) and internal variability (or irreducible uncertainty, due to the inherent chaotic and unpredictable behaviour of the climate system). They are addressed by producing estimates from a range of climate models. Since the 1980s, global warming has been accelerating, and simulated changes for this recent period by CMIP6 models can be compared with observed changes. For a few regions and climate drivers, recent studies revealed discrepancies that cannot be explained by either natural variability or known deficiencies of climate models that can easily be corrected. For Europe this includes, among others, an underestimation of extreme hot days (Vautard et al., 2023) and an underestimation of drying over Europe (Douville and Willett, 2023) by CMIP6 models. This indicates that the uncertainty of climate projections is larger than might be inferred from the spread in CMIP6 models, and that they might severely underestimate the induced hazards and associated risks of certain climate impact drivers.

Scenario uncertainty is addressed in this chapter by using projections that assume high- and low-end emissions scenarios. Uncertainties in regional projections of future CIDs, presented in Section 2.5, have been estimated from the level of agreement in different model projections. In addition, observational uncertainty, due to the inherent limitations in climate observations for historical and spatial reasons, has been considered by using more than one observational climate dataset over the historical period.

Different types of models, such as demographic, economic and integrated assessment models, may be used to project some NCIDs, such as population, economic development or land use. Similar structural uncertainties exist for societal, political, technological and environmental processes as for climate processes. Uncertainties in these projections are often much greater than for the physical climate. This is especially the case over long time horizons, conditional as they are on human decisions and representing socio-economic processes that are often poorly understood. Some examples of these projections are presented in Section 2.5, where a scenario range is provided. For many other NCIDs, quantitative projections may not be available from models, but can instead be constructed using expert methods and qualitative methods, such as narrative descriptions of plausible future developments that describe trends involving governance, institutions and other less tangible dimensions of risk. Storylines can also convey uncertain, non-consensus information about drivers of change.

Beyond this, there are uncertainties that elude easy reduction or quantification. Such 'deep uncertainties' may stem from fundamental ignorance about the workings of a system, ambiguity emerging from disagreements among experts, or indeterminacy resulting from inherent randomness or chaos within a system (Stirling, 2010). Deep uncertainties often manifest in complex systems where our understanding of the underlying physical, biological or social processes is limited (Marchau et al., 2019), or when situations are influenced by human decisions that are yet to be made (Kwakkel and Haasnoot, 2019). In the context of climate change, these uncertainties also extend to fundamental values, beliefs and perspectives regarding the future and how society should respond to potential changes (IPCC, 2022a). As deep uncertainties characterise events that transcend the bounds of conventional expectations, this report makes use of the wildcard concept (Marchau et al., 2019). Wildcards are unpredictable and unexpected factors that may change an expected climate trajectory, pushing understanding out of the linear view offered by scenarios that do not dynamically account for interaction in the responses, learning and new experience.



### 2.4.2 Complementing scenarios with wildcards

Wildcards refer to influential and rapid events that are not described in the standard scenarios but could have a large impact on the trajectory of an integrated climate and socio-economic scenario. They come as a surprise, which may be due to a range of factors, such as a lack of understanding of a system, or sensitivity to small perturbations that trigger a cascading effect. Nonetheless, they are possible and may be catalysts of potent extreme threat multipliers (Kemp et al., 2022; Lenton, 2011). For example, the World Wars were considered wildcards only a few decades before they happened (Rockfellow, 1994). Wildcards may result in unpredictable outcomes that would otherwise not be considered in a risk assessment. In this way, they are a tool that may be useful for anticipating, preparing for and ameliorating the effects of catastrophes, such as a worldwide pandemic (Petersen, 1997). Although plausible, they are not likely to occur and are not usually modelled explicitly in standard scenarios.

Wildcard events might be the trigger for, or the outcome of, exceeding tipping points, critical thresholds beyond which the climate or socio-economic system reorganises, often abruptly and/or irreversibly (IPCC, 2021a). An example for the global climate system could be a collapse of the West Antarctic ice sheet, leading to extreme sea level rise. A more regionalised example concerning economic livelihoods might be a collapse of ski tourism in the Alps due to reduced snow availability.

While there are differences in the projection of CIDs and NCIDs, both climatic and non-climatic wildcards are unexpected. Even for the quantifiable, physics-based CIDs, the motivation for adopting climatic wildcards stems from phenomena like the high frequency of record-breaking changes that occur every year. Disruptive climate changes are not yet communicated broadly, due either to their uncertainty, the inability of climate models to reproduce the underlying processes in a trustworthy manner, the ambiguity of the responsible processes and frameworks for communication, or pure ignorance of what is still possible. An example of such changes is variations in the thermohaline circulation (large-scale ocean circulation influencing regional climate patterns) which, if of sufficient magnitude, may have strong impacts on the European climate (Orbe et al., 2023).

The list of wildcards is long and open ended, relying to some extent on imagination. Within the context of EUCRA, the wildcards considered are those that have been debated extensively in scientific literature and are relevant for Europe and adaptation policies: war, pandemic and West Antarctic ice sheet instability.

## 2.5 Projected changes and wildcards

### *2.5.1 Near-term future*

The projected changes in CIDs for the near term (2021-2040) do not reveal clear differences between the two scenarios of Warming to the Challenge and Struggling in the Heat. The heat and cold indices display a moderate warming trend, which is strongest in southern Europe. For the wet and dry indices, the model agreement is low, probably also due to the influence of natural variability that for the near term is comparable to the climate signal over a 20-year period. An exception is the 1-day maximum rainfall, which reveals a clear and consistent increase in northern and western Europe, resulting in increased flood risk. Also, snowfall shows a clear decrease in all regions (BSC, 2024).

In the near-term future, population and GDP growth are positive, except for a decline in population growth in central-eastern Europe of 5% compared to the baseline (Dellink et al., 2017; Riahi et al., 2017; Kc and Lutz, 2017). The divergence in NCIDs is already present in the near-term future, but the radical response in policy, society and businesses is not visible until the mid-term. The overall focus on resources for defence, energy security and recovery from extremes in the Struggling in the Heat scenario stimulates strong regionalisation and deepening of current inequalities between Member States (Kok et al., 2019). Conversely, in Warming to the Challenge, a response of cooperation between countries and increased investments in social policies facilitate a change in mindset, driven by societal demands (Kok et al., 2019; Andrijevic et al., 2020, 2023).

### 2.5.2 *Mid-term future: Warming to the Challenge*

All heat and cold indices reveal a continuing warming trend for Europe in the period 2041-2060. The signal is strongest for southern Europe, with severe (see Table 2.3) increases for almost all indices. The wet and dry indices display more regional differences, with less precipitation for southern Europe and more for northern Europe. For the two other regions, the signal is mixed, with low agreement among the models. For all regions, an increase in 1-day extreme precipitation is projected. For 5-day extreme precipitation, the projections over southern Europe are mixed, with low agreement among the models. The strongest increase in extreme precipitation occurs in northern and western Europe. The increase in extreme precipitation translates to greater frequency and magnitude of pluvial floods. Large parts of Europe are projected to become dryer (based on the indicator SPEI6), with the strongest signal in southern Europe. There is a weak decrease in mean wind speed projected, while snowfall decreases in all regions (Table 2.3).

**Table 2.3 Projected change in climate impact drivers in Europe**



| | | | Northern Europe | | Western Europe | | Central-Eastern Europe | | Southern Europe | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | SSP1-2.6 | SSP3-7.0 | SSP1-2.6 | SSP3-7.0 | SSP1-2.6 | SSP3-7.0 | SSP1-2.6 | SSP3-7.0 |
| Heat and Cold | T | Change in mean temperature | ↑ | ↑↑ | ↑ | ↑↑ | ↑ | ↑↑ | ↑↑↑ | ↑↑↑ |
| | CD | Change in cooling degree days | ↑ | ↑↑ | ↑↑ | ↑↑↑ | ↑↑ | ↑↑↑ | ↑↑↑ | ↑↑↑ |
| | HD | Change in heating degree days | ↓ | ↓↓ | ↓ | ↓↓ | ↓ | ↓↓ | ↓↓ | ↓↓↓ |
| | FD | Change in frost days | ↓ | ↓↓↓ | ↘ | ↓ | ↓ | ↓ | ↓ | ↓↓ |
| | TN | Change in minimum temperature | ↑ | ↑↑↑ | ↑↑ | ↑↑↑ | ↑ | ↑↑ | ↑↑↑ | ↑↑↑ |
| | TNN | Change in minimum of minimum temperature | ↑ | ↑↑ | ↗ | ↑ | ↗ | ↑ | ↗ | ↑ |
| | TX | Change in maximum temperature | ↑ | ↑↑ | ↑ | ↑↑ | ↑ | ↑↑ | ↑↑↑ | ↑↑↑ |
| | TXX | Change in maximum of maximum temperature | ↑ | ↑ | ↑ | ↑ | ↑ | ↑↑ | ↑↑ | ↑↑↑ |
| | TX35 | Change in days with max. temperature above 35 °C | ↑ | ↑↑ | ↑↑ | ↑↑↑ | ↑↑ | ↑↑↑ | ↑↑↑ | ↑↑↑ |
| | TX35BA | Change in days with bias adjusted max. temperature above 35 °C | ↑↑↑ | ↑↑↑ | ↑↑ | ↑↑↑ | ↑↑↑ | ↑↑↑ | ↑↑↑ | ↑↑↑ |
| | TX40 | Change in days with max. temperature above 40 °C | ↑ | ↑↑↑ | ↑↑↑ | ↑↑↑ | ↑↑ | ↑↑↑ | ↑↑↑ | ↑↑↑ |
| | TX40BA | Change in days with bias adjusted max. temperature above 40 °C | ↑↑↑ | | ↑↑↑ | | ↑↑↑ | | ↑↑↑ | |
| Wet and Dry | PR | Relative change in total precipitation | ↗ | ↗ | ⤮ | ⤮ | ⤮ | ⤮ | ↘ | ↘ |
| | RX1DAY | Relative change in maximum 1-day precipitation | ↗ | ↑ | ↗ | ↑ | ↗ | ↗ | ↗ | ↗ |
| | RX5DAY | Relative change in maximum 5-day precipitation | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ⤮ | ⤮ |
| | CDD | Change in annual maximum consecutive dry days | ⤮ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ |
| | SPI6 | Change in standardized precipitation index for 6 months cumulation period | ↗ | ↗ | ⤮ | ⤮ | ⤮ | ↗ | ↘ | ↘ |
| | SPEI6 | Change in standardized precipitation evapo-transpiration index for 6 months cumulation period | ⤮ | ↗ | ↘ | ↘ | ↘ | ↘ | ↓ | ↓ |
| Wind | SFCWIND | Relative change in surface wind speed | ↘ | ↘ | ↓ | ↘ | ↓ | ↓ | ↘ | ↘ |
| Snow and ice | PRSN | Change in snowfall | ↓ | ↓ | ↘ | ↓ | ↘ | ↓ | ↘ | ↓ |

| | | | Baltic Sea | | Black Sea | | Mediterranean Sea | | North-east Atlantic Ocean | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | SSP1-2.6 | SSP3-7.0 | SSP1-2.6 | SSP3-7.0 | SSP1-2.6 | SSP3-7.0 | SSP1-2.6 | SSP3-7.0 |
| PH | Change in acidity (pH) of seawater | 1 | -0.09 | -0.15 | -0.08 | -0.13 | -0.08 | -0.12 | -0.1 | -0.15 |
| SICONC | Change in sea area covered by ice | % | -2.3 | -3.2 | 0 | 0 | 0 | 0 | -2.5 | -3 |
| SST | Change in sea surface temperature | °C | 1.1 | 1.6 | 1.1 | 1.4 | 0.9 | 1.3 | 0.6 | 0.9 |
| SLR* | Total sea level rise | m | 0.05 | 0.07 | 0.19 | 0.2 | 0.22 | 0.24 | 0.18 | 0.19 |

| | arrow |
|---|---|
| change above 3 standard deviations | ↑↑↑ |
| change above 2 standard deviations | ↑↑ |
| change above 1 standard deviation | ↑ |
| change above 0.25 standard deviations | ↗ |
| change between 0.25—-0.25 standard deviations | ⤮ |
| change below -0.25 standard deviations | ↘ |
| change below -1 standard deviation | ↓ |
| change below -2 standard deviations | ↓↓ |
| change below -3 standard deviations | ↓↓↓ |

| | color |
|---|---|
| high agreement: at least 80% of models of each ensemble show a negative change | dark blue |
| low agreement: at least 50% of models of each ensemble show a negative change | light blue |
| no agreement: ensembles disagree on the direction of change | very light grey |
| low agreement: at least 50% of models of each ensemble show a positive change | light green |
| high agreement: at least 80% of models of each ensemble show a positive change | dark green |
| no available data | white |

**Note**: Summary of confidence in the direction of projected change in climate impact drivers (colour coding), representing their aggregate characteristic changes for mid-century (2041-2060, in reference to the period 1995-2014) for ensemble-scenario combinations CMIP6 SSP1-2.6, CMIP5 RCP2.6, CORDEX-EUR

(0.11°x0.11°) RCP2.6, and CMIP6 SSP3-7.0 within each EUCRA region. Arrows shown are based on detrended standard deviation (1995-2014) multiples and on median changes of the CMIP6 ensemble. A standard deviation of 0.25, 1, 2, 3 corresponds to a moderate, strong, very strong, severe increase/decrease in the text. Values shown are ensemble median changes, except for sea level rise which are ensemble mean changes.

**Source**: Copernicus Climate Change Service (C3S).

GDP is expected to grow by 2-3% per year in Europe (Dellink et al., 2017; Riahi et al., 2017). The potential for adaptative capacity is assumed to be strongly increasing (based on GDP per capita). These lower challenges to adaptation are linked to a transition from GDP accounts to national accounts of wellbeing (Kok et al., 2019). Economic growth is moderate but steady. Migration stabilises (medium) particularly due to a decrease in conflicts in eastern and southern borders and effective investments in those regions (Mitter et al., 2020; Terama et al., 2019). This, together with lower mortality, does not compensate however for the overall slower population growth rate, and even decline in low-fertility countries. The combined effect of GDP and population trends that are slightly positive for northern, southern and western Europe and slightly negative for central-eastern Europe results in a positive trend of 2-3% increase in GDP per capita for Europe overall (Dellink et al., 2017; Kc and Lutz, 2017). Geoengineering and carbon capture storage are effectively regulated (Kok et al., 2019). The ageing population across Europe might present a risk for health and heat stress, although the high potential for adaptation, stemming from effective governance, and access to adaptive services may mitigate that risk ((Andrijevic et al., 2020), Table 2.4). Concerns about coastal and fluvial flooding, as well as stronger regulation for nature protection, reduce the attractiveness of new developments in high-risk areas and sensitive natural landscapes. Population density in urban areas increases, and greener and strict urban planning facilitates compact developments. Future land use in Europe is a predisposing factor for exposure (see Section 2.3.2) as well as itself being affected by socio-economic and climate changes. For example, model results under this scenario indicate that food production shifts northwards with an increase of arable land in northern Europe, whereas the proportion of unmanaged land could increase throughout Europe (Harrison et al., 2019).



### Table 2.4 Direction of projected change in non-climatic impact drivers in Europe

| Drivers for Europe | | SSP1 Europe | SSP3 Europe |
|---|---|---|---|
| DEMOGRAPHY | **Population change** (total) [1] | ↗ | ↘ |
| | **Ageing (+65)** [1] | ↑ | ↑ |
| | **Population density** [1] | | |
| | **Migration** [3] | ↗ | ↘ |
| | **Urbanisation** [1, 3]; [2] | ↗ | ↗ |
| | **Social isolation** Number of people aged 65+ living alone [1] | ↗ | ↘ |
| ECONOMY | **GDP*** [2]; [3] | → | ↘ |
| | **GDP/capita** [1] | ↑ | ↗ |
| | **Market integration** [2] | → | ↓ |
| ENVIRONMENT and RE | **Resource depletion** [2] | ↓ | ↑ |
| | **Resource use efficiency** [2] | ↑ | ↓ |
| SOCIETY | **Consumption** [3] | ↓ | ↗ |
| | **Overweight** [1] | ↘ | ↑ |
| | **Education** (% of people aged 24–65 years old with tertiary education) [1] | ↑ | → |
| TECHNOLOGY | **Technology uptake** (in agriculture [2]) | ↑ | ↓ |
| | **Technology development and transfer** \| [2] | ↑ | ↓ |
| POLICY and INSTITUTIO | **Political stability** [2], [5] | ↑ | ↓ |
| | **Effectiveness of European institutions** [2], [5] | ↑ | ↓ |
| | **Multilevel cooperation** [2], [5] | ↑ | ↓ |
| | **International trade agreements** [2], [5] | ↑ | ↓ |

**Note**: These are aggregated characteristic changes relevant in the mid-century (2050s relative to 2005-2010 baselines) for Paris compliant emissions trajectory approximating SSP1) and Paris non-compliant emissions trajectory (approximating SSP3), without climate policy assumptions of climatic impacts for Europe.

**Sources**: Quantitative projections (Rohat et al., 2019a; Mitter et al., 2020; Papadimitriou et al., 2019) and qualitative expert judgement (Terama et al., 2019; Kok et al., 2019).

### 2.5.3 Mid-term future: Struggling in the Heat

Under the Struggling in the Heat scenario, climate change signals across Europe are generally enhanced compared to the Warming to the Challenge scenario. A key difference is the moderate or strong increase of heat and warming indices for almost all regions, with a large agreement among models. For 1-day extreme precipitation, there is moderate-to-strong enhancement in northern and western Europe, compared to the near term. 5-day extreme precipitation increases over central-eastern Europe, together with the agreement among models. River floods are projected to increase in western and central-Eastern Europe. Drying is projected to increase strongly in southern Europe and moderately in central-eastern Europe. The agreement among models of a reduction in wind speed becomes stronger for southern, central-eastern and northern Europe. Snowfall decreases moderately in the mid-term future for all regions, in line with enhanced warming (Table 2.3). Compound hot and dry extremes are projected to increase in Europe in the mid-term under this scenario, particularly in western and central-eastern Europe (Sedlmeier et al., 2016).

Even if this scenario presents similar changes in CIDs to the previous one, as Section 2.4.1 explained, the SSPs have very different challenges, implying that at that time of the century (2041-2060) the conditions and societal capabilities to respond to the changes in the climatic drivers of risk could be very different. The challenges to adaptation are high under this scenario due to fundamental regionalisation, competition and a reactive approach to planning and adaptation, which replicates previous years' vulnerabilities (Kok et al., 2019; Mitter et al., 2020). GDP growth is still positive at 1% per year in the mid-term future (Dellink et al., 2017; Kc and Lutz, 2017). But more natural disasters leads to increased fiscal strains (Kok et al., 2019). Rather than European cooperation, alliances with other countries are prioritised by states as part of defence and (energy) security, to shore up fossil energy supply (Table 2.4). Because social policies and spending on health and education are projected to be deprioritised, health deteriorates for the majority of Europeans (Rohat et al., 2019a; Mitter et al., 2020). Mortality increases, while migration flows decrease because of security and barriers (Terama et al., 2019). The pace of urbanisation may be lower than in the Warming to the Challenge scenario as a net effect (Mitter et al., 2020). While the countryside is abandoned for better job opportunities, the lack of spatial planning enables sprawling and lower population densities. A counteracting effect is the densification of urban areas where employment and resources are relatively more accessible. Suburbs thus grow the fastest, while overall urban dwelling increases. However, the increase in urban population is less strong compared to Warming to the Challenge, since the overall population increase is smaller (Terama et al., 2019). Overall, population declines in a range of 4-11% will be seen in Europe (Kc and Lutz, 2017). Here, modelled land use outcomes show declining grassland and managed forest throughout Europe, with an increase of arable land in northern Europe (Harrison et al., 2019).

### 2.5.4 Long-term future: Warming to the Challenge

The differences between the two scenarios become even more apparent in the long term (2081-2100). The annual maximum of maximum daily temperature in western Europe increases moderately for the Warming to the Challenge scenario, similar to the mid-term. There is still low agreement among the models on mean daily precipitation changes in the different European regions. Changes in extreme rainfall are also similar to the mid-term. For western Europe, there is now less agreement on an increase in 5-day extreme rainfall. Sea level is projected to continue to rise as a result of slow processes in the oceans and cryosphere. Future snow extent and seasonal duration is projected to reduce, and glaciers are expected to continue shrinking. By the end of the century, most of the northern Europe periglacial areas are projected to disappear (BSC, 2024).

The path to sustainability continues, with similar trends to the mid-term, although the risk of global shocks rises. An increase in climatic extremes, such as serious storm surges and extensive droughts, are anticipated and reflected in planning, for example, a retreat in low-lying coastal areas and investments in undersea grass forests (O'Neill et al., 2017). The population declines by 9% in Europe, with the strongest decline of 20% in central-eastern Europe, whereas northern Europe's population is projected to grow by 11% (Kc and Lutz, 2017). Economic growth is slightly reduced compared to the mid-term period.

### *2.5.5 Long-term future: Struggling in the Heat*

A severe increase applies to almost all heat and cold CIDs for the Struggling in the Heat scenario in the long term. Precipitation is projected to increase in northern Europe and decrease in the south. Extreme precipitation is expected to increase severely for 1-day extreme precipitation in northern and western Europe. Droughts are also projected to increase strongly in central-eastern and western Europe, and even more severely in southern Europe. Ocean acidification continues to increase, together with an accelerated sea level rise and melting of glaciers (BSC, 2024). Compound flooding events due to the combination of extreme sea level and extreme precipitation associated with high levels of run-off is projected to increase along northern European coasts (Bevacqua et al., 2019a).

Under this scenario in the long term, the mid-term changes continue in a snowball effect. Most Europeans are well below the middle class level compared to the beginning of the century, with GDP being close to 0% (Dellink et al., 2017; Kc and Lutz, 2017). While a few pockets of society live longer, mortality is very high throughout Europe. Brain drain is common. Lack of adaptative capacity has translated into high vulnerability for the vast majority of Europeans (O'Neill et al., 2017). The population declines strongly in Europe by 15% on average (Kc and Lutz, 2017).

### *2.5.6 Wildcards across different futures*

This section illustrates how selected wildcards align with emerging evidence of sudden and extreme events as catalysts of potent extreme threat multipliers (Kemp et al., 2022). In these examples, included in EUCRA storylines, climate change could exacerbate or directly trigger other catastrophic risks, such as international conflict, spread of infectious disease, or spillover risk.

The war wildcard can be interpreted both as an exacerbating and triggering risk. Russia's war of aggression against Ukraine is an example of a wildcard leading to shifts in public spending and investments in the military. This could further raise geopolitical tensions, upset power relations and drive more nationalism and isolation. This wildcard, compounded with CIDs, may also affect trade routes and global supply chains (see Chapter 16).

The pandemic wildcard could act as a catalyst in the spread of pests and diseases and the collapse of public health systems, particularly in combination with extreme events such as multi-year droughts or prolonged heat. The shock of a pandemic, similar to COVID-19, can stress test systems´ adaptive capacity, in terms of policy prioritisation, and risk sidelining green political agendas, particularly in systems strongly affected by outsourcing and dependent on external sources. This further delays action and prevention by worsening overall adaptative capacity. It may also lead to more pandemics as the spread of diseases increases. However, the potential to increase preparedness for pandemics can emerge, although this could be limited by the lower capacity in society to prevent such shocks (see Chapters 11 and 14).

The West Antarctic ice sheet instability wildcard focuses on the disintegration of this ice sheet, which would result in an additional sea level rise of about 1m by the end of the century. This has serious implications for coastal protection. Together with the increased probability of heavy precipitation and large river discharge during storm surges across European regions (Paprotny et al., 2018), it would lead to displacement or migration of millions of Europeans, or radically change the perception of what societal preparedness for coastal protection should entail. The risks for public and private financial systems in this scenario are not yet well understood (UKCCRA3, 2021).

# Part B Thematic factsheets

**Thematic factsheets** (alternatively, thematic risk assessments) describe current and future climate risks for an ecological or human system (e.g. terrestrial ecosystems, water, the food system). Factsheets are compiled by expert authors based on an extensive review of existing relevant literature, models and/or datasets.

The thematic factsheets cover the following systems:

- **Chapter 3: terrestrial and freshwater ecosystems** (forests, peatlands, freshwater systems, Arctic and mountains, urban ecosystems, and agroecosystems)
- **Chapter 4: marine and coastal ecosystems** (marine coastal ecosystems, open ocean ecosystems, and Arctic marine ecosystems)
- **Chapter 5: water security** (environment and subsystems, agricultural use, civil and domestic uses, industry and services, and energy)
- **Chapter 6: food production and security** (food production, food storage, processing, distribution, transportation and trade, food consumption, market responses, and food security)
- **Chapter 7: human health** (heat stress, air pollution and airborne allergens, vector-borne diseases, water- and foodborne diseases, and labour force impacts)
- **Chapter 8: energy** (energy demand, energy transportation and storage, energy generation and conversion, and primary energy carriers)
- **Chapter 9: built environment** (residential buildings, non-residential buildings, transport infrastructure, pipelines, communication and electricity lines, energy and industrial infrastructures, and green and blue infrastructures)
- **Chapter 10: EU outermost regions** (small islands in tropical regions, coastal regions in the Amazon, and Macaronesia). European outermost regions are not a system, but a geographic region that could not be covered in the main part and are therefore treated in a dedicated factsheet.

The choice of the systems mentioned does not exclude the importance of other sectors and systems that would merit inclusion in a more extensive follow-up iteration of EUCRA.

**Factsheet structure:** each factsheet is structured in four main sections preceded by a series of key messages that aim to highlight the main learnings and priorities from each factsheet:

- Section X.1 (**Key messages**) focuses on the general status of the system and the connections to climate risks for other systems**.**
- Section X.2 (**Introduction**) focuses on the general status of the system and the connections to climate risks for other systems**.**
- Section X.3 (**Risk drivers and impacts**) identifies and describes relevant subsystems through three main questions:
    - What drives the impact (climatic and non-climatic risk drivers)
    - Current situation
    - Future situation

  The first point ('What drives the impact') is illustrated in graphical representations known as impact chains. **Impact chains** illustrate how climate-related hazards (also known as climate impact or risk drivers), together with non-climatic risk drivers (that influence exposure and vulnerability), can cause major climate risks through cascading impacts. Reflections on **social justice** have been included whenever pertinent to highlight the most vulnerable groups of society for specific climate risks.

- Section X.4 (**Risk assessment and evaluation**) presents the results of a structured risk assessment for each major climate risk identified in the factsheet, including its severity over time and the 'urgency to act' according to five categories. This risk assessment followed a structured and semi-quantitative risk assessment approach that involved the factsheet authors as well as an external risk review panel. More details can be found in Annex 2. Owing to overlaps between thematic factsheets and risk storylines (see Part C) in this report, the risk assessment for a given major risk may draw on evidence from more than one chapter, as well as on additional evidence and expertise considered by the members of the risk review panel. Additionally, this section reports on the **confidence** of the evidence, and on **opportunities, constraints of and limits to climate adaptation.**
- Section X.5 (**Relevant policies**) lists relevant policies for the specific factsheet. Policies are considered for the specific evaluation of the policy readiness and the risk ownership; they are also the basis for the policy analysis in Chapter 20, and they inform the identification of priorities for action in Chapter 21.

# 3 Terrestrial and freshwater ecosystems

## 3.1 Key messages

- Biodiversity loss and ecosystem degradation is a major environmental threat in Europe, and it is accelerating. Climate change is one of the main drivers.
- Key climate risks for terrestrial and freshwater ecosystems are: disruption of food web dynamics and related ecosystem services; climate-induced biological invasions; increased frequency and intensity of wildfires; population declines and local extinctions, particularly in freshwater ecosystems; and soil biodiversity decline, soil erosion and peatland deterioration due to climate- and land use-driven hydrological changes.
- Short-term climate risks for terrestrial and freshwater ecosystems are well established; long-term projections of severity of risks are more uncertain and depend largely on global mitigation actions.
- Risks to terrestrial and freshwater ecosystems may cascade to other sectors such as food and water security, human health, marine and coastal ecosystems, and built environments.
- The climate and biodiversity crises are highly interconnected, requiring coherence between respective policies and actions.
- Key policy priorities include: (1) addressing underlying drivers of biodiversity loss, (2) protection and restoration of nature, which accommodates climate-induced species range shifts, (3) sustainable management aiming to improve climate-resilience of ecosystems, and (4) improving habitat connectivity.



## 3.2 Introduction

Biodiversity is about the variability among living organisms, including the diversity within and between species and ecosystems, and about their services, such as provision of food and water, flood and disease regulation and providing recreation and a sense of place (IPBES, 2018). Biodiversity in terrestrial and freshwater ecosystems is in continuous decline in many places across Europe, with negative consequences for nature itself and for livelihoods, economies and people’s quality of life. Climate change is one of the major drivers of biodiversity loss and ecosystem degradation, worldwide and in Europe (IPBES, 2018, 2019). Climate change also indirectly affects biodiversity because it interacts with, and often exacerbates, other non-climate drivers. At the same time, the climate and biodiversity crises are interconnected, with one stressor contributing to and exacerbating the effects of the other. Biodiversity as such is not only affected by climate change, but it also provides solutions (both mitigation and adaptation).

There is strong evidence that climate change has impacted all European habitat types increasingly over the last 20 years, particularly grasslands, wetlands and peatlands; moreover, climate change is likely to be one of the most important drivers of nature decline in the future (IPBES, 2018; EEA, 2020b).

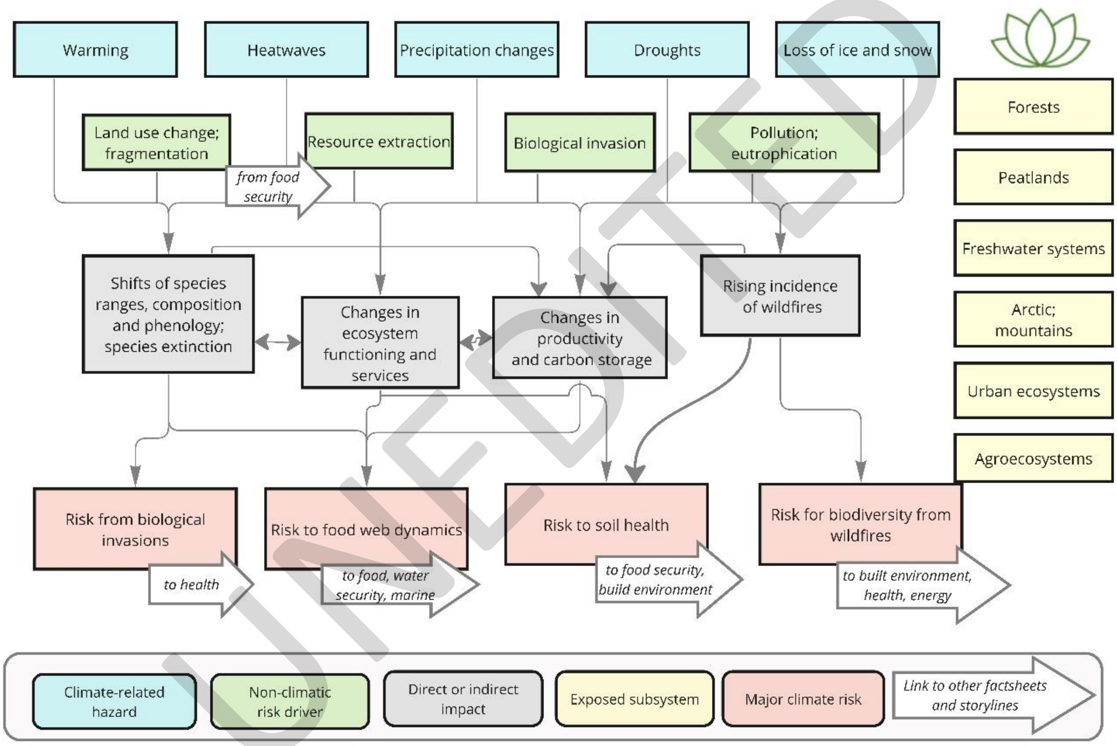
The impacts of climate change on nature are complex and there are considerable variations across regions, ecosystems and species, and depending on whether ecosystem function and productivity is precipitation-, radiation- or temperature limited.

This chapter presents climate change risks to biodiversity in six terrestrial and freshwater ecosystem types in Europe: forests, peatlands, freshwater systems, Arctic and mountain ecosystems, urban ecosystems, and agricultural areas. The subsystems and their climate risks are also interconnected to other chapters. For example, changes in species distributions will directly impact food security (see Chapter 6) and human health (see Chapter 7). The freshwater subsystems are connected downstream to marine and coastal ecosystems (see Chapter 4) and to water security (see Chapter 5), and to the forest subsystem (see Chapter 13), while the urban ecosystem is linked to built environments (see Chapter 9).

## 3.3 Risk drivers and impacts

### *3.3.1 Impact chain*

**Figure 3.1 Impact chain of biodiversity and ecosystems**






**Source**: ETC-CA, 2024.

The loss of biodiversity and degradation of ecosystems in Europe is a result of multiple drivers and their interactions, but climate change is becoming increasingly important (EEA, 2020b). Climate change, in particular warming and changes in precipitation, affects biodiversity through impacts on species and their habitats: altering species' phenology, growth and fitness (e.g. warming shifts the timing of species' life-history events), changing species and community dynamics (e.g. due to species movement), and altering ecological processes and ecosystem functioning, which leads to disruptions in species interaction (IPBES, 2018).

These changes have cascading effects on species abundance, richness and composition, and on ecological functions (including the delivery of ecosystem services). Many species will move (e.g. to higher latitudes) but others will not be able to respond, migrate or adapt fast enough, increasing the risk of species extinctions and co-extinctions.

In the EU, the high altitude (alpine), northernmost and southernmost regions are most at risk. Among species, amphibians, molluscs, bats and birds have been reported as negatively affected by rising temperatures and changes in precipitation, but many more will be affected. Among EU habitats, freshwater, coastal habitats, bogs, mires and wetlands are especially at risk, and there is a risk of severe and frequent wildfires.

### 3.3.2 Subsystem: forests

**What drives the impact**

- Climate change is an important driver impacting the extent and functioning of forests, alongside land use change, forest management, atmospheric pollution and invasive species. Forests are also part of the solution.
- Climate effects can be direct (e.g. on forest growth, species abundance) or indirect (e.g. through frequency and severity of disturbances).
- Climate drivers affect the structure and functioning (including productivity) of forests and the distribution of tree species and gene pools.

**Current situation**

- Past land use changes, including deforestation, have been the most important driver of the observed fragmentation of forests (EEA, 2017a; IPBES, 2018). As a result, forests' ecological conditions became more critical and their functioning came under pressure, including forest biodiversity, timber production and the carbon sink (EEA, 2023j). For example, forest birds already suffer from habitat loss and may disappear locally due to contraction of the suitable area (Mota et al., 2022).
- Forest management has led to significant changes in forest composition and structure, making many forests structurally very vulnerable to climate change. 30% of Europe's forests have only one tree species, and just 27% are uneven-aged forests (EEA, 2016). Due to the increase in wood harvest, the carbon sink in forests has dropped considerably (Korosuo et al., 2023a) (see also Chapter 13).
- Climate change has had considerable direct and indirect impacts on forests' functioning, species distribution and resilience. Temperature increases have resulted in a growing season up to 23 days longer in northern Europe since 1950 (Aalto et al., 2022). Range shifts in forest tree species have been observed towards higher altitudes and latitudes (EEA, 2017a) and negative impacts from invasive alien species have been observed, especially in temperate and boreal forests (IPBES, 2023). More droughts have reduced forest growth (Yuan et al., 2019) and increased tree mortality, even in high-productive forests (Hammond et al., 2022a; Socha et al., 2023). Forests have also been affected indirectly over the past decades by increased incidence of climate-induced droughts, which have augmented the frequency and extent of natural disturbances (Patacca et al., 2023a; van der Woude et al., 2023b; Vacek et al., 2023). Wildfires now appear in various places across Europe and at intensities not common in the past (Patacca et al., 2023a), and unprecedented incidences of insect outbreaks have been observed in central Europe (Hlásny et al., 2021b). As a result, many forests in Europe are experiencing declining resilience (Forzieri et al., 2022a), indirectly declining vitality of one third of the European forests, and a decreasing carbon uptake (van der Woude et al., 2023b; Maes et al., 2023).
- Some of the impacts mentioned have already been recognised by the forest sector. Efforts are being initiated across Europe to improve forest conditions in order to reduce

these impacts (JRC, 2020c), including stimulating more integrated and sustainable forest management (with more attention to natural processes).

**Future situation**

- It is projected that the effects of climate change on forests' functioning, productivity and species distribution will increase further, with impacts on biodiversity. The impacts vary significantly between different climate scenarios, especially for the long term.
- Slow-progressing climatic changes as well as more climate and weather extremes are projected to have large consequences on forest species composition and $CO_2$ sequestration (Reich et al., 2022; del Castillo et al., 2022; Pilli et al., 2022a; Nunes Romeiro et al., 2022). Forests in many places across Europe are projected to suffer from increases in forest fires (JRC, 2020b), and the vitality of various forests is projected to decrease, leading to reduced biomass growth and carbon uptake (>50% reduction of annual growth under high-end scenarios) and eventually increasing tree mortality (Buras and Menzel, 2019; del Castillo et al., 2022; Mauri et al., 2022a). As a consequence, the economic value of a vast amount of European forest land is expected to decrease substantially (Hanewinkel et al., 2013). Only a few tree species, such as the oak (*Quercus* spp.) and maple (*Acer* spp.), are projected to benefit from climate change in some locations across Europe, especially when the changes in climate remain limited (Buras and Menzel, 2019; Reich et al., 2022).
- Changes in forest management – such as targeting a more mixed tree species composition and forest structure, improving growing conditions and stimulating more natural processes – can increase forests' resilience to projected changes in climate and other environmental conditions, partly limiting the negative trends and maintaining carbon sink and biodiversity levels (Muys et al., 2022; Pilli et al., 2022a; Rosa et al., 2023; Vacek et al., 2023).

### 3.3.3 Subsystem: peatlands

**What drives the impact**

- Peatlands are currently affected mainly by anthropogenic impacts: drainage results in lowering of the water table and drying of peatlands, with other land management practices also contributing to impacts (Parmesan et al., 2022).
- Climatic drivers are superimposed on these anthropogenic drivers. Increasing temperatures and evaporation further contribute to drying of peatlands. In addition, changing precipitation patterns affect the water balance in peatlands, which in turn affects the water supply, water quality and the biological, physical and chemical processes in peatlands (Loisel et al., 2021a).
- Increasing temperatures also contribute to permafrost thawing, exposing more currently stable peatland to drying and carbon loss (Hugelius et al., 2020; van der Velde et al., 2021; Fewster et al., 2022).
- These changes in the water balance of peatlands have significant impacts on species composition and biodiversity (Antala et al., 2022), threatening peatlands' ecosystem services as niches of biodiversity, their key role in the water cycle and the carbon storage dynamics of peatlands (Leifeld et al., 2019).
- Drying of peatlands also makes them more vulnerable to wildfires, which can reduce carbon uptake in pristine northern peatlands by up to 35% (Wilkinson et al., 2023).

- Drying of peat causes loss of volume and compaction, leading to soil subsidence and causing a risk to infrastructure.
- Increased protection of peatlands has great potential to limit greenhouse gas (GHG) emissions (Leifeld and Menichetti, 2018), while the combined effects of climate change and peatland degradation will contribute significantly to GHG emissions.
- Peatlands make up an important share of Europe's wetland areas. Nevertheless, riverine, lacustrine, coastal or other types of non-peat wetlands are also important hotspots of biodiversity in Europe that have been subject to substantial losses and degradation historically, and are at serious risk from climate change (Čížková et al., 2013). These wetland types share some drivers and impacts of climate change with peatlands but require specific consideration depending on their type and (climatic) location.

**Current situation**

- In the EU, peatlands cover 268,000 $km^2$, consisting mostly of northern peatland, 51% of which are natural peatlands (EC, 2020c). Peatlands are the most important terrestrial carbon store, storing an estimated 470-1,200 gigaton(Gt) of carbon globally (Parmesan et al., 2022) and 10% of the world's freshwater (Joosten and Clarke, 2002), while covering only around 3% of the world's land area (Yu et al., 2010; Xu et al., 2018).
- 25% of the current peatland area in Europe and 50% of that in the EU was found to be degraded, and conservation targets are often not met (Tanneberger et al., 2021). Current drivers of peatland degradation are mainly anthropogenic, such as land management and drainage. However, the effect of global temperature increases and thawing of permafrost on peatlands is also already observable in Europe, and results in the drying of peatland, die-off of sphagnum moss, and increased intensity and frequency of wildfires (Loisel et al., 2021a; Parmesan et al., 2022).
- Currently, natural peatlands are estimated to be a carbon sink, but anthropogenic impacts such as drainage and land use change contribute to turning peatlands into a carbon source (Leifeld et al., 2019).

**Future situation**

- Increasing temperatures and evaporation will cause further peatland drying in the near term, with add-on effects on species composition and biological, physical and chemical processes (Loisel et al., 2021a).
- Peatlands are projected to go from being a net carbon sink to a net carbon source this century (Loisel et al., 2021a).
- Increasing temperatures will cause further permafrost thaw, resulting in more peatlands being exposed (Parmesan et al., 2022; Fewster et al., 2022), but possibly also extending peatland formation further northward, and longer growing seasons may increase vegetation productivity and carbon sequestration in some peatlands.
- Peatland restoration has the potential to revive ecosystem functions performed by peatlands and can contribute to climate change mitigation (Loisel and Gallego-Sala, 2022).

### *3.3.4 Subsystem: freshwater systems*

**What drives the impact**

- Temperature impacts on freshwater species and communities are evident; they are strongest for cold-adapted species, and regionally in northern Europe and southern Europe (Theodoropoulos and Karaouzas, 2021; Jarić et al., 2019). Increasing temperature favours blue-green algae, causing harmful blooms with socio-economic impacts and decreasing recreational value of freshwaters (Meerhoff et al., 2022). Increasing temperature also influences the length of the ice-free period and temperature stratification in lakes, with effects on biodiversity (Woolway et al., 2021). Global climate warming effects combined with local factors (e.g. riparian tree cutting) can lead to passing of thresholds to more serious ecological impacts (Trimmel et al., 2018).
- Precipitation changes alter water levels and flow rates of streams and rivers, with multiple ecological impacts (Bonada and Resh, 2013; Deitch et al., 2017).
- Extreme weather events may exceed tolerance limits of sensitive species, leading to collapse of their populations (McDowell et al., 2017).
- Climate change causes eutrophication and browning of freshwaters due to increased loading of nutrients and organic carbon from terrestrial systems (Kritzberg et al., 2020; Meerhoff et al., 2022). In lakes, rising temperatures lead to a longer stratification period and thermocline depth. Increasing productivity and loading of organic carbon result in hypolimnetic oxygen depletion and limit suitable habitats to cold stenothermal and oxygen-sensitive species (Jane et al., 2021). These changes in lake conditions can also trigger internal loading of nutrients from the pool accumulated to the sediments (Meerhoff et al., 2022).
- Water abstraction interacts with climate change through increased evaporation and water salinity, and decreased water levels (Jeppesen et al., 2015).

**Current situation**

- Between 1970 and 2010, global warming trends in lake surface waters (0.21-0.45°C per decade) exceeded the rate of sea surface warming (0.09°C), with more rapid warming in northern Europe (Parmesan et al., 2022). Temperature increase has evident biodiversity impacts at species and community levels (Nicola et al., 2018; Haase et al., 2023).
- Reduced river connectivity has been observed in areas of reduced river flows (Parmesan et al., 2022). The decreasing trend in annual and summer precipitation in southern Europe (Deitch et al., 2017) causes harsher conditions and challenges for aquatic biota, while freshwater communities in the region are characterised by high biodiversity with higher site-to-site variability in species composition, and higher rarity and endemicity compared to other European regions (Bonada and Resh, 2013). Despite their adaptation to seasonal droughts, species in southern Europe may be most the susceptible to climate change impacts of all the European regions (Jarić et al., 2019).
- Increased leaching of nutrients and organic carbon from catchments to water bodies has exacerbated eutrophication and caused browning of freshwaters in northern Europe, with consequential impacts on biodiversity and ecosystem services (Kritzberg et al., 2020; Meerhoff et al., 2022).
- Long-term and widespread deoxygenation is evident in lakes (Jane et al., 2021).

**Future situation**

- Local or regional extinctions of cold-adapted species across European regions, with collapses of ecosystem services depending on these species, are expected to increase (Theodoropoulos and Karaouzas, 2021; Comte et al., 2013; Ruiz-Navarro et al., 2016).
- Climate change sensitivity of freshwater taxa is especially high in southern Europe (Theodoropoulos and Karaouzas, 2021; Jarić et al., 2019; Bonada and Resh, 2013). It has been projected that water warming of more than 3°C, with decreased flow rates, will cause irreversible changes in freshwater communities, with cold-dwelling taxa disappearing (Theodoropoulos and Karaouzas, 2021).
- Eurythermal species with wide temperature tolerances are expected to benefit from warming with the northward expansion of their ranges (Ruiz-Navarro et al., 2016; Jeppesen et al., 2012). Cold stenothermal species with narrow thermal tolerances are projected to suffer throughout Europe, with probable local extinctions (Réalis-Doyelle et al., 2016; Ruiz-Navarro et al., 2016; Elliott and Elliott, 2010).
- In lakes, periods of ice cover are expected to shorten, and longer durations of temperature stratification are expected in the future in northern, western and central-eastern Europe (Woolway et al., 2021). Hypolimnetic oxygen concentrations in temperate lakes are expected to decrease, causing losses of cold stenothermal and oxygen-sensitive species populations (Jane et al., 2021).
- Increasing productivities and organic matter inputs to freshwaters are expected to induce stronger impacts on biodiversity, ecosystem functions and services (Kosten et al., 2012; Meerhoff et al., 2022).
- Extreme weather events are projected to increase (Kron et al., 2019), such as heavy rainfall that can cause freshwater pollution from overflowing of wastewater treatment plants or mine tailing (Lin et al., 2022; Rosenzweig et al., 2019).

### *3.3.5 Subsystem: Arctic and mountains*

**What drives the impact**

- The Arctic is warming faster than the rest of the planet, leading to increased extreme heat events, less snow and the thawing of permafrost (Rantanen et al., 2022; Constable et al., 2022). Mining, reindeer herding and tourism are important non-climatic drivers in the Arctic which themselves are also affected by climate.
- Mountain areas have large ecological gradients in short distances, therefore even small changes in climate have a strong effect over a small area (Adler et al., 2022). Europe's mountains have a long history of human use. Many meadows suffer from overgrazing, which leads to simplifying of ecosystem structure (IPBES, 2018). Tourism is another important non-climatic driver of biodiversity in mountain areas.

**Current situation**

- Ecosystem impacts of climate change have been observed widely in the Arctic, including the borealisation of terrestrial systems with increasing productivity and an overall greening, regional browning of tundra and boreal forests, and food web changes resulting in population declines in terrestrial mammals (Constable et al., 2022; Speed et al., 2021).
- The frequency and severity of forest fires in northern Europe has increased, creating a growing risk of permanent forest loss, carbon cycle feedback and modified species composition (Schuur et al., 2022; Burrell et al., 2022).

- Climate change has impacted indigenous subsistence resources, affecting grazing opportunities for reindeer, requiring more flexible reindeer herding (Rosqvist et al., 2022).
- Impacts in Europe's mountain regions include reduced snow cover, retreating glaciers, permafrost thaw and subsequent increases in landslides, increased vegetation productivity and species distribution shifts to higher elevations (Adler et al., 2022; Rumpf et al., 2022), leading to an increase of species richness on mountain tops in northern Europe, but to declines in Mediterranean mountains (IPBES, 2018). Warming-induced species shifts to higher altitudes, however, are constrained, e.g. by the availability of a suitable soil layer (Vitasse et al., 2021).

**Future situation**

- The Arctic is projected to continue having higher warming rates than elsewhere, with increased impacts already observed today that further threaten terrestrial ecosystems and biodiversity (Constable et al., 2022).
- Primary productivity in Arctic ecosystems is projected to increase (Ito et al., 2020),; however, coinciding with declines in endemic Arctic species (Niskanen et al., 2019) and leading to accelerated extinction rates (Niittynen et al., 2018). Some habitat types unique to Arctic environments are projected to disappear from the European part of the Arctic during the 21st century (Fronzek et al., 2011).
- Climate change impacts will further threaten terrestrial subsistence food resources across the Arctic, affecting the indigenous Sámi population (Constable et al., 2022).
- Arctic and alpine ecosystems have been identified as hotspots of future change and are projected to undergo a continued treeline shift, with associated replacement of tundra vegetation with forests (Barredo Cano et al., 2020; Hickler et al., 2012).

### *3.3.6 Subsystem: urban ecosystems*

**What drives the impact**

- Climate change exacerbates urban climate stresses (e.g. urban heat island effect, flooding and drought) and interacts with other environmental stressors (e.g. pollution, biological invasion, pests and diseases), which leads to increased vulnerability of urban ecosystems and species. Compared to other ecosystems, climate change has, however, less strong impacts on urban ecosystems, as many urban species are generally well adapted to harsh climate conditions (IPBES, 2018).
- Urban climate hazards, particularly higher temperatures and drought conditions, impact a broad spectrum of urban biodiversity, directly and indirectly, including increased mortality, community changes and range expansion/contractions of species. Moreover, it may favour different species, including pests and diseases, and invasive alien species.
- Climate change-induced impacts on urban ecosystems often have a cascading effect on the provision of ecosystem services important to urban populations (e.g. local temperature regulation, water supply, health and well-being benefits from contact with nature), and may lead to changes in seasonality of pollen allergies. Sea level rise and coastal and riverbank erosion drive the loss of coastal habitats, increasing risks to people.

**Current situation**

- All European urban ecosystems are already experiencing the effects of climate change (IPBES, 2018).
- Climate risks are highly context dependent (e.g. a city's location and topography). Cities in southern Europe experience heat extremes and a decrease in precipitation, while there is an increase in heavy precipitation events, causing flooding, in many other parts of Europe, particularly northern Europe (EEA, 2020d).
- Cities harbour many vegetation species, which currently grow beyond their optimal temperature and precipitation conditions (Esperon-Rodriguez et al., 2022), and urban tree damage and death can be observed in European cities, caused by heat and drought (Haase and Hellwig, 2022).

**Future situation**

- Urban biodiversity and green spaces will be faced with more frequent and intense extreme weather events, including the increasing risk of high temperatures, flooding, water scarcity and wildfires (EEA, 2023n; Bednar-Friedl et al., 2022b).
- Many urban tree and shrub species may exceed their safe climate margins in 2050 (under RCP6.0) (Esperon-Rodriguez et al., 2022), and many European cities are projected to be especially vulnerable to future climate hazards (e.g. due to coastal flooding, sea level rise, landslides and heatwaves) (EEA, 2020d).
- Heatwaves are likely to become a major threat to urban ecosystems, not only for southern Europe, but also for urban environments in western, central and eastern Europe (Dodman, et al., 2022).
- Urban ecosystems will be faced with more drought periods, particularly in southern Europe (Bednar-Friedl et al., 2022b); northern Europe and some cities in western-central Europe will be exposed to high to very high risk of pluvial flooding (Dodman, et al., 2022).

### *3.3.7 Subsystem: agroecosystems*



**What drives the impact**

- Climate change is likely to become one of the most important drivers of impacts on agrobiodiversity in the future. Currently, the most frequently reported drivers of agrobiodiversity decline are those associated with changes in agricultural practices (IPBES, 2018).
- Most climate change impacts relate to warming both undermining agrobiodiversity and potentially enhancing it.
- Shifts in seasonal timing, caused by warming, may lead, for example, to mismatches between species life-history events and timing of land management practices (Santangeli et al., 2018).
- Warming, variability in winter weather conditions, increase of extreme weather events and lengthening of the vegetation season are particularly detrimental to pollinators (Vasiliev and Greenwood, 2021).
- Climate change impacts soils via increased risk of soil moisture drought and soil erosion, the latter potentially leading to habitat loss. However, overall responses are mixed as, for instance, increased rainfall intensity and wildfires increase erosion risk, while enhanced vegetation growth and decreased spring snowmelt reduce it (Bednar-Friedl et al., 2022b; JRC, 2016b).
- Warming is expected to increase the overall number of pest outbreaks and the risk of invasive pest species, impacting the production of arable plants (Skendžić et al., 2021;

IPBES, 2023), and leading to increased use of pesticides, with widespread impacts on biodiversity (van Lexmond et al., 2015).
- Benefits of warming include increased productivity and the possibility to introduce new crop varieties to Nordic cultivation systems, due to lengthening of the growing season and increase in mean temperature (Wiréhn, 2018).
- Strong interdependencies are found with the water, agriculture, forestry and biodiversity sectors and with non-climatic developments (e.g. changes in land use patterns and population).

**Current situation**

- Many species that contribute to vital ecosystem services in agriculture are in decline due to a combination of threats, including climate change. Ecosystem services most frequently reported to be affected by climate in the agricultural context include regulation of pests, diseases and natural hazards, water cycling, habitat provisioning and pollination (Pilling and Bélanger, 2019).
- Changes in climate, land use and the environment have resulted in a northward and uphill shift of a wide variety of plants and animals in Europe over recent decades (EEA, 2017a).
- Pollinator diversity is documented to be in sharp decline, particularly in the north temperate zone, with no consensus on the major drivers of the decline (Vasiliev and Greenwood, 2021); due to delayed response times, climate change impacts on pollinators may not be fully apparent for several decades (IPBES, 2016).
- Phenological shifts caused by climate change have resulted in mismatches in the interaction of flowering plants and bee pollinators (EEA, 2017a). Weakening interaction is suggested to cause increased self-fertilisation in plants, which may in turn further accelerate pollinator decline (Acoca-Pidolle et al., 2023).

**Future situation**

- Agrobiodiversity is projected to decline across Europe in response to climate change (EEA, 2017a).
- With respect to pollination, climate change is projected to result in (1) a change in community composition due to certain species decreasing and others increasing in abundance; and (2) the seasonal activity of many species changing differentially, causing disruption to the life cycles and interactions between species (IPBES, 2016).
- Climate risks to soils are projected to increase under all climate scenarios. Risks of soil moisture drought are projected to increase in western, central and southern Europe. The risk of soil erosion is projected to increase in western, central and northern Europe, while in southern Europe it is already high (Bednar-Friedl et al., 2022b).

## 3.4 Risk assessment and evaluation

### *3.4.1 Confidence*

Overall, climate change as a direct driver of European biodiversity loss in terrestrial and freshwater ecosystems has a well-established confidence. However, impacts are highly context specific and do not affect biodiversity similarly in all regions or for all taxa.

There is strong evidence that climate change shifts the timing of species' life-history events, growth, reproduction and population dynamics, species ranges and interaction, and habitat occupancy, as well as ecological processes and ecosystem functioning. However, knowledge gaps remain regarding the impact of climate change on physiological processes and evolutionary adaptation capacity to new climatic conditions.

With mostly well-established confidence, climate change is projected to be among the most important threats to future biodiversity, with negative to strongly negative increasing trends across European regions and ecosystems.

### *3.4.2 Adaptation opportunities, constraints and limits*

There are different adaptation options creating opportunities to enhance biodiversity while reducing vulnerabilities to future climate change, including:

- addressing underlying drivers of biodiversity loss (e.g. climate change, pollution, unsustainable resource extraction, fragmentation);
- protection and restoration of nature that accommodates climate-induced species range shifts;
- sustainable management (aiming to improve ecosystems' climate-resilience, e.g. paludiculture, agroforestry, crop diversification); and
- improving habitat connectivity.

Some adaptation options have already been implemented in Europe under the umbrella term nature-based solutions ([6])**,** though not yet at large scale (EEA, 2023j). The potential for, and performance of, nature-based solutions is highly place-based (e.g. dependent on physical constraints and on the severity of climate change scenarios).
The widespread implementation of adaptation options is currently limited due to high management costs, lack of knowledge, undervaluation of nature and a low level of consideration of species shifts in current conservation policies (Bednar-Friedl et al., 2022b; EEA, 2023m; Calliari et al., 2019).
There are also risks for maladaptation, e.g. afforestation of high-latitude peatlands may ultimately result in a net reduction of soil carbon storage (Seddon et al., 2021).

### *3.4.3 Overall assessment*

This section presents the outcomes of the structured risk assessment for the major climate risks identified in this factsheet. This assessment builds on information in this factsheet, and possibly in other chapters of this report. The initial risk assessment was conducted by the authors of this factsheet whereas the final assessment results reported here represent the consensus of the EUCRA risk review panel. Further methodological information is available in Annex 2.

The following risks assessed in other chapters are also relevant for this factsheet, but they are not presented here to avoid duplication:

- Risks to aquatic and wetland ecosystems and their services due to low flow in rivers (see Chapter 5).
- Risk to forest ecosystems and the carbon sink from more severe and frequent hot-dry events and related insect and pest outbreaks (see Chapter 13).

([6]) The European Commission defines nature-based solutions *as 'Solutions that are inspired and supported by nature, which 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 interventions'* (EEA, 2021e).

### Table 3.1 Risk assessment for major risk 1: risk to food web dynamics and related ecosystem services due to phenological changes and species distribution shifts

| | Current/near term (2021-2040) | Mid-term (2041-2060) | Long term (2081-2100)<br>• high warming<br>• low warming |
|---|---|---|---|
| **Risk severity** | **Substantial**<br>Northward shifts and altitudinal movements have caused observed changes in species composition across Europe, with a decrease in species richness in southern Europe.<br>Lengthening of the growing season across Europe offers opportunities in northern Europe. But it can lead to mismatches in the phenological calendar, e.g. in pollination services, increased risk of frost damage due to earlier blooming, altering or reducing the growing range of both natural and agricultural species, affecting species diversity, and reducing yields of crops. | **Critical**<br>Projections for 1.5°C and 3.0°C global warming levels (GWLs) suggest an increase in phenological changes across Europe and an increase in range shifts in southern and western-central Europe, putting a strain on biodiversity, especially for specialist species. In northern Europe, both an increase and a decrease in range shifts are projected under both GWLs. Probabilities of local species extinctions, and in the case of endemic species threatened by multiple stressors, even total extinctions are increased. | **Catastrophic**<br>Overshoot of GWLs has led to extensive shifts in phenology and habitats, with several species unable to adapt fast enough, causing a marked decline in ecosystem services such as pollination and with repercussions for the food web.<br>**Critical**<br>The changing climate causes substantial shifts in phenology and habitats, reducing biodiversity, but species refuges remain, and ecosystem services have not collapsed, partly due to substantial remediation efforts. |
| **Confidence** | **High** | **Medium** | **Medium** |
| **Risk ownership** | **Co-owned**<br>The EU and its Member States both have legislative responsibilities relating to the environment, which includes biodiversity, natural ecosystems and ecosystem services.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Biodiversity strategy for 2030 (2020/380)<br>• Nature Restoration Law (forthcoming)<br>• Plant Health Regulation (2016/2031)<br>• Forest strategy for 2030 (2021/572)<br>• Common agricultural policy (2021/2116)<br>• Floods Directive (2007/60)<br>• Water Framework Directive (2000/60)<br>• Birds Directive (2009/147) and Habitats Directive (92/43)<br>• Regulation on Deforestation-Free Products (2013/1115)<br>• Farm to fork strategy<br>• Global health strategy<br><br>At the national level, the main policies of relevance include those relating to:<br>• Environment<br>• Spatial planning and infrastructure<br>• Civil protection and emergency preparedness<br>• National adaptation funding | | |
| **Policy readiness** | **Medium**<br>The EU's nature policy aims to protect and restore nature with a focus on creating a coherent and resilient trans-European nature network (e.g. Natura 2000), including ecological corridors and investments in green and blue infrastructure. An improved connectivity between habitats helps to limit timing mismatches within food chains. | | |
| **Policy horizon** | **Medium term** | | |
| **Urgency ranking** | **More action needed**<br>• The focus is on executing and implementing existing policies. | | |

**Note**: the risk assessment for this risk showed considerable heterogeneity across evaluators (i.e. authors and the risk review panel).

**Source**: EEA.

### Table 3.2 Risk assessment for major risk 2: risk to ecosystems and society from climate-induced species invasions

| | Current/near term (2021-2040) | Mid-term (2041-2060) | Long term (2081-2100)<br>• high warming<br>• low warming |
|---|---|---|---|
| **Risk severity** | **Substantial**<br>Higher temperature sensitivity and lower drought resilience of native species compared to invasive alien species, especially in freshwater systems and highly modified ecosystems (e.g. urban and agricultural areas). | **Critical**<br>Progressing climate change and further degradation of ecosystems supports the establishment of invasive alien species, especially in northern, western and central Europe. | **Catastrophic**<br>Further strong increase of risk from mid-term.<br>**Critical**<br>Continuation and for some species further increase of risk compared to mid-term. |
| **Confidence** | **High** | **Medium** | **Medium** |
| **Risk ownership** | **Co-owned**<br>The EU and its Member States both have legislative responsibilities relating to the environment, which includes biodiversity, natural ecosystems and ecosystem services.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Invasive Alien Species Regulation (2014/1143)<br>• Biodiversity strategy for 2030 (2020/380)<br>• Nature Restoration Law (forthcoming)<br>• Plant Health Regulation (2016/2031)<br>• Forest strategy for 2030 (2021/572)<br>• Common agricultural policy (2021/2116)<br>• Birds Directive (2009/147) and Habitats Directive (92/43)<br>• Farm to fork strategy<br>• Global health strategy<br>At the national level, the main policies of relevance include those relating to:<br>• Environment<br>• National adaptation funding | | |
| **Policy readiness** | **Medium**<br>• Several EU policies are in place to prevent biological invasion and to manage the impacts of invasive alien species on local biodiversity and economics (e.g. agricultural production), but so far with limited success.<br>• The EU biodiversity strategy for 2030 contains the political commitment to tackle the issue, whereas the Invasive Alien Species (IAS) Regulation includes a set of concrete measures to be taken across the EU Member States.<br>• These policies do not specifically apply to species changing their natural ranges in response to, e.g. climate change. So there is no assessment and regulation of possible future IAS that could rapidly appear under climate change. | | |
| **Policy horizon** | **Medium term** | | |
| **Urgency ranking** | **More action needed**<br>Both IAS and climate are addressed. More research is needed for interrelationships. | | |



**Source**: EEA.

### Table 3.3 Risk assessment for major risk 3: risk to biodiversity and carbon sinks from increased frequency and intensity of wildfires: all Europe and southern Europe

| | Current/near term (2021-2040) | Mid-term (2041-2060) | Long term (2081-2100)<br>• high warming<br>• low warming |
|---|---|---|---|
| **Risk severity: all Europe** | **Substantial** | **Critical** | **Catastrophic** |

| | | | |
|---|---|---|---|
| | Wildfires are increasingly affecting areas that have not been considered fire-prone regions in the past. | Extent and frequency of wildfires are projected to increase. | Further severe increase in risk compared to the mid-term.<br>**Critical**<br>See mid-term. |
| **Risk severity: southern Europe** | **Critical**<br>Southern Europe is experiencing extensive wildfires each year. | **Critical**<br>Increasing frequency, intensity and severity of mega-fires and of soil-moisture drought across southern Europe. | **Catastrophic**<br>In southern Europe, more frequent and severe wildfires lead to potentially irreversible habitat loss.<br>**Critical**<br>See mid-term. |
| **Confidence** | **High** | **Medium** | **Medium** |
| **Risk ownership** | **Co-owned**<br>The EU and its Member States both have legislative responsibilities relating to the environment, which includes biodiversity, natural ecosystems and ecosystem services.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Biodiversity strategy for 2030 (2020/380)<br>• Nature Restoration Law (forthcoming)<br>• Revised Regulation on LULUCF (2023/838)<br>• Plant Health Regulation (2016/2031)<br>• Forest strategy for 2030 (2021/572)<br>• Birds Directive (2009/147) and Habitats Directive (92/43)<br>• Union Civil Protection Mechanism<br>• European Forest Fire Information System<br>• Proposed Regulation on an EU Certification for Carbon Removal<br>• EU Solidarity Mechanism: Social Cohesion Fund<br>• Global health strategy<br><br>At the national level, the main policies of relevance include those relating to:<br>• Environment (e.g. forest management and natural disturbances)<br>• Civil protection and emergency preparedness<br>• National adaptation funding | | |
| **Policy readiness** | **Medium**<br>• Spatial planning including natural disturbances is a responsibility of each Member State.<br>• Several EU policy frameworks exist that set the basis for increased fire prevention and climate resilience of natural ecosystems (see above).<br>• Europe-wide monitoring and reporting has been established, and assistance and funding are available in times of large-scale wildfires. | | |
| **Policy horizon** | **Medium term** | | |
| **Urgency ranking** | **More action needed (all Europe)** | **Urgent action needed (southern Europe)** | |
| | • Multiple policies and plans exist that affect the risk of large-scale fires. But more clarity and research is needed that is also in line with other biodiversity objectives (e.g. the role of deadwood in forests, as dry deadwood can facilitate the spread of fires after ignition).<br>• Funding is needed in many Member States for appropriate monitoring.<br>• The forthcoming EU Nature Restoration Law is a key tool for restoring ecological conditions. Restored ecosystems are less vulnerable to wildfires. | | |



**Note**: the risk assessment for this risk showed considerable heterogeneity across evaluators (i.e. authors and the risk review panel).

**Source**: EEA.

### Table 3.4 Risk assessment for major risk 4: risk to soil health related to direct impacts on soil parameters and soil erosion

| | Current/near term (2021-2040) | Mid-term (2041-2060) | Long term (2081-2100)<br>• high warming |
|---|---|---|---|

| | | | |
|---|---|---|---|
| | | | • **low warming** |
| **Risk severity** | **Substantial**<br>Increased rainfall intensity causes increased risk for soil erosion.<br>Increasing drought frequency, duration and intensity affects soil moisture. | **Substantial**<br>Land use changes cause substantial changes in soil conditions, with both positive and negative impacts on biodiversity and ecosystem services.<br>Management of mediating impacts is partially successful. | **Critical**<br>Substantial impacts of direct and indirect effects of climate change on soils are beyond managing and cause significant cascading impacts on food production, water supply and biodiversity.<br>**Substantial**<br>Both positive and negative impacts on soil, despite careful monitoring and management of long-term direct and indirect impacts of climate change, but soil degradation remains manageable. |
| **Confidence** | **High** | **Medium** | **Medium** |
| **Risk ownership** | **Co-owned**<br>The EU and its Member States both have legislative responsibilities relating to the environment, which includes biodiversity, natural ecosystems and ecosystem services.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Proposed Directive on Soil Monitoring and Resilience (2013/416)<br>• Biodiversity strategy for 2030 (2020/380)<br>• Nature Restoration Law (forthcoming)<br>• Revised Regulation on LULUCF (2023/838)<br>• Plant Health Regulation (2016/2031)<br>• Birds Directive (2009/147) and Habitats Directive (92/43)<br>• Common agricultural policy (2021/2116)<br>• Proposed Regulation on an EU Certification for Carbon Removal<br>• Farm to fork strategy<br>• Communication on EU Action to Protect and Restore the World's Forests<br>• Water Framework Directive (2000/60)<br>• Global health strategy<br>• Floods Directive<br>• Soil strategy<br><br>At the national level, the main policies of relevance include those relating to:<br>• Environment<br>• Agriculture<br>• Water governance<br>• National adaptation funding | | |
| **Policy readiness** | **Medium**<br>• The EU has defined various strategies, plans and guidelines to maintain soil fertility and restore soil biodiversity. Therefore, healthy soils are an integral part of the EU's climate, biodiversity and long-term economic objectives, as formulated in the biodiversity strategy, soil strategy for 2030 and the common agricultural policy, and underlying strategies, plans and guidelines. These strategies also include targets: 'By 2050, all EU soil ecosystems are in healthy condition and are thus more resilient'. There are also concrete actions in the 2021 soil strategy and the proposed Soil Monitoring Law.<br>• Some of these policies still need to be implemented by Member States, and some Member States are currently lacking soil laws, limiting the practical effect of these policies so far. | | |
| **Policy horizon** | **Medium term** | | |
| **Urgency ranking** | **More action needed**<br>• There is a need to further define approaches to make the objectives of the 2021 soil strategy, in particular, more concrete and operational for Member States. | | |

**Source**: EEA.

## 3.5 Relevant policies

- The *Birds and Habitats Directives* and the forthcoming *Nature Restoration Law (adoption expected in spring 2024)*: the overall EU legal framework for protecting, restoring and connecting natural areas within and outside the Natura 2000 network. Both are relevant when managing all four major risks. The major challenge is to ensure effective implementation of policies, extend the Natura 2000 network and increase connectivity between Natura 2000 and other areas.

- *The biodiversity strategy* (2020) and *forest strategy* (2021) are important EU policy strategies to protect existing biodiversity and recover degraded ecosystems, including soils, by 2030. They also represent the EU's contributions to international negotiations on long-term biodiversity frameworks. These strategies aim to build resilience to future threats, including climate change. Wildfires and other disturbances as well as invasive species are explicitly mentioned. Both strategies have links to all four major risks.
- The common agricultural policy, including the new 'green architecture', supports farmers, among others, to protect natural resources, to enhance the variety of species and habitats, and thus to secure a number of ecosystem services, including farmland biodiversity. It addresses all major risks except that on wildfires (major risk 3).
- The *EU soil strategy for 2030* (2021) and the proposed *Soil Monitoring Law* (2023) recognise the importance of healthy soils for climate mitigation and adaption and for limiting land degradation, with their sponge-like function to absorb water and reduce the risk of flooding and drought. Soils are also important for biodiversity, as they host more than 25% of all biodiversity on the planet. The soil strategy's objectives are to have, by 2050, all EU soil ecosystems in healthy condition and more resilient, contributing among others to reversing biodiversity loss. Major risk 4 on healthy soils is explicitly mentioned; other major risks are referenced.
- The *Water Framework Directive* (WFD) and *Floods Directive* (FD) are important EU water-related policies. The WFD focuses on ensuring good quality and sufficient quantity of water in all rivers, lakes, groundwater, etc. across Europe to support human needs and aquatic biodiversity. The FD aims to reduce flood risks. Furthermore, when acting under the FD, Member States should seek common synergies and benefits with regard to the environmental objectives of the WFD. These directives mainly address major risk 1.
- In addition, some new water regulations entered into force in June 2023, which will help address water use, especially in the agricultural sector. It is expected this will relieve some of the current climate pressures on freshwater and groundwater. This will have an effect on water availability, relevant for major risks 1 and 3.
- *Invasive Alien Species* (IAS) *Regulation* (2014). Invasive species are a threat for biodiversity in Europe. The IAS Regulation's objective is to prevent and minimise the effects of invasive alien species on Europe's biodiversity. It includes a set of measures to be taken across Member States in relation to IAS. The core of the regulation is the list of invasive alien species of Union concern (Union List), which is frequently updated. Species on this list are subject to restrictions and measures set out in the regulation. The IAS Regulation mainly addresses major risk 2.
- The *Plant Health Regulation* (2016/2031) includes measures to be taken across Member States in relation to plant health, focusing on prevention and early detection of pests. The regulation mainly addresses major risk 2.
- The EU adaptation strategy identified multiple knowledge gaps related to the vulnerability of ecosystems, habitats and species to climate change. Several of these gaps are related to all four major risks. However, more work is still needed to fill the knowledge gaps identified.
- The *EU adaptation strategy* also includes an action to integrate adaptation in the update of Natura 2000 (action 27). An update of the EC guidelines on Natura 2000 and climate change was expected to be launched by the end of 2023 (relevant for all major risks).

# 4 Marine and coastal ecosystems

## 4.1 Key messages

- Key climate risks related to marine and coastal ecosystems are coastal erosion and inundations; the decline of pelagic primary production; changes to marine ecosystems' functioning and species distribution; and the emergence of algal blooms harmful to human health.
- All of Europe's seas are already strongly affected by climate change and other anthropogenic pressures. Additional warming, deoxygenation and acidification will increase the severity of risk to marine and coastal ecosystems even more in the future. The Arctic Ocean is particularly vulnerable due to unprecedented warming.
- Risks to marine and coastal ecosystems can cascade to water and food security, coastal infrastructures and human health, with clear repercussions on the blue economy.
- Policy priorities are better enforcing existing policies; and implementing integrated long-term observation and early warning systems.

## 4.2 Introduction

Marine and coastal ecosystems sustain life on this planet by controlling flows of energy and materials, producing at least half the world's photosynthetic oxygen, recycling biogeochemical elements and regulating the climate system (IPCC, 2021b).

Europe's seas cover more than 11 million km$^2$, ranging from shallow to deep ocean. They contain a wide range of coastal and marine ecosystems. These seas play a pivotal role for European countries, hosting more than 40% of the EU population in coastal areas and supporting the EU's blue economy. In lien with globally-observed trends, Europe's seas are experiencing drastic changes due to climate change. These include sea warming, sea level rise, acidification, deoxygenation, changes in nutrient availability, wind stresses, increasing extreme events (e.g. marine heatwaves and Mediterranean hurricanes), changes in surface waves and the mixing layer, and sea ice melting (IPCC, 2022b).

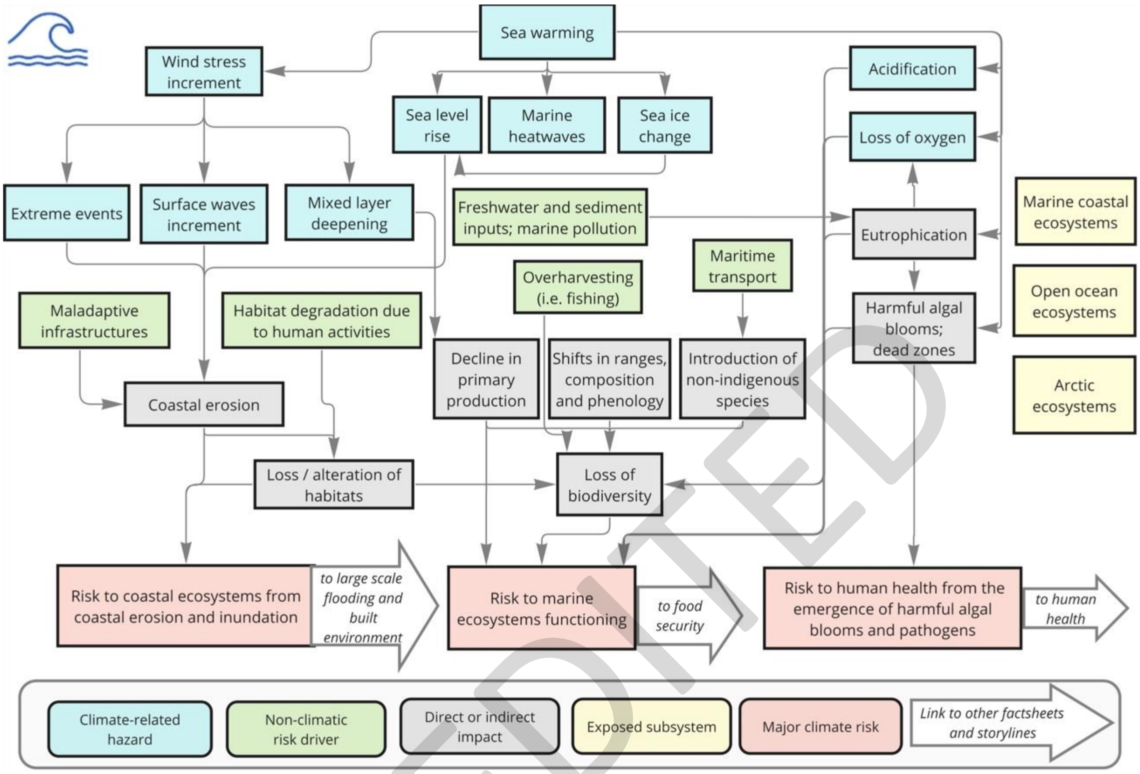
Beside the threats of ongoing climatic impact drivers, marine ecosystems are already significantly affected by non-climatic impact drivers. The cumulative effects undermine their resilience and capacity to provide ecosystem services essential for human life (EEA, 2019f; Rounsevell et al., 2018). The interaction of multiple stressors on organisms and ecosystems, and the varying vulnerability of different species to environmental change, requires an understanding of how key drivers will, individually and collectively, impact ecosystem composition, structure and functioning from global to local scales (Mangano et al., 2020).

This factsheet explains the impact chains of marine coastal, open ocean and polar marine habitats and ecosystems. The subsystems analysed below sometimes overlap with Chapters 3, 5, 6, 7, 9, 10 and 12.

## 4.3 Risk drivers and impacts

### *4.3.1 Impact chain*

**Figure 4.1 Impact chain of marine and coastal ecosystems**




**Source:** ETC-CA, 2024.



This factsheet splits marine and coastal ecosystems broadly into marine coastal ecosystems (compromising the littoral and sublittoral zones) and open ocean ecosystems. Arctic ecosystems, comprising both coastal and open ocean ecosystems, are considered separately due to the very different climatic and ecological conditions in this region. Coastal systems on land, including settlements and infrastructure, are addressed in other chapters, including the storyline 'large-scale flooding'.

### *4.3.2 Subsystem: marine coastal ecosystems*

**What drives the impact**

- Sea warming causes heat stress for marine organisms, thus affecting their life cycles, physiological rates, phenology and distributions. This has cascading effects on ecosystems' functioning. Warmer seawater could also affect the uptake of pollutants in marine organisms, potentially altering species' mortality rates (Sartori et al., 2023; Dinh et al., 2022; Pack et al., 2014);
- Sea warming triggers increased ocean stratification and altered patterns of ocean circulation. This modulates coastal dynamics, winds, precipitations, freshwater inputs and the occurrence of marine heatwaves (von Schuckmann et al., 2022);
- Sea level rise, compounded by extreme weather and storm surge events, waves, rainfall, river run-off and maladaptive infrastructures, is increasing coastal flooding. This entails direct physical impacts on the coast: exacerbating coastal erosion, influencing sediment

dynamics and terrestrial run-off, and damaging the integrity and health of marine coastal ecosystems and their services;

- Increasing acidification significantly changes ocean carbonate chemistry, affecting benthic processes, communities and ecosystems. It can cause detrimental impacts on calcifying organisms in particular, limiting their growth and survival (Hassoun et al., 2022);
- Deoxygenation results from ocean warming, increased stratification and eutrophication, leading to increasing harmful algal blooms and pathogens. The results are anoxic 'dead zones', particularly in inland seas with limited water exchange, exacerbating acidification effects. Climate change will also lead to changes in biogeochemical cycles and nutrient availability (IPCC, 2022b);
- Freshwater and sediment inputs, habitat degradation due to human activities, overfishing, the introduction of non-indigenous species (through maritime transport) and marine pollution (including marine litter, underwater noise, contaminants) are the main, non-climatic impact drivers. In combination with climatic impact drivers, their negative impacts on coastal marine ecosystems are amplified.

**Current situation**

- Marine heatwaves have approximately doubled in frequency, becoming more intense and longer, since 1982 (Holbrook et al., 2019). This has caused mass mortality events of marine organisms across all of Europe's seas (IPCC, 2021b; Garrabou et al., 2022). The Mass Mortality Events database collected 676 such events within the Mediterranean Sea from 1979 to 2017, encompassing 93 species from nine major taxonomic groups (Garrabou et al., 2019);
- Around Europe, sea level has risen by an average of 2-4 mm/year over the past 30 years (EEA, 2024a);
- Seagrasses show a loss of one third of their covered area from 1869 to 2016 (de Los Santos et al., 2019). *Posidonia oceanica,* an endemic plant of the Mediterranean Sea included among the priority habitats of the Habitats Directive (92/43/CEE), provides a wide range of services. This includes fish nurseries, wave mitigation, carbon storage, oxygen production and improving ecosystem resilience. It has lost between 13% and 50% of its areal extent since 1960 (MedECC, 2020a). Canopy-forming macroalgae are also experiencing a severe decline (Smale, 2020);
- Rocky shore habitats are at high risk of decline due to the compound effects of warming, acidification and hypoxia, which affect marine bioconstructions significantly;
- *Paramuricea clavata* decreased by up to 47% in five years in the Adriatic Sea (2014-2019), while up to 96% of the living corals showed signs of stress (Chimienti et al., 2021);
- Fish populations are experiencing changes in stock abundances, poleward shifts and changes in seasonal timing peaks due to sea warming;
- An ongoing tropicalisation and a meridionalisation of the Mediterranean marine fauna have also been registered due to sea warming (Boero et al., 2008);
- Sea level rise is leading to saltwater intrusion in estuaries, altering estuarine tidal range and circulation patterns as well as sediment transport regimes (Kimball et al., 2020). Consequent salinisation of freshwaters and coastal aquifers largely impacts drinking water production and agriculture;
- Sandy beaches and dunes are strongly affected by erosion, with 27-40% of Europe's sandy coast currently eroding (IPCC, 2022b);

- Deoxygenation impacts, including changes in food webs and fish populations, have been observed in semi-enclosed seas, above all in the Baltic and Black Seas. Harmful algal blooms have increased since 1980 in coastal areas in response to eutrophication with the co-occurrence of climate change, with negative impacts on food, tourism, the economy and human health (EEA, 2024b; IPCC, 2022b);
- Multiple pressures arise from maritime traffic, fishing activities, pollution, the spread of invasive species and the emerging sectors of offshore renewable energy and blue biotechnology (EEA, 2019h; European Commission, Directorate General for Maritime Affairs and Fisheries and European Commission, Joint Research Centre, 2019).

**Future situation**

- Marine heatwaves will further increase in frequency, magnitude and duration around Europe throughout the 21st century **(Oliver et al., 2018; MedECC, 2020a)**;
- Relative sea level rise is extremely likely to continue for Europe's seas, ranging from 0.4-0.5 m under the SSP1-2.6 scenario to 0.7-0.8 m under the SSP5-8.5 scenario for 2081-2100 (Ranasinghe et al., 2021a);
- Approximately 3,000-3,500 km$^2$ of the European coastal zone could erode by 2050. Erosion is projected to reach 5,000-7,200 km$^2$ by 2100 under the RCP4.5 and RCP8.5 scenarios, causing the decline of several valuable habitats and the loss of the ecosystem services they provide (4.2% under RCP4.5 and 5.1% under RCP8.5 of the habitats) (Paprotny et al., 2021);
- Under the RCP2.6 and RCP8.5 scenarios, 70-75% of the *Posidonia oceanica* habitat may be lost by 2050. It is expected to disappear completely by 2100 under RCP8.5 (Chefaoui et al., 2018);
- Ocean acidification is projected to affect vulnerable calcifying organisms, limiting their growth and reproduction success. Calcareous algae are the basic builders of coralligenous outcrops; they are expected to experience reduced skeletal functionality in the mid- to long term, with negative consequences for habitat formation (IPCC, 2022b);
- Rocky shores will be strongly affected by the impacts of sea level rise in terms of loss of biodiversity, and alteration of community structure and ecosystem functions (Rilov et al., 2021). Many shorelines are predicted to suffer from coastal squeeze (i.e. due to the presence of artificial structures), which reduces the intertidal zone and prevents species from retreating landward (Pörtner et al., 2022b);
- Sea level rise projections and changes in tidal dynamics could lead to a transition from a tidal-flat-dominated system toward a lagoon-like system in the Wadden Sea (Becherer et al., 2018; Wachler et al., 2020);
- Projected warming, sea level rise and tidal changes will continue to expand salinisation and hypoxia in estuaries, with more pronounced impacts under higher emission scenarios (Pörtner et al., 2022b);
- Estimated annual economic damage due to coastal flooding may rise to EUR 137 billion and EUR 814 billion by 2100 under low and high emissions scenarios, respectively (EC and JRC, 2023);
- Data on dynamics and projections of harmful algal blooms, as well as on their socio-economic effects, are still limited and fragmented at the European level (JRC, 2016a).

### *4.3.3 Subsystem: open ocean ecosystems*

**What drives the impact**

- Oceans have been warming for decades due to increases in greenhouse gases in the atmosphere. They store massive amounts of heat energy. Changes in the air-sea fluxes modify winds and ocean currents, impacting the large-scale atmospheric and oceanic circulations;
- Trends in near-surface wind speeds over the North Atlantic and Europe show that wind speeds are more extreme in all months in southern Europe than in northern Europe (Laurila et al., 2021);
- Mean significant wave height has increased since the 1950s over the North Atlantic north of 45°N, with typical winter season trends of up to 20 cm per decade (Rhein et al., 2013). The warming trend has also increased the frequency and intensity of marine heatwaves which have devastating impacts on marine life (Laufkötter et al., 2020; Holbrook et al., 2019);
- Warmer upper ocean waters drive stronger hurricanes and storms, including the increased frequency of Mediterranean hurricanes (Flaounas et al., 2022);
- Ocean warming is also observed from 4,000 to 6,000 m (IPCC, 2022b), meaning that deep-ocean species could be exposed to its effects as well (Brito-Morales et al., 2020);
- Increased upper ocean stratification and deepening of the mixed layer affect the surface water light regime and nutrient input from the deeper layer, thus reducing phytoplankton growth and productivity (Xiu et al., 2018);
- Acidification, amplified by sea warming, is a major climatic hazard for marine organisms. Global ocean surface pH is 0.1 pH units lower than in pre-industrial times, corresponding to a 30% increase in ocean acidification (C3S, 2023c). It is also impacting deep waters due to the transport of anthropogenic $CO_2$ to depth by ocean currents and mixing (IPCC, 2022b). Altering carbonate chemistry in the deep ocean makes the saturation horizon depth for aragonite and calcite shallower;
- A loss of 2% of dissolved oxygen has taken place since the 1950s. A further reduction of 1-7% is expected by 2100, with detrimental consequences for ecosystems, people and economies (Baillie et al., 2004).



**Current situation**

- Between 1991 and 2022, Europe's seas experienced a sea surface temperature increase of 0.22°C per decade (EEA, 2023f);
- Marine ecosystems in open oceans have declined considerably in terms of species diversity due to the increased mortality of sensitive species and lower food web complexity (EEA, 2019f). Seabirds, marine mammals, fishes and turtles have also declined in abundance (Rounsevell et al., 2018);
- Northward expansion of more than 140 km per decade has been registered on average in the North-East Atlantic Ocean (Poloczanska et al., 2013), especially for pelagic fish communities. Also, the seasonality of some species and the ratio of warm to cold water species has increased in the North-East Atlantic Ocean, and is correlated with sea surface temperature (EEA, 2022g);
- Phytoplankton biomass and productivity in the oceans have showed variable trends in low and mid-latitudes, but globally will decline during the next century due to the deepening of the mixed layer, with consequences for marine food webs;

- Carbonate ion transport towards the deep ocean is about 44% lower than in pre-industrial times, which could severely endanger deep cold-water corals of the Atlantic waters (Perez et al., 2018). In the Mediterranean Sea, the biocalcification process in cold-water corals due to changes in the saturation conditions of aragonite and calcite has decreased drastically by 50%. This is a direct consequence of acidification (Maier et al., 2012);
- Due to its peculiar biogeochemical and physical processes, the Mediterranean Sea is one of the seas most impacted by acidification, displaying a wider range of acidification rates (-0.001 to -0.009 pH units per year) compared to global and Atlantic trends (-0.001 to -0.0026 pH units per year) (Hassoun et al., 2022);
- Overfishing poses a threat to marine ecosystems across Europe. In the North-East Atlantic Ocean, stock status has improved since 2003, with a decrease of overexploited stocks from 74% in 2003-2008 to 26% in 2021 (Gras et al., 2023). In the Mediterranean and Black Seas, the percentage of overexploited stocks decreased from 73% in 2020 to 58% in 2021 (FAO, 2023a). In the Baltic Sea, only four out of 15 commercial stocks had good status on average during 2016-2021 (HELCOM, 2023).

**Future situation**

- Impacts on European open ocean systems are very likely to intensify in response to projected further warming. By 2100, sea surface temperature under the SSP1-2.6 and SSP5-8.5 scenarios will rise between 1°C and 3.5°C in the Mediterranean and Black Seas, and 1.0°C and 2.4°C in the North-East Atlantic Ocean and the Baltic Sea, respectively;
- By 2100, marine primary production is projected to decrease by 0.3% at a 1.5°C global warming level and by 2.7% at 4°C warming (IPCC, 2022b). This is expected to reduce fisheries harvests in low latitudes and alter species distribution at high latitudes (IPCC, 2022b);
- Seawater acidity could increase by 0.4 pH units by 2100 (IPCC, 2022b). Increased stratification and reduced primary production will amplify acidification risks. This will have cascading effects on marine biota and above all on marine calcifying organisms, including deep-water corals;
- The increase of offshore wind farm installations, promoted by the EU's ambition to be carbon neutral by 2050, might severely impact marine fauna, bottom impacts and locally dynamics variations. On the other hand, there are positive environmental impacts, such as the reserve and reef effects of the deployment area (due to reduced fishing) and of the mooring structures (Iza et al., 2022).



### *4.3.4 Subsystem: Arctic marine ecosystems*

**What drives the impact**

- Arctic temperatures are rising more rapidly than the global annual average, driving snow and ice melting, and shrinking polar ice sheet coverage. This contributes to the increase of sea level rise and freshwater intake, influencing circulation patterns, exchange rates and nutrient supply, with direct impacts on marine primary production and on higher trophic levels (IPCC, 2022b). Between 1972 and 2021, the Greenland ice sheet lost a total of 5,362 ± 527 gigatonnes of ice, contributing 14.9 ± 1.5 mm to global average sea level rise (C3S, 2023a);
- More intense and frequent extreme events are occurring than in the past. This is associated with climate change and sea-ice loss (Overland, 2022);

- Acidification is more pronounced than in other oceans due to gases' increased solubility at lower seawater temperatures;
- Human exploitation has intensified due to increased accessibility. Ship traffic grew by 25% during 2013-2019, exposing polar systems to increasing risks from oil spills. This has repercussions for biodiversity, fisheries, and local foods and livelihoods for indigenous Arctic communities (Melia et al., 2016);
- Additional non-climatic impact drivers are land-sea and long-range atmospheric and oceanic pollution; riverine nutrient inputs and erosion; commercial fisheries and emissions from resource exploitation, including mining, minerals, oil and gas extraction.

**Current situation**

- Arctic sea ice area in 2010-2019 decreased by 2 million km$^2$ in summer, compared with 1979-1988 data;
- Increased growth rates at higher temperatures and sea ice decline have resulted in primary production increasing by 40-60%, with cascading effects on polar food web structure and function, biodiversity and fisheries (IPCC, 2022b). This results in additional benefits for fisheries in the Atlantic-Arctic subregion;
- Sea warming, sea ice retreat and decreased salinity have led to range contractions (i.e. when the distribution of a species becomes more limited over time) of Arctic marine and ice-associated species, due to northward shifts of temperate pelagic and benthic species. This provides new opportunities for invasive species (IPCC, 2022b);
- Acidification is affecting polar marine species. This reduces the survival capabilities of sensitive species and early stages of zooplankton and larval fishes, and decreases the calcification rates of some shell-forming organisms;
- Behavioural, physiological and distributional changes are observed in marine mammals and birds in response to altered ecological interactions and habitat degradation (Rounsevell et al., 2018).

**Future situation**

- The Arctic Ocean is predicted to become free of sea ice (i.e. less than 1 million km$^2$ coverage) during the seasonal sea ice minimum (summer) before 2050 (IPCC, 2022b);
- Higher light availability and changes in deep mixing are projected to expand primary productivity. By 2100, this will lead to an increase in phytoplankton biomass of almost 20% for the SSP1-2.6 scenario and 30-40% for the SSP5-8.5 scenario. Phytoplankton richness will also increase by up to 30% (Henson et al., 2021). These changes will have consequences for the potential fisheries catches;
- Surface pH will decrease by 0.1-0.6 units by 2100 (IPCC, 2022b). Polar organisms' sensitivity to acidification may grow with increasing light levels due to the loss of sea ice and temperature stress, or increased heterotrophic bacterial productivity;
- Mid-term projections indicate virtually no shoreline retreat under the RCP4.5 scenario; under RCP8.5, a retreat of around 40 m is expected.

## 4.4 Risk assessment and evaluation

### *4.4.1 Confidence*

Since the level of confidence is a function of the timeframe used, forecast uncertainty increases with longer future horizons, also due to the complexity of marine ecosystems and their ecological dynamics. Overall understanding of the risks to marine ecosystems in Europe due to climate change is well established and widely accepted, and the confidence is mostly high. However, it is still low on future risks associated with harmful algal blooms and their socio-economic effects.

Knowledge gaps also exist on ecological responses to multiple, interacting drivers and their cascading effects.

### 4.4.2 Adaptation opportunities, constraints and limits

Despite the increasing efforts to adapt to climate change, the rate of change is high. This challenges the ability of human and natural systems to adapt quickly enough to avoid negative impacts.

Marine Protected Areas (MPAs) have been identified as good adaptation options, enhancing the resilience of marine ecosystems to climate change and reducing the effects of anthropogenic pressures. The extension of MPAs promoted by the EU biodiversity strategy for 2030 is also fundamental to decrease fragmentation and enhance ecological connectivity. Moreover, broadening the MPA network while considering future climate scenarios is key for future biodiversity protection. Despite MPAs increasing in Europe, many suffer from the lack of management plans and limited resources (EEA, 2015; Claudet et al., 2020).

Adaptation actions to reduce the vulnerability of coastal areas to sea level rise include Venice's MOSE system, the UK's Thames Estuary, the Netherlands' Delta Programme and the flood proofing of the HafenCity area in Hamburg. However, there is limited information on sea level rise planning and policies for most countries in Europe. Also, adaptation capacity to counteract coastal flooding impacts is still based on more traditional water management approaches across Europe (IPCC, 2022b).

In recent decades, nature-based solutions (NBS) have been adopted as new, sustainable approaches to preserve or restore the functionality of natural/damaged ecosystems. NBS enhance nature to provide environmental, social and economic benefits, which in turn contribute to strengthening the European climate strategy (EEA, 2021f). The restoration of coastal habitats (e.g. seagrasses, wetlands, saltmarshes and coral reefs) reduces the risks of climate change, such as sea level rise, storm surges and coastal erosion, and acts as a natural defence against shoreline erosion and flooding (EEA, 2021f).

The main priorities to advance marine NBS are to improve knowledge on marine ecosystem services in order to explore new ecological solutions for mitigating climate change; provide scientific guidance for designing NBS; and increase communication to raise awareness of NBS and co-create solutions with stakeholders.

Uncertainties around future climate change often lead to maladaptive actions being adopted. These can include the intensive use of non-renewable resources; engineered coastal defences that do not consider wider impacts nor long-term risks (as mentioned above, to counteract coastal flooding); and actions that ignore local traditions and cultures. In this context, implementing integrated long-term observing systems — including cost-effective technologies, modelling (downscaled for coastal processes), citizen science and early warning systems — is fundamental to support an informed decision-making process.

### 4.4.3 Overall assessment

This section presents the outcomes of the structured risk assessment for the major climate risks identified in this factsheet. This assessment builds on information in this factsheet, and possibly in other chapters of this report. The initial risk assessment was conducted by the authors of this factsheet whereas the final assessment results reported here represent the consensus of the EUCRA risk review panel. Further methodological information is available in Annex 2.

### Table 4.1 Risk assessment for threats to coastal ecosystems from coastal erosion and inundation caused by climate change in combination with other anthropogenic drivers

| | Current/near term (2021-2040) | Mid-term (2041-2060) | Long-term (2081-2100)<br>• high warming<br>• low warming |
|---|---|---|---|
| Risk severity | Critical | Critical | Catastrophic<br>Critical |
| Confidence | High | High | High |
| Risk ownership | Co-owned<br>The EU and Member States both have legislative responsibilities relating to coastal ecosystems, especially regarding the environment and infrastructure.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Marine Strategy Framework Directive (2008/56)<br>• Maritime Spatial Planning Directive (2014/89)<br>• Floods Directive (2007/60)<br>• EU biodiversity strategy for 2030 (2020/380)<br>• Birds Directive (2009/147) and Habitats Directive (92/43)<br>• Water Framework Directive (2000/60)<br>• Birds Directive (2009/147) and Habitats Directive (92/43)<br>• Action plan on protecting and restoring marine ecosystems<br>• EU principles on integrated coastal zone management<br><br>At the national level, the main relevant policies include those relating to:<br>• Spatial planning and infrastructure<br>• The environment<br>• Industry (e.g. fisheries and aquaculture)<br>• Tourism<br>• National adaptation funding | | |
| Policy readiness | *Medium*<br>• Sea level rise is not consistently considered in coastal ecosystem management in Europe. | | |
| Policy horizon | Medium term | | |
| Urgency to act | *Urgent action needed*<br>• Reduction of anthropogenic pressures to allow the recovery of marine habitats which provide natural barriers on the coasts;<br>• Expansion and adaptation of the MPA network to cope with future climate scenarios;<br>• Ensure a proper, well-managed MPA network designed not only to protect vulnerable species and habitats, but also to protect the structure and functions of ecosystems/habitats;<br>• Implement integrated long-term observing systems, including cost-effective technologies, modelling (downscaled for coastal processes), citizen science and early warning systems. | | |

**Source**: EEA.

### Table 4.2 Risk assessment for threats to marine ecosystems from climate change in combination with other anthropogenic drivers

| | Current/near term (2021-2040) | Mid-term (2041-2060) | Long-term (2081-2100)<br>• high warming<br>• low warming |
|---|---|---|---|
| Risk severity | Critical | Critical | Catastrophic<br>Critical |
| Confidence | High | High | Medium |
| Risk ownership | EU<br>From a legal perspective, this risk addresses both the exclusive competence of the EU (relating to the conservation of marine biological resources under the common fisheries policy, CFP) and shared | | |

| | |
|---|---|
| | competences. Owing to the cross-border nature of the risk and the affected systems, the EU is best positioned to implement relevant adaptation measures through its CFP, in line with EU competences and the principle of subsidiarity. Therefore, this risk is classified here as 'EU'.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Marine Strategy Framework Directive (2008/56)<br>• Maritime Spatial Planning Directive (2014/89)<br>• Common fisheries policy (2023/103)<br>• EU biodiversity strategy for 2030 (2020/380)<br>• Action plan on protecting and restoring marine ecosystems<br>• Birds Directive (2009/147) and Habitats Directive (92/43)<br>• Proposed revisions of the Urban Wastewater Treatment Directive (98/15)<br>• EU principles on integrated coastal zone management<br>• Proposed Regulation on EU Carbon Removal Certification<br>• Floods Directive (2007/60)<br><br>At the national level, Member States are responsible for implementing the policies and actions outlined in these directives, covering policy areas such as:<br>• Fisheries<br>• The environment (e.g. national marine strategies)<br>• Tourism<br>• National adaptation funding |
| **Policy readiness** | ***Medium***<br>• To halt the loss of biodiversity, the EU's biodiversity strategy for 2030 has been adopted — a long-term plan with the target of protecting 30% of the EU's seas by 2030;<br>• The European Green Deal tracks the roadmap towards a carbon-neutral economy by 2050, in line with the objectives of the Paris Agreement. |
| **Policy horizon** | **Medium term** |
| **Urgency to act** | ***Urgent action needed***<br>• Ensure that marine ecosystems are as healthy as possible through MPAs and by reducing human impacts (e.g. pollution, habitat destruction, overfishing);<br>• Enhance adaptation and mitigation capacity against climate change impacts through nature-based solutions;<br>• Fill the lack of data to reduce the uncertainty of climate projections through the implementation of integrated observing systems. |

**Source**: EEA.



### Table 4.3 Risk assessment for threats to human health from the emergence of harmful algal blooms and pathogens

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long-term (2081-2100)**<br>• **high warming**<br>• **low warming** |
|---|---|---|---|
| **Risk severity** | Substantial | Substantial | Critical<br>Substantial |
| **Confidence** | Low | Low | Low |
| **Risk ownership** | **Co-owned**<br>The EU and Member States both have legislative responsibilities relating to marine and coastal ecosystems, as well as public health.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• EU4Health<br>• Health emergency preparedness and response<br>• Marine Strategy Framework Directive (2008/56)<br>• Water Framework Directive (2000/60)<br>• Proposed revisions of the Urban Wastewater Treatment Directive (98/15) | | |

| | |
|---|---|
| | • EU biodiversity strategy for 2030 (2020/380)<br>• Birds Directive (2009/147) and Habitats Directive (92/43)<br><br>At the national level, the main policies of relevance include those relating to:<br>• The environment (e.g. monitoring nutrients and harmful algal blooms)<br>• Public health |
| **Policy readiness** | ***Medium***<br>• Need to implement specific knowledge-based adaptation capacity;<br>• Need to implement prevention measures centred on ecosystems, including on land and in agriculture/farming, wastewater and other impactful land activities. |
| **Policy horizon** | ***Medium term*** |
| **Urgency to act** | ***Further investigation***<br>• Need to deepen understanding of the dynamics of harmful algal blooms in a climate change context and their socio-economic effects. |

**Source**: EEA.

## 4.5 Relevant policies

Habitats Directive (92/43/EEC): adopted in 1992, this requires all Member States to protect, maintain or restore natural habitats and species to favourable conservation status;
Water Framework Directive (2000/60/EC): the framework law for water protection in Europe, applied to inland, transitional and coastal surface waters as well as groundwaters. It requires Member States to achieve good status in all bodies by 2027;
Marine Strategy Framework Directive (2008/56/EC): the reference framework for community action in the field of marine environmental policy. It requires Member States to ensure that their marine waters achieve 'good' environmental status. Its implementation is further specified in Commission Decision (EU) 2017/848 of 17 May 2017, laying down criteria and methodological standards on good environmental status of marine waters, and specifications and standardised methods for monitoring and assessment;
Maritime Spatial Planning Directive (2014/89/EU). This promotes the sustainable development of human activities and use of marine resources through an ecosystem-based approach;
Floods Directive (2007/60/EC). This is relevant for flood prevention along the marine coast and in estuaries. EU countries are required to create and update flood hazard maps and flood risk maps;
Common fisheries policy (CFP). This drives EU legislation to preserve fish stocks, protect the marine environment and ensure sustainable exploitation of living resources. The fisheries package adopted in February 2023 lays down the next steps in developing the CFP;
Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention, 1992). This aims to prevent and eliminate marine pollution and, therefore, protect the North-East Atlantic maritime area from the adverse effects of human activities;
Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention, 1974). This is a set of guiding principles and obligations on the protection of the marine environment of the Baltic Sea;
Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention, 1976). This promotes cooperation among Mediterranean countries to protect the marine environment and coastal areas in the region;
Convention on the Protection of the Black Sea against Pollution (Bucharest Convention, 1992). This aims to protect the marine environment and coastal areas of the Black Sea region from pollution and other environmental hazards;

EU strategy on adaptation to climate change (COM (2021) 82): this provides a framework to prepare the EU for the impacts of climate change, updating the earlier strategy from 2013. It contains several actions that are specifically relevant for dealing with climate change impacts in coastal and marine areas;
EU biodiversity strategy for 2030 (COM (2020)380 final). This aims to halt the loss of biodiversity through a long-term plan, with the target of protecting 30% of the EU's seas by 2030;
EU Nature Restoration Law (formal adoption expected in early 2024). This is a proposed directive for the recovery of Europe's natural habitats which sets specific, legally-binding targets and obligations for the restoration of ecosystems, including marine ecosystems;
Integrated coastal zone management. This is EU communication that promotes the sustainable management of coastal zones through a multidisciplinary approach, taking into account compatibility among the multiple uses of natural resources;
EU Mission 'Restore our Ocean and Waters'. This aims to protect and restore the health of Europe's seas and waters through research and innovation, citizen engagement and blue investments, addressing the ocean and waters as one;
EU action plan 'Protecting and restoring marine ecosystems for sustainable and resilient fisheries' (COM/2023/102 final). This this outlines various actions to reduce the impact of fisheries on sensitive species and the seabed;

# 5 Water security

## 5.1 Key messages

- Climate risks to water security include: low flow episodes threatening water quality and aquatic ecosystems; risk to water supply due to scarcity and insufficient quality; risks to agriculture due to temporary water shortages and increase in irrigation demand; risks to tourism from insufficient availability of snow in winter and water in summer; and risk of disrupted power supply due to decreased water reliability for energy production plants that depend on water.
- Risks to the availability of water for renewable energy sources can hamper climate change mitigation efforts.
- Current water scarcity and future risks are most severe in southern Europe. Climate change worsens existing vulnerabilities, particularly for marginalised communities.
- Transformative adaptation policies and actions in water management should be considered, particularly in southern Europe.
- Mainstreaming of water-related objectives into sectoral policies is crucial at the EU and national level, including agriculture, energy, industry, tourism, and transport, to avoid inconsistencies. Mainstreaming into regional policies and plans can be supported by targeted assessments addressing specific regional needs.

## 5.2 Introduction

Precipitation distribution across Europe varies widely, ranging from less than 400 mm/year in parts of the Mediterranean region and the central plains of Europe to more than 1,000 mm/year along the Atlantic shores, the Alps and their eastern extension. However, precipitation is lost due to evapotranspiration, and the remaining 'effective rainfall' is no greater than 250 mm/year across much of Europe, and lower than 50 mm/year in some parts of southern Europe. Over the 20th century, some seasonal changes have occurred, notably an increase in winter precipitation for most of western and central Europe and a decrease in southern and parts of central Europe. Climate models predict a general future increase in precipitation in northern Europe and a decrease in southern Europe (see Chapter 2).

In 2019, the largest contributors to annual water abstraction in the EU-27 were cooling in electricity generation (32%), agriculture (28%), public water supply (20%), manufacturing (13%) and related cooling (5%), with mining, quarrying and construction each accounting for only 1% of total abstraction (EEA, 2022n). From 2000 to 2019, EU-27 annual water abstraction decreased from about 215 billion $m^3$ to 202 billion $m^3$ (EEA, 2022n), partly due to policy measures under the Water Framework Directive. Cooling in electricity generation decreased by 27% from 2000 to 2019, but cooling in manufacturing almost tripled, and public water supply increased by 4% (which included an increase of 14% since 2010). Water abstraction for agriculture decreased between 2000 and 2019 but increased by 8% from 2010, mainly due to higher irrigation demands in southern Europe, which has the highest share (>50%) of water used for irrigation.

The relative share of groundwater in comparison with surface water in overall water abstraction has grown from 19% to 23%. For public water supply especially, groundwater is an important source (65%), while for agriculture, 25% of the water comes from groundwater. European surface waters and groundwaters, and their associated human and ecosystem uses, face multiple simultaneous climate drivers that affect quantity and quality (EEA, 2021a; Caretta et al., 2022a), as well as other systemic challenges. The latter include population growth, pollution, the need for new or upgraded infrastructure, integrated management and governance, and threats to ecosystem health. Climate drivers include reduced recharge, altered hydromorphology, diminished soil moisture and snow cover, pollution from extreme floods, rising air and water temperatures, and sea level rise (Grizzetti et al., 2017).

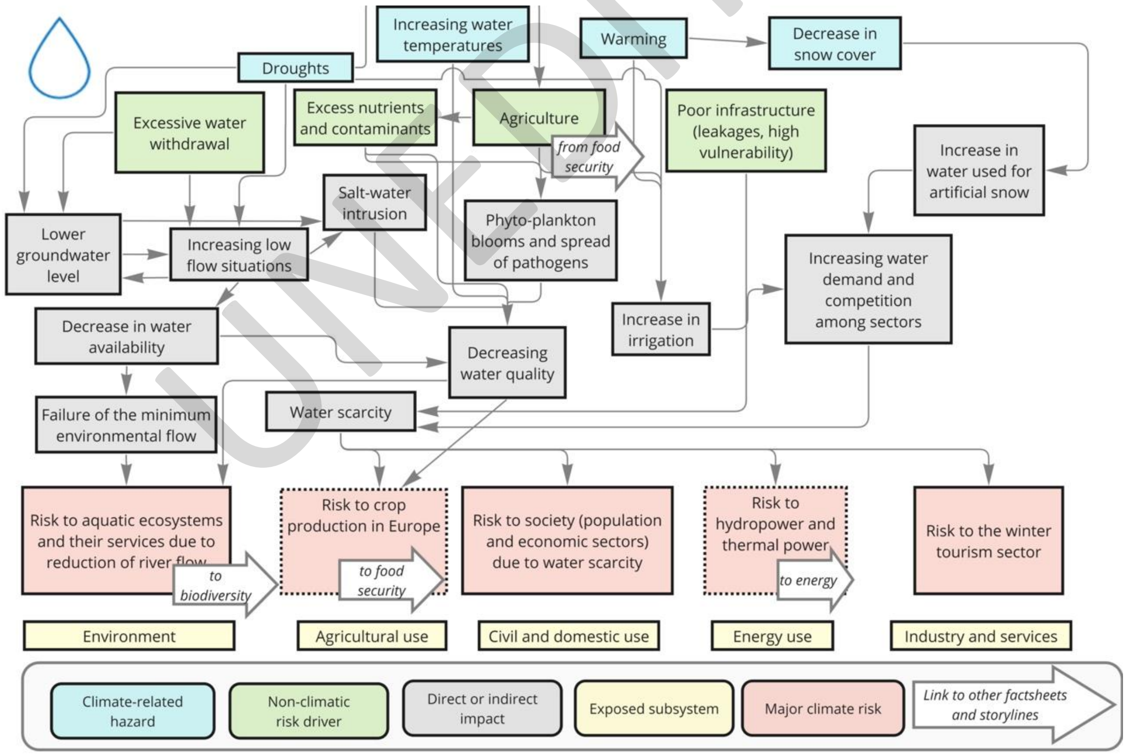
Water security can be defined as the capacity of a population to ensure sustainable access to adequate quantities of acceptable-quality water for various purposes, protection against water-borne pollution and disasters, and preserving ecosystems in a climate of peace and political stability (UN-Water, 2013; IPCC, 2022c). This definition involves multifaceted aspects (quantity vs quality; surface water vs groundwater) considered in this chapter in terms of various water-depending sectors (subsystems), ranging from ecosystems to domestic, agricultural, industrial, services, energy uses. This is why the issue of water security is covered by many EU policies, directives and strategies.

This factsheet focuses on the water scarcity side of water security, but some subsystems in Section 5.3 refer to additional aspects that have links with, and are better addressed in, other factsheets, like Chapters 3, 4, 6, 7, 8, 9 as well as the storylines Chapters 11 and 12.

## 5.3 Risk drivers and impacts

### *5.3.1 Impact chain*

**Figure 5.1 Impact chain for water security**




**Source:** ETC-CA, 2024.

### *5.3.2 Subsystem: environment*

**What drives the impact**

- Rivers and lakes are at the top of ecosystem services' value when considering euros per km$^2$ of ecosystem extent (EC, Statistical Office of the European Union, 2020).

- Environmental flows benefit ecosystems and humans. While preserving them is essential for water bodies' ecological quality and functions (Monico et al., 2022), this can reduce water availability for other uses (Vanham et al., 2022).
- Droughts disrupt the hydrological cycle, affecting soil moisture, groundwater levels, saltwater intrusion, water quality and river flows (EEA, 2021h).
- Excess nutrients or other pollutants from atmospheric deposition or direct contamination in water cause eutrophication, algal blooms, oxygen depletion and harm to environmental health and ecosystems (EEA, 2018a).
- Floods, resulting from a combination of extreme weather events and land management, pose risks to natural habitats and human assets.

**Current situation**

- Escalating groundwater pumping and declining recharge threaten groundwater levels, baseflow, and coastal saltwater intrusion (Bednar-Friedl et al., 2022c).
- One proxy of the minimum environmental flow is the 10th percentile of daily flow; this percentile increased in northern Europe but decreased in southern Europe and the Mediterranean from 1971-1980 to 2001-2010 (Gudmundsson et al., 2019), meaning that ecosystems in the south gradually had to adapt to lower water availability while those further north could rely on more water availability.
- Maximum values of daily flows, which are a proxy for quality issues in water bodies due to pollutants and/or sediments transport, increased in northern and central Europe but decreased in southern Europe and the Mediterranean from 1971 to 2010 (Gudmundsson et al., 2019).
- Water temperatures have risen by ca 1-3°C in major European lakes and rivers over the past century, threatening aquatic ecosystems (EEA, 2017b), 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.
- Changes in the annual cycle of precipitation and temperature will contribute to the intensification of sediment and nutrient wash-out, and lead to the more frequent occurrence of conditions favoring eutrophication (Szalińska et al., 2021; Wilk et al., 2022; Orlinska-Wozniak et al., 2021).
- In Europe, 10% of coastal waters have bad or poor ecological status, as do 12% of lakes, 19% of rivers and 23% of transitional waters (EEA, 2021b).

**Future situation**

- The Intergovernmental Panel on Climate Change (IPCC) and Joint Research Centre are key sources for future projections (Bednar-Friedl et al., 2022c; JRC, 2018).
- Increasing frequency and severity of low flows will lead to hydrological droughts and worsening water scarcity in southern and western-central Europe.
- Groundwater-related scarcity will expand to nearly all basins, threatening environmental flows and possibly resulting in saltwater intrusion.
- Rising sea levels and consequent seawater intrusion into estuaries will cause salinisation and water inlet closures during summers that are more water demanding.
- Accelerating river water warming, reaching 0.8°C and 1.2°C under global warming levels (GWLs) of 1.5°C and 3°C, respectively, relative to the period 1971-2000, aggravated by declining summer river flows.

### *5.3.3 Subsystem: agricultural use*

**What drives the impact**

- According to Eurostat, in 2016 almost 9% of the agricultural area utilised in the EU was irrigable but only about 6% was actually irrigated (Eurostat, 2019b). Agriculture accounts for around 24% (60 billion m3) of water abstraction across European countries, varying largely among them (EEA, 2021j).
- Rising temperatures increase evaporation and evapotranspiration and, combined with prolonged, more frequent and more severe droughts, impact rainfed and irrigated agriculture across the EU (Ceglar et al., 2019a).
- Unsustainable irrigation, often due to the choice of high water-demanding but profitable crops, leads to groundwater depletion, wetland and coastal habitat changes, soil salinisation and sea water intrusion (Berbel et al., 2015; Daliakopoulos et al., 2016a; Greggio et al., 2012; Zajac et al., 2022).
- Water quality issues in agriculture include nitrate pollution, biocides and pesticide residues, with low flows exacerbating the poor chemical status of freshwaters, affecting water bodies for about 38% and 18% for diffuse and point sources, respectively (EEA, 2018a). Aquifer pollution from agriculture occurs all over Europe, taking decades to recover (EEA, 2022i), and affecting uses in downstream areas.
- Erosion caused by heavy rainfall events combined with, for example, unsustainable land use, removal of vegetation, low carbon content and overgrazing, damages cultivations.
- Floods, despite being beneficial for agriculture when depositing fresh clays, might have negative impacts on agriculture and aquaculture, and alter the capacity of soil to retain and infiltrate water.
- Inappropriate agricultural practices, such as unmanaged drainage of agricultural areas, humus consumption and homogeneous (cleared) landscapes, limit the water-holding capacity of soil.



**Current situation**

- Irrigation sustains agricultural production in the Mediterranean and enhances yields in northern and central Europe (Zajac et al., 2022; Malek and Verburg, 2018); it has increased particularly in southern Europe, comprising up to 70% of total consumption (Wada et al., 2013; EEA, 2022j).
- Water consumption peaks during summer, especially over dry climate areas in southern Europe, leading to competition with domestic and touristic uses, mainly on coastal plains.
- Irrigation and other agricultural water uses negatively impact groundwater status in about 7% of the EU-27's groundwater body area (EEA, 2022i).
- In 2021, almost 10% and 6% of monitored surface water and groundwater sites, respectively, exceeded the threshold limit for pesticides (EEA, 2024c).
- Soil erosion affects 12 million hectares (Mha) of agricultural areas annually (Panagos et al., 2018).

**Future situation**

- Although rising temperatures will prolong the growing season, increasing variability in precipitation (and thus in intra-annual water reliability) will lead to substantial agricultural production losses in the coming decades, with different drivers across Europe – i.e. warm and dry conditions in the south and altered rainy seasons in the north. Losses could reach up to 10-25% for key crops like maize and wheat under low and moderate impact scenarios, even with CO2 fertilisation effects (Bezner Kerr et al., 2022b).

- Absolute yield losses are hard to estimate due to the uncertainty of existing models, in particular the uncertain role of CO2 fertilisation effects (Bednar-Friedl et al., 2022c; Donatelli et al., 2015).
- Without climate change adaptation and mitigation efforts, agricultural economic losses in the EU and UK are expected to exceed EUR 65 billion per year (Naumann et al., 2021).
- Increasing irrigation cannot compensate for losses caused by anticipated water scarcity, especially under a 3°C GWL (Bednar-Friedl et al., 2022c).
- Soil losses due to water-driven erosion linked to heavy rainfall events are projected to increase by 13-22.5% in the EU and UK's agricultural lands by 2050, with respect to the baseline average value of around 3 ton/ha per year, and total 553 million tonnes (Mt)/year (Panagos et al., 2021).

### *5.3.4 Subsystem: civil and domestic uses*

**What drives the impact**

- Rising temperatures and population growth impact domestic water demand (Wang et al., 2016; Bar et al., 2021); freshwater supply is further impacted by changing rainfall patterns and other climate impacts, including saltwater intrusion leading to aquifer salinisation (Jimenez Cisneros et al., 2014).
- Contaminants like nitrates, heavy metals, biocides, pesticide residues and pharmaceuticals impact public water supply services (EEA, 2021h), as do pollutants from atmospheric deposition and those directly discharged into rivers, such as per- and polyfluoroalkyl substances.
- Increased water temperature leads to phytoplankton blooms and the spread of pathogens, restricting the use of reservoirs for drinking water and recreation (EEA, 2017b). It also leads to the growth of bacteria.
- Drinking water for urban areas often originates from distant sources, with infrastructure issues leading to significant leakages (EurEau, 2017; ERM, 2013a).
- Drinking water supply, sanitation and wastewater systems – in particular small/local ones – are vulnerable to extreme events like flooding (Sinisi and Aertgeerts, 2011; Khan et al., 2015).
- Water treatment plants are not built for a potential influx of pathogens caused by climate change (see Chapter 14).

**Current situation**

- Recent trends show that water abstractions for public use have increased by over 20% in southern Europe since the early 1990s (EEA data).
- In the EU and UK, around 51.9 million people are at risk of water scarcity, with 3.3 million of these at risk of severe water scarcity (Bisselink et al., 2020).
- Competition for water is growing between domestic uses in cities and all other needs, particularly in western-central Europe (Wada, 2016) and southern Europe (Bednar-Friedl et al., 2022c). In southern Europe, this is due in particular to irrigation demand (Garrick et al., 2019a).
- Urban areas are becoming more vulnerable to water scarcity due to population growth, urbanisation, ageing infrastructure and changing water use (Caretta et al., 2022a).

- Extreme excesses of water have mainly negative impacts on European cities, damaging urban assets and infrastructure, as well as posing risks to health due to water quality issues (Caretta et al., 2022a).
- Groundwater serves as a crucial resource for domestic use, but surface water is still a significant source, leading to potential competition (EEA, 2021h, 2022i).
- Increasing water demand and low recharge rates worsen groundwater depletion and lower groundwater levels in southern Europe, especially during the summer tourist season, and in western-central Europe (Aeschbach-Hertig and Gleeson, 2012; Xanke and Liesch, 2022).

**Future situation**

- Altered streamflow will affect the inflow to urban reservoirs, worsening capacity challenges (Caretta et al., 2022a), especially in summer, or damaging supply systems, in the case of floods.
- At 1.5°C GWL, the number of people exposed to water scarcity (annual ratio of consumption vs demand) could increase by 14%, and those exposed to severe water scarcity by 2.4% (Bisselink et al., 2020).
- With a 1.5°C (2°C) GWL, southern Europe is expected to face more days of water stress (ratio of annual demand vs supply), affecting up to 18% (54%) of the population (Naumann et al., 2018; Byers et al., 2018). Moderate water scarcity at 2°C GWL could affect 16% of the population in western-central Europe (Byers et al., 2018; JRC, 2018).
- In a 4°C GWL scenario, western-central Europe is likely to face water scarcity, especially in summer and autumn; the situation will be worse in southern Europe due to more intensive water use (Bednar-Friedl et al., 2022c).
- Altered variability of inflow to urban storage reservoirs may exacerbate existing challenges to their capacity, such as sedimentation and poor water quality (Caretta et al., 2022a).

### *5.3.5 Subsystem: industry and services*

**What drives the impact**

- European industrial and service sectors contribute 85% to the EU-27+UK's gross value added (Eurostat, 2020) and are affected by flooding and drought (TEG, 2019).
- Floods impact industrial, service and transport infrastructure located in flood-prone areas and disrupt manufacturing and production services (e.g. energy, logistics).
- Droughts affect industries like pulp and paper, chemicals, semiconductor manufacturing and food and beverages, as well as activities such as tourism, shipping and waterways, and public water supply (Bednar-Friedl et al., 2022c; Naumann et al., 2021; Teotónio et al., 2020a).
- Water quality affects food systems through irrigation and processing (Linderhof et al., 2021).
- Banking and insurance are indirectly impacted via customers and financial markets (Bank of England, 2019).
- Impacts are exacerbated by high exposures and vulnerabilities, including pressure on services' delivery coming from urbanisation dynamics and ageing infrastructure (Dodman et al., 2022a).

**Current situation**

- Current damage in Europe is mainly caused by river floods and storms, with future concerns about droughts and water scarcity (Bednar-Friedl et al., 2022c).
- Urban areas in Europe house 74% of the population, and many cities show medium to high vulnerability to droughts and floods (UN DESA, 2018; Tapia et al., 2017a).
- Ageing and/or incorrectly sized combined (foul, surface) urban sewer systems reduce capacity to cope with pluvial floods, causing overburdening of drainage systems, with health and pollution impacts (EEA, 2020c; Kourtis and Tsihrintzis, 2021).
- The effects of droughts are exacerbated by increasing industrial water consumption, reaching 70-90% of overall consumption in some European countries (Wada et al., 2013).
- Decreased snow cover adversely affects tourism, as seen recently in some areas (Bednar-Friedl et al., 2022c; Masloumidis et al., 2023), and water abstraction for artificial snowmaking is altering the overall cycle.

**Future situation**

- Climatic conditions at 1.5-2°C GWL will favour summer tourism in northern Europe and parts of western-central Europe and EEU, but may have the opposite effect in southern Europe from June to August (Bednar-Friedl et al., 2022c).
- Rising sea levels may decrease European beaches' amenity due to coastal erosion and inundation risks.
- Flood damage will increase in coastal areas due to sea level rise and changing social and economic conditions.
- Snow tourism will be negatively affected by insufficient snow in winter through to spring (Bednar-Friedl et al., 2022c; Morin et al., 2021), with increased snowmaking needs. Summer tourism can also be affected through a combination of unsustainable energy demand and reduced hydropower production due to reduced streamflow.
- The probability of default for firms, across different sectors of activity, in regions most exposed to physical risks, may increase up to four times faster than that of an average firm by 2050 (European Central Bank, 2021).
- Future climate hazards will augment climate risks for many cities, especially beyond 3°C GWL (Bednar-Friedl et al., 2022c). Northern and western-central European cities may experience a high increase in pluvial and fluvial floods (EEA, 2020c), while southern European cities may face a high to very high increase in meteorological droughts.



### *5.3.6 Subsystem: energy*

**What drives the impact**

- The water-energy nexus manifests itself through changes in energy demand, with warming temperatures reducing heating demand while significantly increasing cooling demand, and also due to geopolitical, consumption and supply trends (EP, 2012; EEA, 2019b).
- Climate change can stimulate the transformation of energy needs towards decarbonisation and renewable sources (Eurostat, 2023g).
- Hydro- and geothermal electricity depend highly on water regime (i.e. the prevailing pattern of water flow over a given time) (IEA, 2021a; Eurostat, 2022): 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 decades.

- Extreme weather events, such as floods and heatwaves, can reduce electricity production and thus increase electricity prices. For example, high water temperature and evaporation reduces the cooling capacity of thermal power plants, while floods can damage power plants or transmission infrastructure, affecting electricity production.

**Current situation**

- Heating degree days decreased after 1980 and cooling degree days increased (Bednar-Friedl et al., 2022c).
- Europe's precipitation patterns are changing, with northern regions getting wetter and southern regions becoming drier (IEA, 2021b).
- Regional differences in run-off and discharge affect hydropower generation (Wasti et al., 2022).
- Climate extremes have impacted thermal plants' cooling systems (Bednar-Friedl et al., 2022c).
- Northern and central Europe experience both beneficial and adverse impacts on water-dependent energy systems, while southern Europe faces predominantly adverse impacts as availability of water to support hydropower production or cooling is less reliable (EEA, 2019b).

**Future situation**

- Energy demand is projected to increase, with peak load shifting from winter to summer (Bednar-Friedl et al., 2022c).
- The transition to renewables will increase water demand – for hydropower, cooling of geothermal plants and for hydrogen production (via electrolysis) on a large scale.
- Energy generation may increase in northern Europe, but in eastern Europe this is uncertain. Projections suggest reduced thermal power across Europe and reduced hydropower in western-central and southern Europe (Tobin et al., 2018).
- Loss of snow and glacial retreat in the Alps will limit hydropower generation during some seasons, especially spring (IEA, 2021b; Wasti et al., 2022).
- New hydropower projects may experience increased water losses from evaporation, due to warming, while also increasing the competition for water from multi-purpose reservoirs (IEA, 2021a).
- Without adaptation, direct economic losses to the European energy system could reach billions of euros per year by 2100, with larger indirect costs (EEA, 2019b).

## 5.4 Risk assessment and evaluation

### *5.4.1 Confidence*

Understanding of the water security risks in Europe due to climate change is well established and widely accepted.

Member States and the EU engage actively in climate adaptation efforts, developing strategies and policies for water security.

Confidence on current climate impacts on water is high and based on empirical evidence, observed events and climate-related challenges like altered precipitation patterns, heatwaves, droughts and floods.

Confidence on the future climate impacts needs to be supported by uncertainty analysis and ensemble evaluations.

Extensive scientific research, including innovative ways to integrate climate and hydrological models, contributes to a robust understanding and management of risks relating to water balance, demand and supply.
The IPCC's periodic assessments and special reports reinforce the understanding of water security risks in Europe.
Localised research conducted by Member States and regions has tailored analysis and reinforced knowledge on local features.
Several knowledge gaps and uncertainties require further investigation. These include:

- Localised impacts of climate change and slow-to-rapid onset extremes across European regions;
- Consequences of climate on water quality issues and thus on human health and aquatic ecosystems;
- Effects on groundwater resources, including changes in recharge rates and quality, are more uncertain and heterogeneous than effects on surface water;
- Vulnerability of key infrastructure like treatment plants, sewage systems and dams;
- Complex interactions between climate change, alterations in land use, population growth, and urbanisation and water security, including equity and justice issues;
- Enhancing cross-border cooperation and research to manage transboundary waters.

### *5.4.2 Adaptation opportunities, constraints and limits*

Traditional water management methods, which are static rather than adaptive and flexible, remain prevalent in Europe (Bubeck et al., 2017; Kreibich et al., 2015; Wiering et al., 2017), while transformative options such as land use changes, relocation, and restricting future development are still rarely considered in existing assessments.
Current adaptation measures focus on structural flood protection and water supply, aiming to preserve existing land use and development patterns. However, these measures are challenged by reinforcing path dependency, as flood defence and water supply – even where safe now – can lead to further development that requires additional protection and supply in a changing climate.
Water laws, policies and guidance documents increasingly address climate impacts and adaptation, but there are differences among European countries.
Research and development opportunities to formulate and test adaptation options arise from the current Horizon Europe programme's mission 'Restore our ocean and waters'.
Adaptation options are categorised into two main groups: excess water (floods) and water scarcity (consequence of drought).
Floods can be categorised into pluvial, river (fluvial), lake or coastal events and require different measures: avoidance, protection, accommodation, retreat and support.
Protection options include flood defence (grey), ecosystem- or nature-based solutions (green), and flood preparedness and early warning plans (soft).
Retreat (relocation, resettlement) is an effective but culturally and socially challenging option, and it is often poorly understood or accepted by communities.
Insurance provides support against flood damage, but it can have the drawback of diverting incentives for climate-proof construction.
Drought management distinguishes between supply and demand-side options. Supply-side options involve storage, diversion, transfer facilities, desalination and water re-use, which each have economic and ecological considerations, in particular paying attention to nature-based

solutions. Demand-side options include monitoring scarcity, controlling demand, regulating distribution, economic instruments, managing land cover, saving water, and efficiency solutions. Drought monitoring and early warning systems are feasible but their impact is limited on water use despite co-benefits across sectors and in terms of costs (Benítez-Sanz et al., 2023). The benefits in avoided damage were assessed as four to ten times higher (Veerkamp et al., 2021; Dottori et al., 2023; Feyen et al., 2020).

More comprehensive assessments of adaptation options and how they could be made flexible under various global warming levels and over the medium to long term, ensuring robustness under the inherent uncertainty, are lacking in the scientific literature.

The main adaptation barriers for droughts are cultural and technological, whereas economic, financial, governance-institutional-policy, human capacity, information and awareness, and physical barriers are limited (Benítez-Sanz et al., 2023).

### 5.4.3 Overall assessment

This section presents the outcomes of the structured risk assessment for the major climate risks identified in this factsheet. This assessment builds on information in this factsheet, and possibly in other chapters of this report. The initial risk assessment was conducted by the authors of this factsheet whereas the final assessment results reported here represent the consensus of the EUCRA risk review panel. Further methodological information is available in Annex 2.

The following major risks assessed in other chapters are also relevant for this factsheet, but they are not presented here to avoid duplication:

- Risk to rainfed and irrigated crop production in Europe from heat, drought and other adverse weather conditions (factsheet 'Food security').
- Risk of electricity disruption due to heat and drought impacts on energy production and peak demand (factsheet 'Energy security').



**Table 5.1 Risk assessment for risk to aquatic and wetland ecosystems and their services due to reduction of low flow in rivers**

| | Current/near term (2021-2040) | Mid-term (2041-2060) | Long term (2081-2100) |
|---|---|---|---|
| ***Risk severity*** | **Substantial**<br>Aquatic ecosystems are already impacted by droughts, in combination with other risk drivers (e.g. pollution). | **Critical**<br>Under 2°C GWL (potentially occurring very close to this period according to the 'most optimistic' models sub-ensemble under SSP5-8.5 in the IPCC Sixth Assessment Report (AR6) Working Group II), decrease of low flow (5th percentile) in southern Europe, up to -40% in the extreme south of Spain, Portugal and Greece, and including France in June-July-August (JJA) and September-October-November (SON). | **Critical**<br>Under RCP8.5 (3.5/4°C GWL), decrease of low flow (5th percentile) in the southernmost part of western and central Europe and across southern Europe, up to -40% in many parts of Italy, Spain, Portugal and Greece, and including central-southern France in JJA and SON. |
| ***Confidence*** | **High** | **Medium** | **Medium** |
| ***Risk ownership*** | **Co-owned**<br>The EU and its Member States both have legislative responsibilities relating to the environment, including water governance.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Biodiversity strategy for 2030 (2020/380) | | |

| | |
|---|---|
| | • Forthcoming EU Nature Restoration Law (adoption expected for spring 2024)<br>• Water Framework Directive (2000/60)<br>• Nitrates Directive (91/676)<br>• Groundwater Directive (2006/118)<br>• Farm to fork strategy<br>• Action plan towards zero pollution for air, water and soil<br>• Environmental Quality Standards Directive<br>• Habitats Directive<br><br>At the national level, the main policies of relevance include those relating to:<br>- Environment (including agriculture and water governance)<br>- Industry |
| ***Policy readiness*** | **Medium** |
| ***Policy horizon*** | **Medium term** |
| ***Urgency to act*** | **More action needed** |

**Sources:** EEA, (JRC, 2018)

### Table 5.2 Risk assessment for risk to population and economic sectors due to water scarcity: all Europe and southern Europe

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)**<br>• **High warming**<br>• **Low warming** |
|---|---|---|---|
| **Risk severity: all Europe** | **Limited** | **Substantial** | **Critical**<br>**Substantial** |
| **Risk severity: southern Europe** | **Substantial** | **Critical** | **Catastrophic**<br>**Critical** |
| ***Risk severity*** | Water scarcity is already impacting society during drought periods, in particular in southern Europe. | Under 2°C GWL (potentially occurring very close to this period according to the 'most optimistic' models' sub-ensemble under SSP5-8.5 in the IPCC AR6 Working Group II), the number of people affected by water scarcity increases slightly from 85 million to 94 million people without taking the population change into account, mainly in the Mediterranean countries. | For the European part of the Mediterranean (Portugal, Spain, Italy and Greece), the number of people affected by water scarcity increases from 85 million under the current climate to 104 million under the changed climate and population, reaching 295 million people if considering all for the EU and the UK. |
| ***Confidence*** | **Medium** | **Medium** | **Medium** |
| ***Risk ownership*** | **Co-owned**<br>The EU and Member States both have legislative responsibilities relating to the environment, including water governance.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Water Framework Directive (2000/60)<br>• Nitrates Directive (91/676)<br>• Common agricultural policy (2021/2116)<br>• Communication on Water Scarcity and Droughts<br>• Regulation on Minimum Requirements for Water Reuse (2020/741)<br>• Environmental Quality Standards Directive (2008/105)<br>• Renewable Energy Directive (2023/2413)<br>• Circular economy action plan (2020/98)<br>• Blueprint to Safeguard Europe's Water Resources (2012/0673)<br>• Urban Wastewater Treatment Directive<br>• Bathing Water Directive<br>• Drinking Water Directive<br>- | | |

| | |
|---|---|
| | At the national level, the main policies of relevance include those relating to:<br>• Environment (e.g. water governance)<br>• Industry (e.g. circular economy and pollution) |
| ***Policy readiness*** | **Medium** |
| ***Policy horizon*** | **Medium term** |
| ***Urgency to act*** | **Further investigation (all Europe)**<br>**More action needed (southern Europe)** |

**Sources**: EEA, (JRC, 2018)

**Table 5.3 Risk assessment for risks to the winter tourism sector and countries or regions strongly dependent on it**

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)**<br>• **High warming**<br>• **Low warming** |
|---|---|---|---|
| ***Risk severity*** | **Limited**<br>Winter tourism is already facing considerable impacts due to snow scarcity, but these are concentrated in a few European regions. | **Substantial**<br>A reduction of 19% (RCP2.6) to 36% (RCP8.5) of the number of days with medium amount of natural snow above 30 cm at 800 metres above sea level. | **Critical**<br>A reduction of around 67% (RCP8.5) of the number of days with medium amount of natural snow above 30 cm at 800 metres above sea level.<br>**Substantial**<br>A reduction of around 18% (RCP2.6) of the number of days with medium amount of natural snow above 30 cm at 800 metres above sea level. |
| ***Confidence*** | **High** | **High** | **Medium** |
| ***Risk ownership*** | **National**<br>Since tourism falls under the EU's supportive competences, policies relating to tourism reside largely under the legislative responsibilities of Member States.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>- European agenda for tourism<br><br>At the national level, the main policies of relevance include those relating to:<br>- Tourism<br>- Environment (e.g. water governance)<br>- Industry | | |
| ***Policy readiness*** | **Advanced**<br>Countries and regions with significant snow-dependent tourism are aware of the risks of climate change and are managing them, although many actions have a short-term focus. | | |
| ***Policy horizon*** | **Medium term** | | |
| ***Urgency to act*** | **Sustain current action** | | |

**Sources**: EEA, (C3S, 2020c) and indicator selected as Fig. 5 in (Morin et al., 2021).



## 5.5 Relevant policies

- European policies aim to address water security but require better integration, implementation and effectiveness concerning climate change impacts. It is crucial to integrate water objectives with other policy areas like the agriculture, energy, transport, tourism and domestic sectors to reduce inconsistencies.
- Several EU policies, strategies and plans relevant for water security include:
- EU Blueprint to Safeguard Europe's Water Resources, encompassing various policies and measures to safeguard water resources.
- Water Framework Directive, setting goals for European water policy.
- Environmental Quality Standards Directive, establishing limits for priority substances.

- Groundwater Directive, setting groundwater quality standards.
- Floods Directive, to assess and manage flood risks.
- Water Reuse Regulation, stimulating water reuse for agricultural irrigation.
- Recast of Drinking Water Directive, addressing water supply quality.
- Urban Wastewater Treatment Directive (including proposal for a recast), aiming to reduce pollution and energy use.
- Nitrates Directive, prevents water pollution from agricultural sources.
- Communication on Water Scarcity and Droughts, lists options for efficient water use and pricing.
- Bathing Water Directive, ensures high-quality bathing water.
- Water Resilience Initiative, to coordinate efforts across water security, social justice and green development.
- EU Mission on Ocean and Water, aimed at protecting and restoring the health of our ocean and waters.

Some other EU documents refer to policies in the context of other broad sectors:

- Strategy on adaptation to climate change, emphasising sustainable freshwater availability and quality.
- Farm to fork strategy, targeting nutrient reduction, pesticide risk and plant protection products.
- Circular economy action plan, promoting water reuse and efficiency.
- European Green Deal, focusing on sustainable water management.
- Action plan towards zero pollution for air, water and soil, addressing pollution reduction.
- Biodiversity strategy for 2030, emphasising river restoration and freshwater legislation.
- Industrial Emissions Directive, regulating pollutant emissions.
- Nature Restoration Regulation, complementing the Water Framework Directive (WFD).
- Strategic environmental assessment and environmental impact assessment, reviewing development projects, including under a climate-proof perspective.
- Common agricultural policy (CAP; 2023-2027), affecting water use and pollution from agriculture, and aiming for integration with the WFD, but there is scope for CAP strategic plans to improve support for enhancing water resilience in agriculture.
- Renewable energy policies, impacting water use and aquatic ecosystems, and promoting mainstreaming of climate change adaptation in energy planning.
- European Climate Law, calling for adaptation of EU water resources.
- Union Civil Protection Mechanism, supporting disaster risk management activities relating to water, including prevention and response to relevant climate-related hazards and their impacts.
- Cohesion policy, to reduce gaps between countries, including via investments dedicated to water.

- Beyond EU policies, the following international legal instruments serviced by United Nations Economic Commission for Europe (UNECE) and World Health Organisation (WHO) Europe are relevant: the Protocol on Water and Health, addressing, among others, climate change and safe management of water supplies, and the Convention on the Protection and Use of Transboundary Watercourses and International Lakes, to enhance transboundary cooperation in Europe.

# 6 Food production and food security

## 6.1 Key messages

- Key climate risks to European food production are reductions in crop and livestock production from changing growing conditions and extreme weather events, particularly in southern Europe (SEU).
- Food production is at risk from reduced water availability and quality as well as the deteriorated status of terrestrial and marine ecosystems. Impacts on fisheries and aquaculture arise through changing habitats, diseases and water stress.
- Uncertainties in the mid-and long-term are related to pollinator decline, pests and diseases in crops, livestock and aquatic environments, the climate resilience of new crop production systems, technological progress, the uptake of existing and new technologies, as well as geopolitical and socio-economic conditions.
- Key climate risks related to food and nutrition security are: increasing and volatile food prices due to climate impacts on food production in Europe; climate impacts on agricultural production and supply chains outside Europe.
- Food security, in particular access to healthy food, is strongly affected by socio-economic drivers, and affects human health and social justice, in particular compromising food access and affordability for disadvantaged groups.
- Policies addressing the socio-economic conditions can improve access to healthy and nutritious diets.
- Dietary shifts towards reduced consumption of animal-based products and reducing food waste can greatly improve the resource use efficiency of food production and improve food security under current and future climate conditions.



## 6.2 Introduction

Food production (see Section 6.3.2) in Europe is intricately influenced by numerous climatic and non-climatic factors, including droughts, heatwaves, biodiversity loss and socioeconomic dynamics (Bednar-Friedl et al., 2022b; Bezner Kerr et al., 2022a). Climate change reshapes the conditions suitable for crop production, intensifies risks for weather-related crop/food losses, causes the introduction and establishment of new plant pests, increases the physical and biological risks to animal production systems, and shifts the food web and species abundances relevant for fisheries. Together they escalate risks for food security. Under high-end climate change scenarios, southern Europe is particularly vulnerable to deteriorating conditions for food production (Bednar-Friedl et al., 2022b; Rossi et al., 2023a). The climate impact drivers influencing the region include declining precipitation and increased frequency of extreme heatwaves and droughts, as well as periods of extremely high precipitation, impacting yields of staple crops, fruits and vegetables, and raising food prices, especially of nutritious foods. Moreover, the region is susceptible to the establishment of most (sub-)tropical plant pests. A northward shift of agro-climatic zones and the climate suitability of specific crops requires changes in the entire agricultural production system in southern Europe; northern regions, too, face considerable challenges, but also opportunities, associated with climate change (Franke et al., 2022).

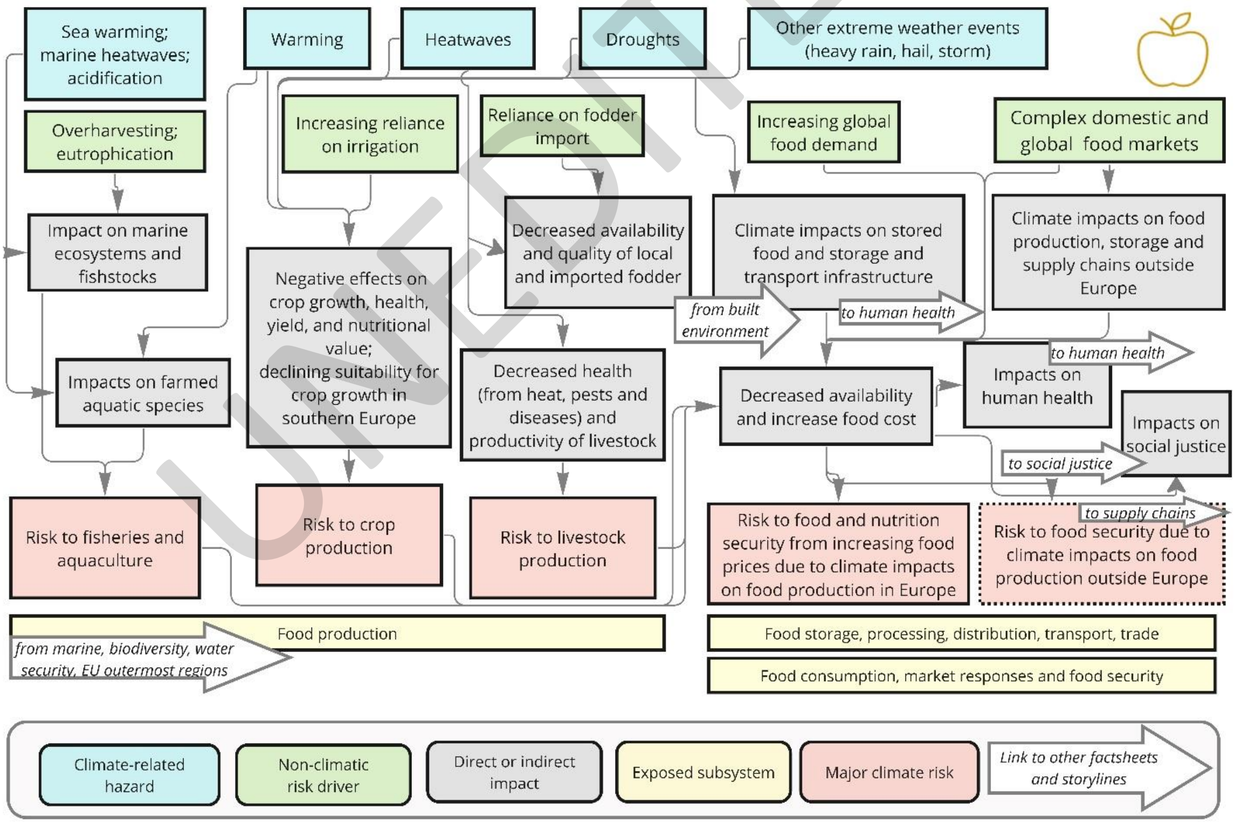
While Europe is self-sufficient in most food commodities, trade dependencies and global markets co-determine consumer food prices (Hedlund et al., 2022). Also, climate-related changes to transport, food storage and processing can contribute to food insecurity (see Section 6.3.2). Currently, approximately 7% of the European population faces moderate-to-severe food insecurity, notably affecting disadvantaged groups, and south-eastern European countries are most affected (FAO et al., 2022). Risks to food security (see Section 6.3.3) depend on income levels, food prices, and accessibility to and affordability of food, with risks originating inside and outside Europe.

This factsheet explores climate-related risks to food production and security, emphasising the interplay with underlying non-climatic drivers, e.g. technological and demographic developments. It underscores the need for comprehensive and integrated policies and mitigation strategies to ensure sufficient food production and food security in the face of climate change. The Chapters 3, 4, 5, 7, 11, 14, 16 provide additional perspectives for this factsheet.

## 6.3 Risk drivers and impacts

### 6.3.1 Impact chain

**Figure 6.1 Impact chain for food production and security**






**Source**: ETC.

### 6.3.2 Subsystem: food production

**What drives the impact**

- Crops: climate change directly affects crop production and shifts suitable regions northwards, with increased associated risks such as late frost events. More frequent, severe and complex (e.g. compound) extreme events reduce crop production and increase its variability.
- Crops: food production is affected indirectly by climate change impacts on systems that are intimately linked with the food supply chain, such as terrestrial (e.g. through pollination and pests) and freshwater ecosystem conditions, energy costs and infrastructure.
- Livestock: increased temperatures and humidity affect animals directly, leading to reduced productivity. Indirectly, health and productivity of livestock are affected via altered and more variable availability of feed and water, and potentially reduced feed quality.
- Livestock: increased pest and disease prevalence affects the health and market suitability of livestock.
- Fish: ocean warming and acidification affect marine habitats and feed availability, impacting aquaculture and fisheries.
- Fish: climate change leads to the increasing presence of pests, diseases and invasive species and to changes in current distribution and migration patterns of fish stocks.

**Current situation**

- Crops: heat stress and droughts already negatively affect European crop production compared to their yield potentials, especially in southern Europe, with wheat and maize yield reductions of over 60% in some southern European regions, and up to 30% in other European regions (Webber et al., 2018), causing substantial economic damage. Unusually severe droughts in the recent past constitute new threats throughout Europe.
- Crops: excessive rainfall can also lead to crop failures, e.g. as observed in the 2016 wheat production failure in France, with losses of up to 55% in specific regions (Nóia Júnior et al., 2023).
- Crops: Europe relies heavily on irrigation, with a total of 5.9% of agricultural land irrigated in 2016, but up to 30-50% locally in southern Europe (Eurostat, 2019a). Agriculture is the largest net water-using sector and puts pressure on water resources (EEA, 2020g). Several countries exceed thresholds for sustainable water use (Berbel et al., 2019).
- Livestock: current temperature-humidity stress is a low risk to livestock production in southern Europe (North et al., 2023). Pests and diseases affect livestock production but the link to climate change is less clear.
- Livestock: feed imports (ca 70-75% of animal protein feed is imported) are sensitive to concurrent climate events outside Europe and substantial import price fluctuations (Goulart et al., 2023).
- Fish: distribution, migration and seasonality of fish stocks are affected by climate change, with consequences for fishing in international waters (EC et al., 2022). Harmful algae blooms due to eutrophication and stimulated by higher temperatures cause dead zones and fish kill (FAO, 2020). Still, current pressure on fish production stems mostly from unsustainable (over)fishing, in particular in the Black Sea and the Mediterranean

(FAO, 2023b) and to a lesser extent in the Baltic Sea (EEA, 2024d). Aquaculture strongly depends on imports of feed proteins. Marine aquaculture is affected by warming-related jellyfish blooms, while water availability and quality are increasingly under pressure for terrestrial aquaculture.

**Future situation**

- Crops: staple crops like wheat and maize are affected by climate change, with substantial differences in impacts on yield, protein content and nutritional value between climate projections, regions and crops. Yield volatility is likely to increase. Europe is among the least negatively affected continents globally (Jägermeyr et al., 2021) but rising global demand may increasingly affect production in Europe (Hristov et al., 2020). Northward shifts of production (Franke et al., 2022) pose challenges to production and processing systems. Generally, warmer conditions are conducive to the spread of pests and diseases, but there is limited evidence for impacts on future yields.
- Crops: changes in irrigation water availability (Elliott et al., 2014) could lead to additional yield declines.
- Crops: many crops in Europe may benefit from $CO_2$ fertilisation if water and nutrients are sufficiently available, possibly overcompensating for direct climate impacts on production, but this is less the case for maize and most other crops of tropical origin (Toreti et al., 2020a).
- Livestock: health and productivity of livestock will decline due to climate change, especially in southern Europe (Bednar-Friedl et al., 2022b).
- Livestock: substantial, but highly uncertain, novel transmission pathways of complex diseases and increased incidence of (new) diseases may pose a high risk to animals across Europe (Brooks et al., 2022).
- Fish: ocean animal biomass may decrease with regional and scenario-specific differences, with shifts in spatial distribution and fish stock productivity (Cooley et al., 2022). Aquaculture may be impacted more frequently by extreme weather events and the spread of pests, diseases and parasites (Huntington, 2022). Terrestrial aquaculture will increasingly face shortages of freshwater.

### *6.3.3 Subsystem: food storage, processing, distribution, transportation and trade*

**What drives the impact**

- In the food supply chain, extreme weather events 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.
- Higher energy prices affect logistics and eventually lead to increased food prices for consumers.
- Increased post-harvest temperatures and humidity shorten post-harvest storage times, alter product quality during processing and increase food safety risks and losses from rodents and insects, also pushing up prices.
- Europe has an overall positive trade balance for agricultural products, but is a net importer of seafood products, fruits/nuts, oilseeds and protein crops (animal feed),

coffee/cocoa and spices, and hence is sensitive to global food and feed prices. In addition, Europe relies on imported input materials for food production, e.g. fertiliser, natural gas and oil products (EC, 2022d).
- Southern European countries are particularly susceptible to shocks in agricultural commodity flows due to their dependence on food imports.
- Migration of fish stocks and related fishing opportunities affect trade in and outside the EU.

**Current situation**

- Europe's inland waterways are important for food distribution, with agricultural and food products representing 10% and 23% of the tonnage transported on the Rhine and Danube, respectively (CCNR, 2022). Regional climate change impacts, in particular those associated with low water levels, like the droughts in 2018 and 2022, had severe consequences on commercial navigation in multiple European waterways, in particular in southern and central Europe (EEA, 2014).
- Climate change hazards (e.g. heat, flooding, storms) disrupt road and railway infrastructure, affecting domestic and international transportation of agricultural goods. Southern Europe's road and rail infrastructure is vulnerable to summer heat (Koks et al., 2019a).
- Currently, there is only limited evidence for climate-driven impacts on storage of specific food products and related deteriorated quality and appearance.
  Trade chokepoints crucial for global food distribution include the Panama Canal, the Strait of Malacca and in particular the Turkish Straits, which handle a significant portion of global wheat trade stemming from the Black Sea region (Bailey and Wellesley, 2017). Geopolitical events (e.g. the Russian war of aggression against Ukraine) can severely impact these trade routes. In particular, fertiliser availability and prices in 2022 raised strong concerns about food security in Europe (EC, 2022a).

**Future situation**

- Changes in crop suitability and agricultural zone can shift production centres, possibly necessitating adjustments in storage, processing and distribution logistics, and ultimately supply chain adaptations (Bezner Kerr et al., 2022a).
- Climate-change induced impacts on (riverine, rail, road) transportation of food products are uncertain. Risks for overall riverine transport are lower in northern Europe and highest in the southern Danube region (Rossi et al., 2023a).
- Future temperature increases can compromise food safety due to increased incidence of food-borne diseases. A compound risk results from increasing temperatures and possible disruption of cold chain integrity (EFSA et al., 2020a). Southern Europe faces significant challenges for storage and transport due to its high share in production of fruits and vegetables for the European market. Energy and storage costs may increase and affect producer incomes and consumer prices.

### *6.3.4 Subsystem: food consumption, market responses and food security*

**What drives the impact**

- Food choices are shaped by consumer prices, availability and access to food, and information ((including marketing and advertising). Final food demand and consumption

behaviour depend on factors like income and poverty, dietary preferences, physical activity, urbanisation and demographics. Food choices and consumption are not directly influenced by climate change, but indirectly through food prices. Agency and awareness in the food sector can reduce climate risks through diminishing demand.
- Climate change can raise food prices due to impacts on production and the supply chain leading to changes in food availability. Both EU and global production impacts can influence prices, as can global trade. Price changes can impact market competitiveness, leading to shifts in production for export versus domestic use and altering sourcing patterns for companies.
- Indirectly, climate and environmental measures that influence food production systems, e.g. those related to land needed for bioenergy production or competition for water resources, can also affect food availability and prices.

**Current situation**

- Currently, climate change is more likely to cause price rises and volatility than shortages in the EU food system, contingent on the magnitude of shocks and the preparedness and organisation of market actors across the food system to deal with them (EC, 2023e).
- Reduction of food waste and the share of animal-based products in diets can greatly improve the resource use efficiency of food production and contribute to food security (Bodirsky et al., 2020). Currently, more than half of EU cereal production is used for animal feed (Herrero et al., 2013).
- The EU imports 70-75% of its total protein-rich animal feed (EC, 2022f); the EU's import dependence on soybean as animal feed, mainly from Argentina, Brazil and the USA poses a vulnerability influenced by changing climatic conditions in both the EU and major feed-producing nations.
- In Europe, about 7% of the population is currently moderately-to-severely food insecure, with strong differences among countries and dominated by vulnerable groups (FAO et al., 2022). Climate change impacts have increased the food insecurity of 11.9 million people in Europe, with negative implications for health (The Lancet Countdown in Europe, 2024).

**Future situation**

- Socio-economic developments are the strongest driver of food insecurity. Future food demand will depend on regional demographics and per capita calorie and protein consumption. By 2050, projections suggest a 50% increase in global caloric food demand (Bodirsky et al., 2020). Still, a meta-analysis of 57 studies suggests a change in the global risk of hunger between -91% and +8% between 2010 and 2050. Considering climate change, the risk can change with -90% to +30% (van Dijk et al., 2021).
- For Europe, by mid-century, limited evidence suggests a slight uptick (1.3 to 4.8 percentage points increase) in risk for moderate-to-severe food insecurity due to climate change alone (Climate Vulnerable Forum and Vulnerable Twenty (V20), 2022).
- A reduction of animal production and meat and dairy consumption both in Europe and worldwide could substantially increase cereal availability for human consumption, thus enhancing food security.

## 6.4 Risk assessment and evaluation

### 6.4.1 Confidence

There is robust evidence that climate change impacts, as well as the spatial extent and frequency of extreme events, scale with radiative forcing, so that climate mitigation eases the challenges for food production and food security (Masson-Delmotte et al., 2021).

There is high confidence that $CO_2$ fertilisation will (over)compensate for negative climate change impacts on C3 crops (which constitute the majority of crops in Europe, e.g. wheat) in terms of average productivity, but nutritional quality may decline (Toreti et al., 2020b). Maize for food and feed, the second most important crop in Europe, does not see this effect and is sensitive to future reductions in water availability.

There is high confidence that European crop production systems will be less negatively affected than other continents (Jägermeyr et al., 2021). There is a lack of knowledge about climate change impacts on the productivity and quality of most non-staple crops and many livestock and fish production systems, hampering comprehensive understanding of the risks to food security and the planning of adaptation options.

Uncertainties in climate projections are not sufficiently represented in climate impact studies, in particular for regional impacts (McSweeney and Jones, 2016). In addition, differences in impact model structure and parameterisation and the inability to project future production systems add substantial uncertainty to future projections (Müller et al., 2021). The impacts of changing environmental conditions (e.g. pollution, pollination, desertification, erosion) are generally not included in studies.

Model projections suggest increasing interannual variability of crop production under future climate change, but models have limited ability to reproduce impacts of other climate impact drivers, such as intensified extreme events, excessive rainfall and compound events (Kornhuber et al., 2023).

Climate-driven pests and diseases pose a significant risk to crops and livestock, but uncertainty is high due to fundamental knowledge gaps and hitherto unknown threats (Lehmann et al., 2020).

Underlying drivers of food security, such as household income, equality, geopolitical stability and global market dynamics, greatly affect future food security and constitute a major source of uncertainty in the assessment of risks to future food security in Europe (Adams et al., 2021a).

### 6.4.2 Adaptation opportunities, constraints and limits

Adaptation of European food production systems is key to address the forthcoming increase in climate impacts and implications for food security. Adaptation strategies should include sustainability aspects. Transformation of food systems, e.g. moving to healthy diets and reducing food waste, may alleviate pressures on Europe’s food production capacity (Gerten et al., 2020).

A multitude of interacting adaptation strategies exist across regional to local scales. These can be combined for effective, locally suitable adaptation to climate change. Diversification of production at farm level can be enabled by suitable value chains, if infrastructure and financial risks are adequately addressed (Bednar-Friedl et al., 2022b; Bezner Kerr et al., 2022a).

Sectoral adaptation strategies integrating climate services and technological solutions coupled with compensating mechanisms may reduce the impacts of climate change on both production and farmers’ economic stability. Uptake of these will benefit from generational renewal of farmers and targeted training opportunities.

The practical constraints of a northward shift of production areas and the potentially limited availability of suitable and resilient breeds (crops, livestock) and of irrigation water in the future can substantially constrain the ability for adaptation (Zabel et al., 2021; Elliott, J., 2014).

With dynamic and ongoing climate change, flexibility in response choices and good skill in predicting near-term future conditions, such as seasonal-to-decadal forecasts, are needed (Toreti et al., 2023).

Europe's substantial role in global food systems (production, processing and transport) as both importer and exporter implies that adaptation and transition of the food system in Europe can also affect third parties, such as import and export partners, as well as the global food market as a whole, emphasising the importance of European policymaking in this respect (Hedlund et al., 2022).

### 6.4.3 Overall assessment

This section presents the outcomes of the structured risk assessment for the major climate risks identified in this factsheet. This assessment builds on information in this factsheet, and possibly in other chapters of this report. The initial risk assessment was conducted by the authors of this factsheet whereas the final assessment results reported here represent the consensus of the EUCRA risk review panel. Further methodological information is available in Annex 2.

The following risk assessed in another chapter is also relevant for this factsheet, but it is not presented here to avoid duplication:

- Risk to food security in Europe from climate impacts on agricultural production and supply chains outside Europe (Chapter 16).

**Table 6.1 Risk assessment for the risk to crop production in Europe from adverse weather conditions due to climate change: all Europe and southern Europe**

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)<br>- high warming<br>- low warming** |
|---|---|---|---|
| **Risk severity (all Europe)** | **Substantial**<br>Drought, heat and overly wet conditions impact on regional production.<br>Regional production variations tend to level off at EU level, reducing risk to overall European food production. Therefore, currently only relatively moderate impacts on Europe as a whole. | **Substantial**<br>Water stress is increasingly a problem for more regions. | **Critical**<br>Risks further increase under a high warming scenario. The impact of long droughts can be quite widespread and more persistent throughout Europe, with major declines in productivity due to drought or high temperatures during critical crop phases (flowering, grain filling).<br>**Substantial**<br>See mid-term |
| **Risk severity (southern Europe)** | **Critical**<br>The impacts of recent heatwaves and droughts, aggravated by climate change, have been much higher in southern Europe than in other European regions. | **Critical**<br>Increasing risks of yield losses due to enduring drought and long-term water scarcity in southern Europe. | **Catastrophic**<br>Considerable increase in heat and drought risks for crop production in southern Europe.<br>Limits of autonomous adaptation reached. Some current agricultural systems will no longer be viable.<br>**Critical**<br>See mid-term |

| *Confidence* | High | Medium | Medium |
|---|---|---|---|
| Risk ownership | **Co-owned**<br>The EU and its Member States both have legislative responsibilities relating to agriculture and food production. The EU has an important role for income support for farmers and measures relating to market and rural development. In common agricultural policy (CAP) strategic plans, Member States detail their targeted interventions, implementation, needs and contribution to EU-level objectives, but also provide support in the context of climatic events, such as droughts.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Common agricultural policy (2021/2116)<br>• Farm to fork strategy<br>• Regulation on Land Use, Land Use Change and Forestry<br>• Water Framework Directive (2000/60)<br>• Regulation on Minimum Requirement on Water Reuse (2020/741)<br><br>At the national level, the main policies of relevance include those relating to:<br>• Environment (including agriculture and water governance)<br>• Industry<br>• National adaptation funding | | |
| Policy readiness | **Medium**<br>Agricultural policies mostly address near-term conditions. The CAP has a flexibility mechanism to deal with crisis situations, which may not be sufficient to deal with future climate risks. There is underutilised potential of the CAP to address adaptation needs in agriculture to deal with higher climate risks. Compulsory and voluntary interventions are available in the CAP with direct effect on climate adaptation, with 25% of green direct payments related to eco-schemes, and a minimum of 35% of European Agricultural Fund for Rural Development (EAFRD) funding ring-fenced for environmental and climate objectives. Related policies for improving soil carbon can also increase climate resilience.<br>Nevertheless, the climate-resilience benefits of these policies need to be better quantified, and adaptation measures could be highlighted more and integrated into the policies and be made more binding for the regions most at risk. The current level is not sufficient for addressing the medium and long-term risks. | | |
| Policy horizon | **Short term** | | |
| Urgency to act | **More action needed (all Europe)**<br>**Urgent action needed (southern Europe)** | | |

Source: EEA.

### Table 6.2 Risk assessment of the risk to fisheries and aquaculture in Europe and international waters from changed environmental conditions due to climate change and related ocean acidification

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)** |
|---|---|---|---|
| **Risk severity** | **Substantial**<br>Impacts of over-exploitation of fish stocks dominate marine fisheries. Climate change and environmental drivers are affecting systems and pose additional risks in complex and uncertain food web interactions (e.g. invasion of alien species). | **Critical**<br>Ocean warming, acidification and other environmental pressures will steadily increase, with likely more dominant climate impacts.<br>Large, species dependent, local declines of fish species are projected, and migration of fish species more | **Critical**<br>Further changes in fish communities' composition and location under continued ocean warming |

| | | | |
|---|---|---|---|
| | Migration of fish stocks may affect fisheries in and outside EU waters and imports of seafood products, with geopolitical risks. Aquaculture depends on imports of protein-rich feed products. | significant. There are increasing, but differing, risks to freshwater and ocean-based aquaculture due to extreme events. | |
| *Confidence* | **Medium** | **Low** | **Low** |
| **Risk ownership** | **Co-owned**<br>The EU and its Member States both have legislative responsibilities relating to fisheries and aquaculture. For instance, the common fisheries policy regulates fishing quotas to ensure the sustainable supply of seafood and aquaculture, but aquaculture also falls under national legislation with some action at EU level.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Marine Strategy Framework Directive (2008/56/EC)<br>• Common fisheries policy<br>• Maritime Spatial Planning Directive (2014/89)<br>• Biodiversity strategy for 2030 (2020/380)<br><br>At the national level, the main policies of relevance include those relating to:<br>• Environment (e.g. marine ecosystems)<br>• Industry (e.g. fisheries and aquaculture) | | |
| **Policy readiness** | **Medium**<br>The common fisheries policy sets rules (e.g. fishing quotas for Member States) to ensure an environmentally and economically sustainable supply of seafood and aquaculture. There is a monitoring framework and policy awareness, but management support tools and the policy do not specifically address long-term impacts of climate change. | | |
| **Policy horizon** | **Short term** | | |
| **Urgency to act** | **Further investigation** | | |

Source: EEA.



### Table 6.3 Risk assessment for the risk to livestock production in Europe from direct climate change impacts and increased spread of pests and diseases

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)** |
|---|---|---|---|
| **Risk severity** | **Limited**<br>Production losses due to impacts of climate change on the physical environment of animals are currently low, and risks to forage quantity and quality are manageable.<br>Incidence of animal disease outbreaks is increasing in Europe, with evidence for new transmission routes and suitable habitats for diseases or their vectors associated with climate change.<br>High dependency on feed imports. | **Substantial**<br>Increasing temperatures, lower water availability and increasing impacts on forage production (including from outside Europe) and quality.<br>High risk for spreading of animal diseases leading to substantial impacts at large scale. | **Substantial**<br>Possible impacts scale with climate forcing, but risk severity will depend on the transformation of animal production systems due to climatic and non-climatic drivers. |
| **Confidence** | **Medium** | **Medium** | **Low** |
| **Risk ownership** | **Co-owned** | | |

| | |
|---|---|
| | The EU and its Member States both have legislative responsibilities relating to agriculture. Several delegated and implementing acts have been introduced under the Animal Health Law, but Member States are largely responsible for the implementation of these acts.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Animal Health Law (2016/429)<br>• European Convention for the Protection of Animals kept for Farming Purposes (98/58/EC)<br>• Common agricultural policy (2021/2116)<br>• Veterinary Medicinal Products Regulation (2019/6)<br>• Regulation on serious cross-border threats to health (Regulation (EU) 2022/2371)<br>• Farm to fork strategy<br><br>At the national level, the main policies of relevance include those relating to:<br>• Environment<br>• Industry (e.g. agriculture)<br>• Public health |
| **Policy readiness** | **Medium**<br>Detailed regulations and protocols are in place for detected outbreaks but are not prepared for possible larger-scale outbreaks under climate change conditions. There is a lack of systematic pre-outbreak monitoring, and insufficient EU vision and incentives on fast development of new vaccines for outbreaks of animal diseases. |
| **Policy horizon** | **Short term** |
| **Urgency to act** | **Watching brief** |

**Source:** EEA.

### Table 6.4 Risk to food and nutrition security from increasing food prices due to climate impacts on food production in Europe

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)** |
|---|---|---|---|
| **Risk severity** | **Substantial**<br>Impacts on quantity and quality of food production, and non-climatic drivers can increase food prices, hence reducing food affordability. EU-wide offset of local reductions of food availability through trade.<br>Reduced affordability of nutritious food may lead to less healthy/nutritionally balanced diets, especially for low-income households, aggravated by increasing societal inequality. | **Critical**<br>Intensified climate impacts on food production increase the variability of food availability.<br>More frequent and regionally low annual yield cannot always be compensated by intra-EU trade, causing lower food affordability and leading to high risks to food security, specifically for low-income households.<br>Increasing food insecurity for socio-economic pathways associated with higher societal challenges and increasing inequality. | **Critical**<br>Possible impacts scale with climate forcing, but risk severity will depend on the transformation of food systems, trade and societal developments in response to climatic and non-climatic drivers and are difficult to quantify. |
| **Confidence** | **Medium** | **Medium** | **Low** |
| **Risk ownership** | **Co-owned**<br>The EU and its Member States both have legislative responsibilities relating to agriculture and social support. Taxation, subsidies for vulnerable/low-income groups and information about healthy diets are under national responsibility. | | |

| | |
|---|---|
| | At the EU level, the main relevant policy frameworks and initiatives include:<br>• Farm to fork strategy (2020/381): provides an overall framework<br>• European Food Security Crisis preparedness and response mechanism (EFSCM): assesses how to improve cooperation between the public and private sectors and evaluate risks when crises arise.<br>• Fund for European Aid to the Most Deprived (FEAD): integrated in the European Social Fund Plus (ESF+), regulates inter alia support of food to the most deprived.<br><br>At the national level, the main policies of relevance include those relating to:<br>• Social policies<br>• Tax policy |
| **Policy readiness** | **Medium**<br>Several frameworks and policies at different governance levels affect food production, food security, climate change mitigation and adaptation, social justice, intra-European trade, etc. Alignment and coherence of these policies in view of food and nutrition security of vulnerable groups does not seem fully ensured. |
| **Urgency to act** | **Further investigation** |

Source: EEA.

## 6.5 Relevant policies

- ***European Green Deal***: outlines the EU's sustainability goals.

Climate:

- ***European Climate Law***: addresses the need for climate adaptation to reduce climate-related risks, emphasising health, food and water security threats through, for example, the EU adaptation strategy and LULUCF Regulation.

- ***EU strategy on adaptation to climate change***: addresses droughts, ecosystem services, nature-based solutions and local adaptation, among others, and stepping up international action on agricultural production.

- ***Land Use, Land Use Change and Forestry (LULUCF) Regulation***: includes avoiding emissions and enhancing sequestration of carbon, with measures like grassland maintenance and peatland restoration, aiding soil preservation for enhancing resilience of agriculture.

Food systems, agriculture and fisheries:

- ***Farm to fork strategy***: integrated package of 27 policy actions, promoting a sustainable food systems approach, emphasising environmental, biodiversity and climate impact reduction, circular resource use, food and nutrition security (including aid for the most deprived through FEAD/ESF+ (see below)), affordability of food and fair business, including the common agriculture and fisheries policies.

- ***Common agricultural policy***: aims for fair farmer income, competitiveness, environmental care, climate action, biodiversity preservation and innovation, incorporating eco-schemes, climate-friendly practices and crisis reserves. Associated with a large budget and complex set of funding mechanisms.

- ***Soil Monitoring Directive***: on monitoring and assessing soil health, aiming at protecting and restoring soils and ensuring they are used sustainably.
- ***Carbon removal certification framework*****:** proposal that outlines a voluntary framework for certifying carbon removals created in Europe, and establishes criteria for high-quality carbon removals.
- ***Plant Health Regulation*****:** aims to modernise the plant health regime, with more effective measures for the protection of the EU's territory and its plants; also aims to ensure safe trade and mitigate the impacts of climate change on the health of crops and forests.
- ***Common fisheries policy***: a set of rules for sustainably managing European fishing fleets, conserving fish stocks and manages fisheries, focusing on sustainable fish stocks.

Water and pollution:

- ***Water Framework Directive***: governs water use, ensuring clean water for food production and promoting efficient agricultural water use, indirectly safeguarding food security.
- ***Water Reuse Regulation***: aims to encourage and facilitate water reuse in the EU by setting out requirements for quality, monitoring and permissions, provisions on transparency and risk management.
- ***Nitrates Directive***: aims to protect water quality across Europe by preventing nitrates from agricultural sources from polluting ground and surface waters and by promoting the use of good farming practices.

Crisis, socio-economy and food security:

- ***European Social Fund+*** *(ESF+)*: aims to support Member States in achieving high employment levels and fair social protection, and to foster a skilled and resilient workforce that is ready for the transition to a green and digital economy. It has been instrumental in tackling the crisis caused by the COVID-19 pandemic.
- ***European Food Security Crisis preparedness and response mechanism***: aims at ensuring food supply and food security in times of crisis, through improved cooperation between the public and private sectors and through risk evaluation.
- ***Fund for European Aid to the Most Deprived*** *(FEAD)*: supports EU countries' actions to provide food and/or basic material assistance to the most deprived.

# 7 Human health

## 7.1 Key messages

- Key climate risks for human health are: mortality and morbidity arising from increased heat stress together with air pollution; geographic expansion and increased transmission of infectious diseases; pressure on health systems; and risks to outdoor workers due to increased heat stress.
- Climate risks to human health depend on many issues beyond health policy, including housing stock, availability and pricing of cooling options, urban design, and labour regulations.
- Climate-related health risks are disproportionately felt by socially disadvantaged population groups.
- Alignment and coordination across Europe are required to address climate change-induced health impacts. The most important policy priorities are: integrating human health into all climate change adaptation policies; increasing the capacity and preparedness of the health sector; increasing the resilience of critical health infrastructure; and designing adaptation measures to limit disparities in levels of vulnerability.

## 7.2 Introduction

Climate change-related warming and more frequent and intense extreme weather events, such as heatwaves, storms, floods and droughts, are already putting the health of the European population at increasing risk. The direct health impacts of heat include deaths from heatwaves, heat stress, work-related injuries and disrupted sleep patterns (van Daalen et al., 2022; Dasgupta et al., 2021; Minor et al., 2022). Climatic conditions are also becoming increasingly favourable for the emergence and transmission of several climate-sensitive infectious diseases. More extreme flooding events lead to direct physical injuries, increased exposure to waterborne diseases, and damage and disruption to health services (ECDC, 2021). Drought reduces food production, contributing to increased food insecurity and reduced nutrition. Heat and drought together increase the likely spread of wildfires, which harm human health through burns, injuries, worsening air quality and impacts on mental health (Dasgupta and Robinson, 2022; van Daalen et al., 2022; EEA, 2022b). Floods, storms and other extreme events can also lead to substantial psychological impacts, even in those not physically injured.

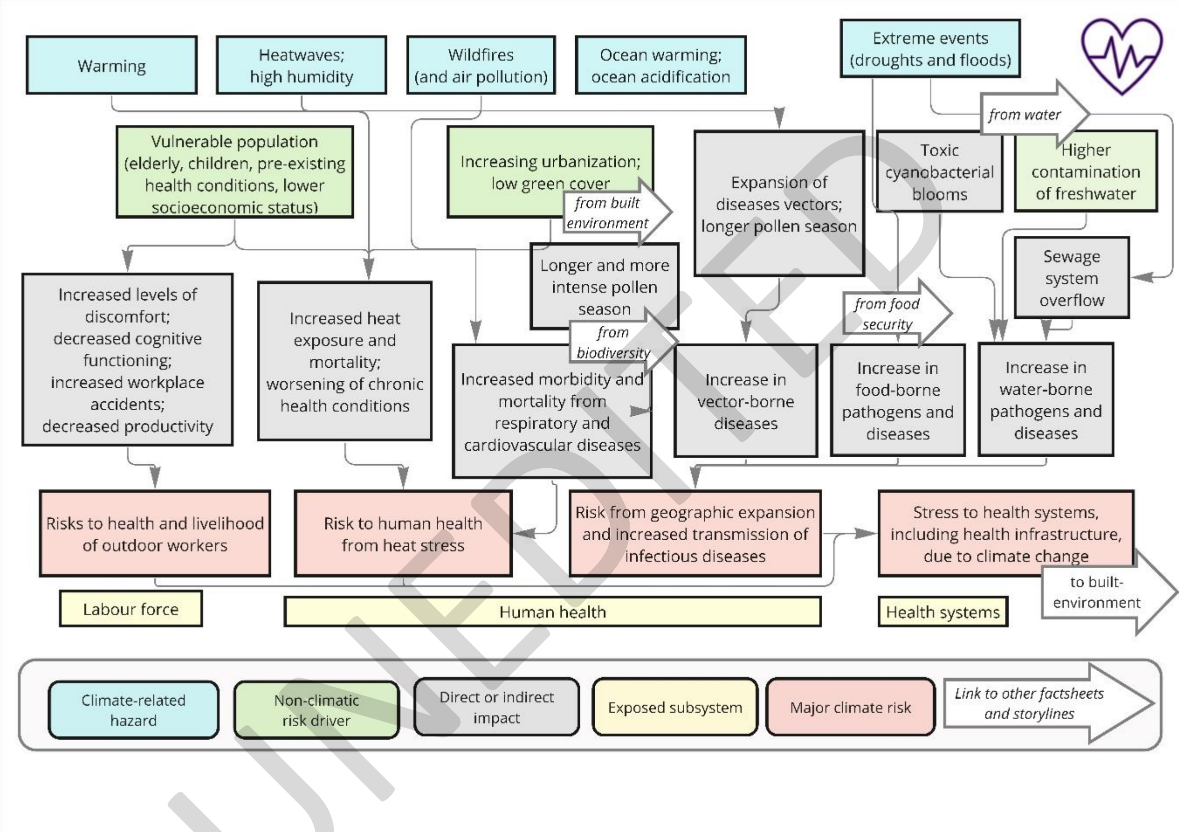
Climate-sensitive health risks are disproportionately felt by the most vulnerable and disadvantaged population groups, including lower-income households, the elderly, children, youth, migrants, outdoor workers, pregnant women and those with pre-existing health conditions (Dasgupta et al., 2021; Minor et al., 2022; van Daalen et al., 2022). Europe's ageing population, high urbanisation rate, changing patterns of societal inequality and high incidences of non-communicable diseases make the region particularly vulnerable to climate-related health risks. Impacts and risks are regionally heterogeneous, with southern Europe at highest risk. As the intensity and frequency of extreme events increase, without sufficient adaptation the health burden is projected to increase substantially (EEA, 2022b; Romanello et al., 2023).

There is a need to improve our understanding of health impacts of climate change to enable policy changes at the EU, national and local levels. This factsheet explores the following subsystems: heat stress and air pollution; climate-sensitive infectious disease; water and foodborne diseases; and labour force impacts. The human health factsheet has synergies with Chapter 14 (major risks and cross-border EU health policies), the Chapter 6 (climate, nutrition and health linkage), the Chapter 5 (waterborne diseases), Chapter 9 (urban heat island and mortality, exposure to schools), and Chapter 15 (impact on health care infrastructure).

## 7.3 Risk drivers and impacts

### *7.3.1 Impact chain*

**Figure 7.1 Impact chain for human health**




Source: ETC-CA, 2024.



### *7.3.2 Subsystem: heat stress, air pollution and airborne allergens*

**What drives the impact**

- Gradual warming and increasing frequency and intensity of heatwaves is affecting human health through compromised ability to regulate internal body temperature, resulting in heat cramps, exhaustion, heat strokes, and worsening of chronic conditions such as cardiovascular, respiratory and cerebrovascular diseases, and mental health-related problems such as anxiety (van Daalen et al., 2022; EEA, 2022b; Romanello et al., 2023; Helldén et al., 2021; Florido Ngu et al., 2021).
- Air pollution and exposure to ozone increase the risk of strokes, chronic obstructive pulmonary disease, asthma, lung cancers, cardiovascular diseases and lower respiratory infections. The interaction between air pollution and extreme heat is particularly harmful to those with pre-existing conditions (EEA, 2022a, 2018).

- While the main drivers of allergies are non-climatic (e.g. increased urbanisation and hygiene), climatic stressors are linked to the spread of some allergens, thus exacerbating existing allergies and causing new ones. Increased temperature potentially leads to longer pollen seasons and higher concentrations, triggering reactions such as hay fever, conjunctivitis and asthma (D'Amato, 2020; EASAC, 2019).

**Current situation**

- During 2010-2019, heatwave exposure was 64.4% higher (1.07 billion person-days/year) than in 2000-2009 (0.65 billion person-days/year) among over-65s and children under 1 year old (van Daalen et al., 2022).
- The 2022 summer heatwave resulted in more than 60,000 heat-related deaths in Europe, with the highest share in Italy, Spain, Germany, France and Greece (Ballester et al., 2023).
- In 2020, 311,000 premature deaths in the EU were attributable to exposure to air pollution ($PM_{2.5}$, $NO_2$ and $O_3$) (EEA, 2022a). The interaction between heat stress and air pollution exposure has already been linked to higher mortality rates, mainly driven by cardiovascular and respiratory disease (EEA, 2022c).
- Cardiovascular diseases (ischemic heart disease, strokes) cause around 48% of air pollution-related excess mortality in Europe (Lelieveld et al., 2019). At least 18% of all cardiovascular disease deaths in Europe are estimated to be due to environmental factors (exposure to air pollution, extreme temperatures, second-hand smoke) (EEA, 2023). Cardiovascular diseases are estimated to cost the EU a total of EUR 282 billion/year, with health and long-term care accounting for EUR 155 billion (11% of EU health expenditure) (Luengo-Fernandez et al., 2023).
- Maternal exposure to air pollution during pregnancy has been associated with increased risks of adverse birth outcomes, such as preterm birth, low birth weight, being small for gestational age, gestational diabetes, intrauterine growth retardation and delayed psychomotor development during childhood. Maternal health is also affected by extreme heat (Guxens et al., 2014; Mitku et al., 2023).
- Studies have highlighted that climate change, through its impact on mean temperature and lengthening of activity season, has already impacted ragweed pollen loads (Ambrosia sp.) in Europe (Hamaoui-Laguel et al., 2015) and globally (Xian et al., 2023).
- Increases in melanoma cases have been observed in Norway, the Netherlands, Denmark, Sweden and Germany. Increased exposure to ultraviolet B radiation can be driven by stratospheric ozone levels, cloud cover, surface albedo and human behaviour. There is medium confidence that solar radiation is increasing over southern Europe and decreasing over northern Europe (Ranasinghe et al., 2021c; EEA, 2021g).

**Future situation**

- Under a 1.5°C global warming level (GWL) in the near to mid-term future, 100 million people/year in the EU and the UK are expected to be exposed to extreme heatwaves (one with a 2% probability of occurring in any given year), compared to 10 million people/year under the 1981-2010 baseline. Population exposure to extreme heat is projected to increase to 172 million/year by 2100 under a low-emissions scenario and to nearly 300 million/year under a high-emissions scenario in the long term (Cammalleri et al., 2020).
- The share of EU elderly people aged over 65 is projected to increase from 19% currently to 30% by 2100, exacerbating the risk of heat-related exposure and mortality (Rohat et

al., 2019). Without adaptation, and given the expected demographic changes, extreme heat-related mortality in the EU is projected to increase 10-fold under 1.5°C GWL but by more than 30-fold at 3°C GWL (Forzieri et al., 2017; Gasparrini et al., 2017; Guo et al., 2018; Vicedo-Cabrera et al., 2021). The effects on mortality and morbidity will be highest in southern Europe (Åström et al., 2013).

- The increasing share of the elderly population in Europe, combined with an increase in underlying health problems, are expected to result in an increase of the burden of disease related to air pollution. Under 2°C GWL, annual premature mortalities due to exposure to near-surface ozone are projected to increase up to 11% in western-central Europe and southern Europe (Orru, 2019).
- Pollen seasons are likely to be extended and start earlier due to future climate change, with the largest increase in pollen counts anticipated over eastern and southern Europe (Hamaoui-Laguel et al., 2015; Lake et al., 2012).
- A projected increase in wildfires and reduced air quality is expected to increase respiratory illnesses, morbidity and mortality, especially in southern Europe. Europe's ageing population will likely increase the air pollution-related mortality burden by 3-13% by 2050 (Slezakova et al., 2013; De Rigo et al., 2017).

### *7.3.3 Subsystem: vector-borne diseases*

**What drives the impact**

- Many infectious diseases are affected by climatic conditions, including common respiratory diseases, such as influenza and COVID-19. However, there is currently no robust evidence suggesting that climate change would significantly alter the risk of those diseases in Europe (Lane et al., 2022). Therefore, the focus of this subsystem is on vectorborne diseases.
- Increasing temperature, frequency and intensity of extreme events, such as heatwaves, floods and droughts, can accelerate the transmission of various infectious diseases, by enhancing the survival, reproduction and distribution of pathogens, and their vectors. This can result in a range expansion (northwards and in altitude), a longer transmission season, and the emergence and spread of infectious diseases in humans, animals and plants (EEA, 2022b; Semenza et al., 2022; Mora et al., 2022; McIntyre et al., 2017).
- Infectious disease risk is also influenced by non-climatic risk drivers, such as travel and tourism, land use, urban environments, socio-economic factors and human behaviour (Semenza et al., 2016b).
- Climatic conditions affect the distribution of hosts and vectors, and their seasonal activity, impacting the length of the transmission season. Rainfall provides potential breeding sites, and temperature affects the development and mortality of mosquito vectors during their life stages. Higher temperatures significantly shorten the time required for a mosquito to become infectious (Semenza and Paz, 2021).
- Temperature plays a crucial role in viral replication rates and pathogen transmission, affecting the length of extrinsic incubation. Elevated ambient temperatures also increase growth rates of vector populations, decrease the interval between blood meals and accelerate the rate of virus evolution (Semenza and Paz, 2021).
- Key examples of mosquito- and tick-borne diseases that have either expanded their range or recently emerged in the EU include: West Nile virus, chikungunya, dengue,

Lyme disease, tick-borne encephalitis and Crimean-Congo haemorrhagic fever (EEA, 2022b; Semenza et al., 2022; Semenza and Paz, 2021).

- Climate and land use change could facilitate zoonotic spillover. Species will aggregate in new combinations at high elevations, in biodiversity hotspots, and in areas of high human population density, increasing the risk of cross-species transmission of their associated viruses (Carlson et al., 2022).
- A wide range of zoonotic diseases have shown to exhibit climate sensitivities (Mora et al., 2022), but many of these are not well studied. Many vector-borne diseases are also connected to zoonotic cycles (tick-borne diseases, West Nile virus and leishmaniasis), and evidence suggests that climate change is increasing the risk of zoonosis (Rupasinghe et al., 2022). For example, while wild bird behaviour and migration affect West Nile virus outbreaks, they also influence the outbreak patterns of avian flu linked to changes in hydrological patterns (Prosser et al., 2023).
- Increased temperature and changes in humidity and precipitation patterns affect the transmission and spread of antimicrobial resistance (MacFadden et al., 2018; Meinen et al., 2023).

**Current situation**

- Chikungunya: two large outbreaks in Italy (2007 and 2017) with hundreds of cases, and three in France (2010, 2014, 2017) with over 10 cases each (ECDC, 2023d). Threshold conditions for mosquitoes' capacity to transmit disease among humans are highly influenced by ambient temperature (Semenza and Paz, 2021).
- Dengue: transmission has been reported in France, Spain, Croatia, Italy and on the Portuguese island of Madeira since 2010. The number of autochthonous cases has increased significantly, with a marked increase in southern France in 2022. In 2023, a cluster of cases was also reported in the Île-de-France region (Fournet et al., 2023). According to the Lancet Countdown in Europe, the dengue transmission season in Europe increased by 1 week between the periods 1951-1985 and 1986-2020 (van Daalen et al., 2022).
- West Nile virus: most human infections in Europe occur in the summer and early autumn; mosquito vectors feed on migrating birds, horses and humans. A small percentage of human infections can be fatal. The current expansion and outbreak patterns are mainly driven by climatic conditions. Higher spring temperatures in 2018 has been associated with an early onset of West Nile virus transmission and the magnitude of the outbreak (Farooq et al., 2022; Heidecke et al., 2023). In 2023, 707 human cases of West Nile virus and 67 deaths were reported in Europe (in Italy, Greece, Romania, France, Hungary, Spain, Germany, Croatia and Cyprus) (ECDC, 2023b).
- Malaria: sporadic cases have been reported among migrants and local populations in Greece. Given that competent malaria vectors are still present, the public health risk is heightened (Tsioni et al., 2019; Spanakos et al., 2018).
- Tick-borne diseases: from 2012 to 2020, 19 countries reported 29,974 tick-borne encephalitis cases, of which 24,629 (98.6%) were autochthonous. Czechia, Germany and Lithuania reported 52.9% of all cases. Many areas in Europe already have suitable climates for ticks, including central and northern Europe (Van Heuverswyn et al., 2023).
- Leishmaniasis: increasing temperature has increased climatic suitability for sandflies and will likely result in northward expansion (Semenza and Paz, 2021). Countries with

moderate or high endemicity include Albania, Bulgaria, Croatia, Cyprus, France, Greece, Italy, Malta, North Macedonia, Portugal and Spain (WHO, 2023b).
- Social vulnerabilities can lead to higher exposure among farmers and forestry workers, and lower detection and later control in less privileged areas and communities in Europe (van Daalen et al., 2022).

**Future situation**
- Chikungunya: a moderate increase is expected in climatic suitability in central Europe, France, Italy and areas surrounding the Rhine and Rhone rivers (Tjaden et al., 2017).
- Dengue and malaria: the transmission season could increase by 1-2 months (eventually by 6 months for malaria) in southern and eastern Europe by 2080; an additional 150-200 million and 200-250 million people, respectively, are projected to be at risk (Colón-González et al., 2021).
- West Nile virus: an expected expanding area in western Europe; transmission increase over southern and Eastern Europe, north-east Italy and southern France (Farooq et al., 2022; Semenza et al., 2016).
- Lyme disease: under RCP2.6-SSP1 reduced risk for Lyme disease but high increase projected in northern Europe under RCP4.5 (Li et al., 2019).
- Leishmaniasis: increase in climatic suitability, with expansion towards western Germany and Switzerland in the mid-term, and south-east Germany and north-east Austria by 2100 (Fischer et al., 2011; Koch et al., 2017; Chalghaf et al., 2018; Erguler et al., 2019).
- Future climate change will likely lead to bacterial pathogen spread and increased antimicrobial resistance in Europe, exerting additional stress on Member States' healthcare systems (Kaba et al., 2020; United Nations Environment and Programme, 2023).
- Viruses are estimated to be much more likely to cross over from one zoonotic host animal to another with climate change, potentially resulting in higher exposure for humans and a higher risk of zoonotic spillover. These changes are mediated through changes in the distribution and abundance of zoonotic host animals adapting to changing climate conditions, for example, seeking out new habitats in previously unsuitable areas (Carlson et al., 2022).

### *7.3.4 Subsystem: water and foodborne diseases*

**What drives the impact**
- Increase in temperature combined with extreme precipitation results in cascading events (Semenza et al., 2022). Rainfall mobilises faecal pathogens from pastures and fields, transferring them to downstream rivers and lakes where they can enter water treatment plants and distribution systems, resulting in potential waterborne disease outbreaks (Semenza, 2020).
- Flooding has been associated with outbreaks of waterborne diseases, such as leptospirosis, in both urban and agricultural areas (Suk et al., 2020). In urban areas, extreme precipitation and flooding can cause sewage overflow, increasing the infectious disease risk, particularly in children (Semenza et al., 2022; Semenza, 2020; Funari et al., 2012; EEA, 2020).
- Wildfires can compromise water quality if ash settles on lakes or reservoirs used for drinking water. Even after a fire has been extinguished, wind erosion can degrade water quality and hamper water treatment (Semenza, 2020).

- Waterborne diseases: salmonellosis, non-cholera Vibrio infections, campylobacteriosis and giardiasis demonstrate distinct seasonal peaks during the warmer season (e.g. increase in bacterial diarrhoeal infections due to Salmonella and Campylobacter (Semenza et al., 2017).
- Many cyanobacterial blooms in the EU are toxic and their spatial distribution is expected to increase due to warming (Meriluoto et al., 2017).
- Climate change increases the risks to food safety, including those posed by toxigenic fungi, plant and marine-based pathogens and from increased use of chemicals (Bezner Kerr et al., 2022). Higher temperatures and altered moisture conditions increase the risk of infections by several climate-sensitive foodborne pathogens, such as Salmonella spp., Campylobacter spp. and toxin-producing Escherichia coli strains (FAO, 2020; EFSA et al., 2020). Risks to food safety may increase associated with standard hygiene in processing plants, and nutritional content and preservability of food may be affected as well (FAO, 2020).
- Consumption of seafood and fish infected by cyanotoxins associated with algal blooms has resulted in food safety issues (FAO, 2020; EFSA et al., 2020). Climate change has affected the accumulation of contaminants (heavy metals, persistent organic pollutants, fertiliser residues) and mycotoxins in food, impacting the availability of safe food for human consumption (FAO, 2020; EFSA et al., 2020).

**Current situation**

- Campylobacteriosis, giardiasis, hepatitis A and shigellosis are the most reported gastrointestinal infectious diseases that can be attributed to contaminated food or water in Europe (Kulinkina et al., 2016; WHO, 2022).
- In 2020, nine EU Member States (Austria, Belgium, Denmark, Finland, France, Greece, Ireland, Italy and Sweden) reported 35 waterborne outbreaks associated with the consumption of either 'tap water, including well water' (26 outbreaks), 'drinks, including bottled water' (8 outbreaks), or 'water, unspecified' (1 outbreak) (EFSA and ECDC, 2021). In northern Europe and the UK, extreme precipitation events have been associated with waterborne disease outbreaks (Nichols et al., 2009; Funari et al., 2012; Guzman Herrador et al., 2016).
- Several waterborne and foodborne diseases demonstrate seasonal peaks during the warmer season, such as salmonellosis, non-cholera Vibrio infections, campylobacteriosis and giardiasis (Semenza and Paz, 2021; Semenza et al., 2017).
- Sea surface temperature warming patterns have coincided with the unexpected emergence of Vibrio infections in northern Europe, particularly around the Baltic Sea area for 1980-2010 (Baker and Anttila, 2020).
- The melting of permafrost led to the release of anthrax spores from dead reindeers that infected nomadic Siberian populations (Ezhova et al., 2021). While other prehistoric eukaryotic viruses have been revived from the permafrost, and they present substantial risk, the public health risk is considered to be low (Polar Research Board et al., 2020; Alempic et al., 2023; Strona et al., 2023).

**Future situation**

- Scandinavia may experience a doubling of Campylobacter cases by the end of the 2080s, corresponding to around 6,000 excess cases per year caused only by climate change (Kuhn et al., 2020).

- For marine bacteria in the Baltic Sea, such as non-cholera Vibrio, climate change projections indicate an upward trend of these infections during the summer months and an increase in the relative risk in the coming decades (Semenza et al., 2017). Moreover, the number of months with risk of Vibrio transmission is projected to increase and the seasonal transmission window will expand (Trinanes and Martinez-Urtaza, 2021).
- Major outbreaks of Salmonella are linked to consumption of leafy vegetables; a 1°C increase in ambient temperature above 5°C may cause a 5-10% increase in Salmonella infections (Semenza and Menne, 2009). By 2100, 50% of the additional Salmonella infections in Europe are projected to be caused by increased temperature, and not by a population increase (Rupasinghe et al., 2022).

### *7.3.5 Subsystem: labour force impacts*

**What drives the impact**

- Climate change affects workers' safety and health through heat stress, ultraviolet radiation exposure, contact with pathogens, indoor and outdoor air pollution and extreme weather. This can result in higher health costs, reduced quality of life and declines in labour supply and productivity (Kjellstrom, 2016; Dasgupta et al., 2021; Dasgupta and Robinson, 2023).
- Heat stress leads to 'thermal stress', affecting both the health and human capital of workers. Worker health is negatively affected through increasing levels of discomfort, decreased cognitive functioning and an increase in workplace accidents. Workers exposed to high heat will typically reduce their work output, take more unplanned breaks or work at a slower pace (Dasgupta and Robinson, 2023). However, some workers, particularly those undertaking piecework, may feel pressured not to reduce their output, thereby compromising their health further (European Climate and Health Observatory, 2022).
- Some materials and equipment may also be affected by higher temperatures, and higher exposures to chemicals may be related to working in hot environments, for example, when working with solvents and other volatile substances (Kutanjac, 2023).



**Current situation**

- 23% of EU workers report being exposed to high temperatures at work (Eurofound, 2017).
- In 2021, 9.3 million people in the EU (4.5% of total employment) worked in the agriculture, forestry and fishing sectors; 13.9 million (6.4% of total employment) worked in construction (Eurostat, 2023).
- Extreme temperatures and frequent heatwaves in southern Europe in 2020 and 2023 resulted in instances of heat stroke and fatalities among outdoor workers, especially those in the agriculture, construction, street maintenance and waste collection sectors (Martínez-Solanas et al., 2018; Nybo, 2021).
- The farming population in the EU is relatively old, with a third of workers aged over 65 (Jones, 2020; El Khayat et al., 2022). As such, they are particularly vulnerable to heat stress, including heat-related kidney diseases (Jones, 2020; Meima, 2020; Covert and Langley, 2002).
- Heat stress is already affecting the EU labour force. Compared to the 1965-1994 reference period, the number of working hours (labour supply) declined by 0.23% (4 hours per worker/year) during the period 1995-2000, but by 0.98% (16 hours per worker/year) during the period 2016-2019 due to warming. The highest declines are

estimated to be in Cyprus, Greece and Spain (Dasgupta et al., 2021; van Daalen et al., 2022). Past major EU heatwaves (August 2003, July 2010 and July 2015) have led to GDP reductions of 0.3-0.5%.

- Increasing temperatures have had differentiated impacts on the EU labour force, with a higher impact in southern Europe (van Daalen et al., 2022). Heat stress also has a disproportionately higher effect on outdoor workers, with inequality and poverty implications as incomes in these sectors (agriculture and construction) are lower (Dasgupta et al., 2021). Heat stress impacts on the labour force are also a climate justice issue (Dasgupta and Robinson, 2023).
- Workers in indoor sectors such as electricity, gas and water supply and manufacturing and service sectors like healthcare and food services are also at risk from increased heat stress, particularly when the job involves physical work, or when protective clothing is worn.
- At the EU level, there is currently no binding legislation protecting workers from extreme temperatures and only a few Member States have developed specific plans for protecting the working population from heat events, including maximum temperature thresholds. In the case of national legislation, an acceptable range of temperature conditions for work is not always specified, especially for outdoor work.

**Future situation**

- Effective labour (a combination of the number of working hours and output during these working hours) in the high-exposure sectors in southern Europe is expected to decrease by up to 13.6 percentage points (pp) points under 1.5°C GWL (2030-2050), 18.2 pp points under 2°C GWL (2050-2070) and 28.5 pp points under 3°C GWL (2070-2090) (Dasgupta et al., 2021).
- Even in the low-exposure sectors in southern Europe, these declines are projected to be 0.9 pp points under 1.5°C GWL, 1.7 pp points under 2°C GWL, and 3.7 pp points under 3°C GWL (Dasgupta et al., 2021).
- In the near term and under a low-emissions scenario, heat stress is projected to reduce the summertime work capacity of outdoor workers in southern Europe to 60% of maximal capacity (Ioannou, 2022).
- The European workforce lacks information on effective measures to mitigate occupational heat stress, and employers are unlikely to provide adequate protection for workers without regulations.
- A major gap in our understanding of future impacts on the labour force is the lack of projections on the impacts of future climate change on occupational injuries (Dasgupta and Robinson, 2023).
- Labour laws stipulating reasonable and maximum temperature thresholds for working will likely have to be mandated by government agencies in collaboration with the European Agency for Safety and Health at Work (EU-OSHA).

## 7.4 Risk assessment and evaluation

### *7.4.1 Confidence*

- Uncertainty in future projections of health impacts will be driven by climatic, demographic, environmental and socio-economic trajectories.

- A source of uncertainty in our understanding of the health impacts of climate change is the differentiated responses of public health systems.
- Sources of uncertainty in the projections of heat-driven mortality include acclimatisation, the population's ability to adapt to extreme heat, and climatic tipping points.
- There is limited evidence on the impacts of wildfires and smoke on the health of the European population (*medium confidence, low evidence*).
- There is limited evidence on the association between drought and waterborne disease outcomes (*low confidence, low evidence*). However, the evidence base differs across diseases.
- Warming can accelerate the replication rate of certain pathogens and thus reduce the shelf-life of food (*low confidence*). Extreme precipitation and flooding can result in food contamination and increased incidences of foodborne diseases (*low confidence, low evidence*).
- Heat stress and more frequent and intense heatwaves have increased the incidences and risk of occupational injuries in Europe, especially among outdoor workers (*high confidence*, *low evidence*). These health effects are already reducing labour supply and productivity (*high confidence*). However, the total number of European workers being harmed by climate change and the effects of extreme events remain to be quantified (*high confidence*, *low evidence*).

### *7.4.2 Adaptation opportunities, constraints and limits*

The EU adaptation strategy highlights the need to develop a deeper understanding of the climate-related risks for health, such as increasing cross-border health threats and stress on public health systems (Semenza et al., 2022), and building capacity to counter them (EC, 2021). The European Climate and Health Observatory provides a platform to pool and connect data, tools and expertise to communicate, monitor, analyse and prevent the effects of climate change on human health.

At national and local levels, adaptation is largely siloed in separate departments without the inclusion of health officials or consideration of health co-benefits and trade-offs. Key enabling conditions to extend the solution space include increasing the role for national and regional governments in facilitating knowledge-sharing across scales, allocating dedicated financial resources, and creating dedicated knowledge and policy programmes on climate and health (Wolf et al., 2014; Akin et al., 2015; Curtis et al., 2018). Integrating human health into all climate change adaptation policies including heat health action plans, supporting the capacity and preparedness of the health sector, and designing socially just adaptation measures can limit risks from climate-related health effects (van Daalen et al., 2022).

Health and health-determining sectors have the opportunity to address the health and well-being impacts of climate change by:

- increasing the climate resilience of health systems (Semenza, 2020) and facilities and decarbonising service delivery;
- establishing health-centred targets in national planning, as well as developing, updating and implementing national health adaptation plans (EASAC, 2019);
- developing accessible medical countermeasures;
- developing and updating heat health action plans and adapting urban planning to address the impacts of urban heat island effects, while reducing overheating of buildings, particularly concerning vulnerable population groups;
- establishing and updating regulatory requirements to ensure the climate resilience of water and sanitation services;
- strengthening disaster risk reduction policies and early warning and surveillance systems; and

- Supporting the education and training of public health and healthcare professionals on climate change threats (World Health Organization, 2023).

There is a further need to strengthen and invest in prevention of non-communicable diseases, the prevalence of which is expected to rise in a rapidly ageing society, which, together with climate-related risks for health, will put more pressure on health systems.

Lack of quantitative assessments of adaptation options under future warming is a constraint (van Daalen et al., 2022). Efforts are needed to overcome the lack of health impact assessments in proposed initiatives and the lack of monitoring of climate and health data, to assess the effectiveness of adaptation and mitigation strategies (EASAC, 2019). Consideration of the varying vulnerability and exposure of different demographic and socio-economic groups is needed, together with monitoring, evaluation and dissemination of knowledge on the effectiveness of solutions (EEA, 2022b).

### *7.4.3 Overall assessment*

This section presents the outcomes of the structured risk assessment for the major climate risks identified in this factsheet. This assessment builds on information in this factsheet, and possibly in other chapters of this report. The initial risk assessment was conducted by the authors of this factsheet whereas the final assessment results reported here represent the consensus of the EUCRA risk review panel. Further methodological information is available in Annex 2.

The following major risks assessed in other chapters are also relevant for this factsheet, but they are not presented here to avoid duplication:

- Risk to human health from the emergence of harmful algal blooms and pathogens (Chapter 4).
- Risk of public health crises due to interrupted healthcare supply chains, including pharmaceuticals and other medical supplies, caused by extreme weather events outside Europe (Chapter 16).

### Table 7.1 Risk assessment for the risk to human health from heat stress increased by climate change

| | Current/near term (2021-2040) | Mid-term (2041-2060) | Long term (2081-2100) |
|---|---|---|---|
| **Risk severity** | **Critical**<br>Heatwaves in 2003 alone led to over 70,000 excess deaths, which drove a shift to adaptation options, such as spreading of cooling systems, awareness of health risks and early warning systems. Yet, recent 2022 heatwaves have caused more than 60,000 heat-related deaths in Europe, with the highest share in Italy, Spain, Germany, France, the UK and Greece. If pollution levels are not reduced, the interaction between heat and pollution will exacerbate exposure. | **Catastrophic**<br>Projected increases in length and intensity of heatwaves, combined with growing urbanisation and an ageing population will result in more vulnerable groups and high health risks, especially in southern Europe. By 2050, citizens aged over 65 will constitute almost 30% of the population. | **Catastrophic**<br>Health-related risks further increasing, especially in southern Europe. Under high-emission scenarios, intense heatwaves may occur almost every year in southern Europe, and every 3-5 years in other European regions. In heat-related mortality will increase by 3 and seven times, respectively, under low and high warming.<br>Without proper adaptation, 30,000 deaths from extreme heat may be expected annually under low warning, and up to 90,000 under high warming. southern Europe is at relatively higher risk. |
| **Confidence** | **High**<br>High risks are already being observed. | **High**<br>Increasing severity of heat risks to the population is a robust finding, even though the exact size of the effect is uncertain. | **High**<br>Increasing severity of heat risks to the population is a robust finding across all studies, even though the exact size of the effect is uncertain and depends on the warming scenario. |
| **Risk ownership** | **National**<br>• EU Member States are responsible for organising and delivering health services and medical care. The EU's role in health policy is therefore complementary to national policies.<br>• In the specific case of adaptation to heat-related health risks, the EU may assume a more prominent role in providing support. | | |
| **Policy readiness** | **Medium**<br>• National governments calculate heat-related mortality in different ways.<br>• Data on the effects of extreme heat events on Member States' health systems are widely lacking.<br>• Need for effective regulation to protect workers, in particular in new and non-standard forms of employment, from heat stress.<br>• EU-OSHA published heat at work guidance in May 2023.<br>• There are plans to use green spaces to mitigate the urban heat island effect, but the timeframe to achieve these objectives and the rate at which green spaces can cool the urban environment do not match the rate at which heat affects health.<br>• Aspects of social justice (towards vulnerable elderly and chronic illness groups, for example) are often missing from policies.<br>• Different approaches are used to estimate the heat-related mortality burden across Member States. | | |
| **Policy horizon** | **Long term** | | |
| **Urgency to act** | **Urgent action needed**<br>This applies particularly in the context of early warning and response systems and heat-related health adaptation actions. | | |

**Source**: EEA.

### Table 7.2 Risk from geographic expansion and increased transmission of infectious diseases

| | Current/near term (2021-2040) | Mid-term (2041-2060) | Long term (2081-2100)<br>• high warming<br>• low warming |
|---|---|---|---|
| **Risk severity** | **Limited**<br>Geographical and temporal suitability of | **Substantial** | **Critical** |

| | | | |
|---|---|---|---|
| | several infectious diseases (e.g. tick-borne diseases) are already on the rise. | Range expansions of vector-borne diseases into previously colder areas.<br>Increased risk from tick-borne diseases, vector-borne diseases and *Vibrio* will materialise in the medium term across Europe.<br>This expansion will largely be driven by land use change and vector control.<br>Risks of vector-borne disease would become severe with high warming and current levels of vulnerability. | Higher risk of tick-borne diseases under 1.5°C GWL compared to 3°C GWL. Northern Europe will be at higher risk.<br>Increased risk of West Nile virus under both warming scenarios. Higher risk in southern Europe, and western and central Europe.<br>Higher risk of chikungunya, dengue, malaria and Zika in southern Europe, and western and central Europe.<br>High risk for *Vibrio* in western and central Europe and to a lesser extent northern Europe.<br>Tick-borne infections could increase further in northern Europe in the future.<br>**Substantial**<br>See mid-term |
| **Confidence** | **High** | **Medium** | **Medium** |
| **Risk ownership** | **Co-owned (European and national)**<br>• Public health is under the jurisdiction of Member States.<br>• Infectious diseases with cross-border impacts are covered by EU policies. | | |
| **Policy readiness** | **Advanced**<br>• The EU policy and institutional framework for addressing infectious diseases with cross-border impacts has been strengthened recently with the Regulation (EU) 2022/2371 on serious cross-border threats to health, and the establishment of the Health Emergency Preparedness and Response Authority.<br>• The European Centre for Disease Prevention and Control provides operational knowledge.<br>• The efficiency of relevant health policies addressing infectious disease risks varies across Europe. | | |
| **Policy horizon** | **Short term** | | |
| **Urgency to act** | **Sustain current action** | | |

**Source**: EEA.

### Table 7.3 Risk assessment for stress to health systems, including health infrastructure, from climate change

| | Current/near term (2021-2040) | Mid-term (2041-2060) | Long term (2081-2100)<br>• high warming<br>• low warming |
|---|---|---|---|
| **Risk severity** | **Limited**<br>Most public health systems across Europe are adequately prepared to address the increase in hospital admissions due to increased heat stress. | **Substantial**<br>If population vulnerability increases and preventive measures are insufficient, increasing climate-related risks will exert pressure on public health systems. | **Critical**<br>Health systems can reach their limits to adaptation.<br>**Substantial**<br>See mid-term |
| **Confidence** | **High** | **Medium** | **Medium** |
| **Risk ownership** | **National**<br>• Public health is under the jurisdiction of Member States, but climate change-induced health impacts are a pan-European issue and will need Europe-wide policies.<br>• Substantial institutional barriers complicate widespread implementation of health policy measures. | | |
| **Policy readiness** | **Medium**<br>• Highly heterogenous as the health system infrastructures of Members States vary significantly, as do existing capacities to deal with climate-related extreme events. | | |
| **Policy horizon** | **Medium term** | | |
| **Urgency to act** | **Further investigation**<br>• Potential for cascading risk – morbidity and mortality from heat stress and risk of infectious diseases, occupational settings will increase the stress on public health systems across Europe.<br>• Limited mainstreaming of climate change due to low to moderate societal pressure to change, combined with lack of awareness of links between human health and climate change.<br>• Increased coordination of health policies and actions across scales and between Member States is needed to ensure timely and effective responses for a diversity of health impacts. | | |

**Table 7.4 Risk assessment for health risks to outdoor workers from increased heat stress: all Europe and southern Europe**

| | Current/near term (2021-2040) | Mid-term (2041-2060) | Long term (2081-2100)<br>• high warming<br>• low warming |
|---|---|---|---|
| **Risk severity (all Europe)** | **Limited**<br>Most European regions are below the peak temperature for outdoor work. | **Substantial**<br>Increasing risk of occupational health impacts and reduced labour productivity. | **Critical**<br>Further increasing risk of occupational health impacts. Manual and field workers are particularly at risk.<br>**Substantial** |
| **Risk severity (southern Europe)** | **Substantial**<br>Many regions in southern Europe are closer to the peak temperature thresholds for outdoor work. | **Critical**<br>Increasing risk of occupational health impacts and reduced labour productivity. | **Critical**<br>Thermal comfort hours during summer will decrease by as much as 74% in southern Europe, increasing the risk for outdoor workers. |
| **Confidence** | **High** | **High** | **High** |
| **Risk ownership** | **Co-owned (European and national)**<br>• National labour laws<br>• EU-OSHA at the European level | | |
| **Policy readiness** | **Medium**<br>• While the EU-OSHA published the *Heat at work – Guidance for workplaces* in 2023, most European countries do not have maximum temperature thresholds for work.<br>• Lack of awareness of occupational risks is a major barrier to policy adoption and implementation. | | |
| **Policy horizon** | **Short term** | | |
| **Urgency to act** | **Watching brief (all Europe)**<br>**More action needed (southern Europe)**<br>• Early warning systems and implementation of labour protection regulations.<br>• Right to safe working conditions. | | |

**Source**: EEA.



## 7.5 Relevant policies

- **EU adaptation strategy**: sets out how the EU can adapt to the unavoidable impacts of climate change and become climate resilient by 2050. It established the **European Climate and Health Observatory** to provide access to information and tools to support Europe in preparing for and adapting to climate change impacts on human health. Its role to 'better understand, anticipate and minimise the health threats caused by climate change' is further confirmed by the **European Climate Law** (EC, 2021n). Provisions on climate change adaptation oblige Member States to develop adaptation strategies that take the vulnerabilities of relevant sectors into consideration, and to consistently integrate adaptation across all policy areas, while considering the most vulnerable and impacted populations and sectors.

- **EU4Health programme**: aims to improve and foster health in the EU, complementing the policies of Member States; protect people in the EU from serious cross-border threats to health; improve medicinal products, medical devices and crisis-relevant products; and strengthen health systems. This programme specifically proposes the mainstreaming of climate action in EU policies, including health policies. With a EUR 5.3 billion budget for the 2021-2027 period, the programme addresses long-term health challenges facing Europe. EU4Health provides a potential funding source for actions on climate change and health, including those foreseen under the 'Healthier Together' initiative.

- **Health Emergency Preparedness and Response Authority** (HERA): aims to fill a gap in the EU's health emergency response and preparedness by anticipating threats and potential health crises, through gathering intelligence and building response capacities. It is a key pillar of the European Health Union, established in 2021 following the COVID-19 pandemic, to prevent, detect and rapidly respond to health emergencies. HERA operates in two modes: preparedness or response. In the preparedness phase, investment and action are directed towards strengthening prevention, preparedness and readiness for new public health emergencies. In the response phase, the Health Crisis Board is mandated to ensure coordinated action by the European Commission, relevant EU agencies and bodies, and Member States to ensure the development, production and distribution of medicines, vaccines and other medical countermeasures.

- **Emergency framework Regulation (EU) 2022/2372**: constitutes the legal basis for crisis activities regarding medical countermeasures in the event of a public health emergency, facilitating the purchase of medicines, vaccines and raw materials, activating emergency funding and enabling the monitoring of production facilities. When the EU Council recognises a public health emergency at EU level and activates the emergency framework, **HERA** shifts into the crisis phase, allowing for swift decision-making and the activation of emergency measures.

- **Serious cross-border threats to health Regulation (EU) 2022/2371**: sets out to deliver a strengthened framework for health crisis prevention, preparedness and response at EU level by addressing the weaknesses exposed by the COVID-19 pandemic. The regulation specifically mentions threats due to environmental and climate change. It lays down rules on prevention, preparedness and response planning; joint procurement of medical countermeasures; emergency research and innovation; epidemiological surveillance and monitoring; a network of epidemiological surveillance; an early warning and response system; risk assessment for all hazards; coordination of response; and recognition of public health emergencies at an EU level. It also establishes a network of EU reference laboratories for public health; a network for substances of human origin; and an advisory committee for the occurrence and recognition of a public health emergency at EU level. Additionally, the EU element of the 'shared competence' in public health has been strengthened following the COVID-19 pandemic.

- **EU Civil Protection Mechanism**: aims to strengthen cooperation between EU countries and 10 participating states to improve prevention, preparedness and response to disasters. It applies a joint approach to pool expertise and capacities of first responders, to avoid duplication of relief efforts and ensure that assistance meets the needs of those affected when an emergency overwhelms the response capabilities of an individual country. Specialised teams and equipment can be mobilised at short notice for deployment inside and outside Europe.

- **OSH Framework Directive (89/391/EEC)**: introduces measures to encourage improvements in the safety and health of workers at work, and encourages prevention of all occupational risks that may emerge in employers' work activities from all branches of economic activity (public or private), and which can affect their workers and third parties. Relevant directives based on the OSH Framework Directive that address heat at work include the **Temporary or Mobile Construction Sites Directive (92/57/EEC)** and the **Workplace Directive (89/654/EEC)**.

- **EU-OSHA Heat at work – Guidance for workplaces**: provides practical organisational and technical guidance on managing the risks associated with working in heat for both employers and workers to mitigate, manage and train for occupational risk.

- **Drinking Water Directive ((EU) 2020/2184)**: sets requirements on the quality of and access to water intended for human consumption. It provides safety standards, a strong link to risk assessment and management in catchments of drinking water supplies (including climate risks) and a watch list of emerging substances. Member States are required to improve and maintain access to drinking water for all, in particular vulnerable and marginalised groups.
- **Horizon Europe**: funds EU research and innovation for the 2021-2027 period. A cluster of health-focused projects aims to improve and protect the health and well-being of citizens by generating new knowledge and developing innovative solutions.

# 8 Energy

## 8.1 Key messages

- Climate risks for energy security vary across Europe. Overall, southern Europe faces increasing risks from heat, droughts and water scarcity, whereas northern Europe can experience both risks and opportunities.
- Major climate risks for the European energy system include increased demand for cooling, regional reductions in hydropower potential, reduced efficiency of thermal power plants and electricity transmission, and impacts of extreme weather events on energy infrastructure.
- Prolonged droughts affecting electricity supply in combination with heatwaves affecting peak electricity demand can lead to power cuts, in particular in southern Europe.
- Coastal floods, inland floods, storms, wildfires and other climate-related hazards can cause damage to energy production and transmission infrastructure, and disrupt energy supply.
- Policies aimed at decarbonising the European energy system must consider the changing climate conditions during the usually long lifetime of energy infrastructure.
- A stable and affordable energy supply is central to nearly all activities in a modern society. Therefore, risks to energy supply can cascade to all economic sectors, but also to human health and wellbeing.
- Enhanced energy system resilience requires integrating climate change adaptation into planning, prioritising infrastructure maintenance, and leveraging technological innovations. Increasing energy efficiency, demand-side management, and smart grids can further increase energy security.
- Social justice considerations are essential in energy adaptation planning, ensuring equitable access to resources and addressing energy poverty.



## 8.2 Introduction

Climate change poses a significant challenge to the European energy sector, which must adapt and enhance its resilience. Key EU policies like the European Green Deal highlight the necessity to integrate climate change adaptation into energy planning (EC, 2023m). As Europe transitions to a low-carbon energy system, understanding climate impacts becomes crucial. This chapter focuses on how climate change affects four key energy subsystems:

- energy demand, encompassing electricity, heating, cooling and transport demand;
- energy transportation and storage, involving transmission and distribution grids, electricity networks, district heating systems, gas networks, etc.;
- energy generation and conversion, encompassing conventional and thermal power plants, hydropower plants and renewable energy sources;
- primary energy carriers.

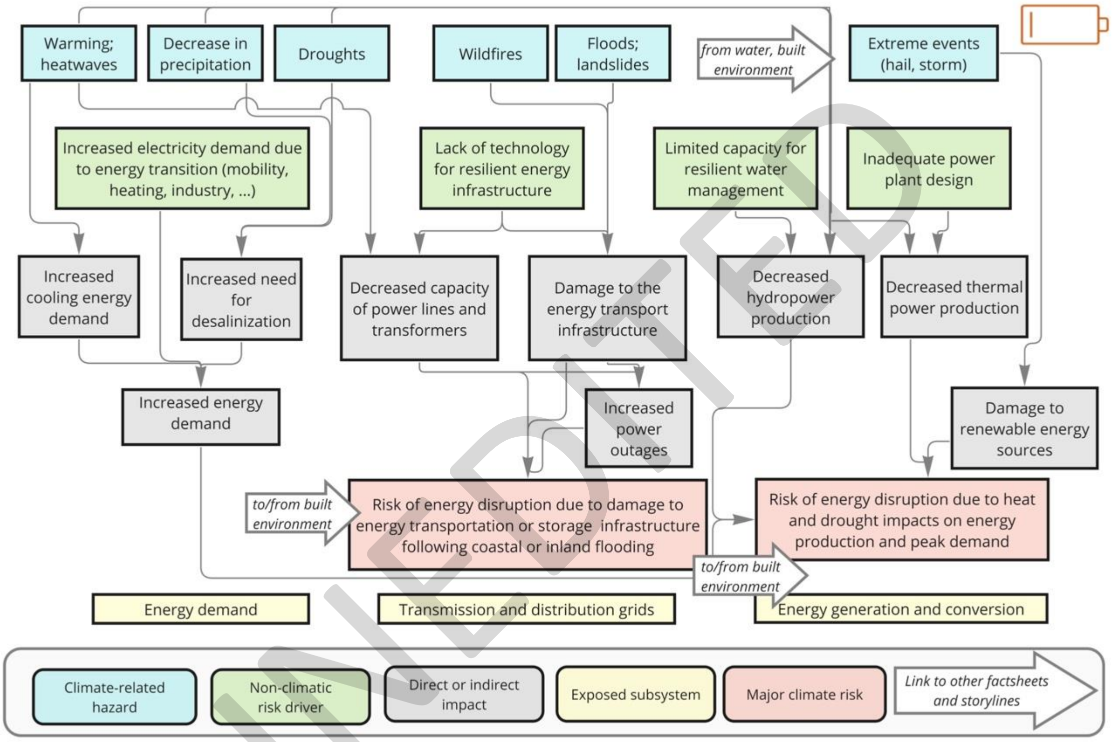
The chapter summarises current and projected climate change impacts and major risks for these subsystems. The main climatic drivers are rising temperatures, varying water availability, more frequent extreme weather events, and coastal and marine hazards. These can lead to higher energy demand, damage to infrastructure and disruptions in supply (EEA, 2019a; IPCC, 2022d).

Impacts and risks differ across Europe, with predominantly adverse effects in southern regions. Adaptation strategies like infrastructure enhancements, energy storage and regional planning are needed to increase resilience. However, barriers exist regarding resources, stakeholder engagement and urgency (EEA, 2019a). There are also implications for social justice, as climate risks can exacerbate regional inequalities (IPCC, 2022d).

## 8.3 Risk drivers and impacts

### *8.3.1 Impact chain*

**Figure 8.1 Climate change impact chain for the subsystems of the energy system**






**Source:** ETC-CA, 2024.

### *8.3.2 Subsystem: energy demand*

**What drives the impact**

- Changes in ambient temperature reduce total energy demand in colder countries but increase demand in warmer countries (Harang et al., 2020; Pérez-Andreu et al., 2018a).
- Heating and cooling degree days show decreasing and increasing trends, respectively (EEA, 2019e; Spinoni et al., 2015, 2018).
- Changes in water availability increase energy demand for agriculture, households and desalination (Caldera and Breyer, 2020).

**Current situation**

- Energy use in households shows no clear trend, while demand from transport and services is increasing.
- Heating accounts for a large share of final energy consumption in buildings and industry (Heat Roadmap, 2019).
- Cooling accounts for only a small fraction of energy use, except in southern Europe (EEA, 2022f; Pezzutto et al., 2022).

**Future situation**

- Per capita energy demand may peak around 2030 due to efficiency gains (IEA, 2016; Troccoli, 2018; WEC, 2016).
- Electricity demand could double by 2060 due to electrification, urbanisation and lifestyle changes (Troccoli, 2018).
- EU strategy focuses on reducing overall energy demand through efficiency and behavioral changes (EC, 2023m).
- Climate change alone is expected to increase EU-wide national average electricity demand by <5% by mid-century (Damm et al., 2017).
- Peak electricity demand for cooling will increase, especially in southern Europe (Damm et al., 2017; Wenz et al., 2017).

### *8.3.3 Subsystem: energy transportation and storage*

**What drives the impact**

- Higher temperatures and heatwaves reduce transmission capacity (Burillo et al., 2019; Sathaye et al., 2013).
- Droughts and low river levels hinder fuel transport and raise costs (Christodoulou et al., 2020; Lehane, 2018).
- Extreme weather events like floods, windstorms, forest fires and ice can damage energy infrastructure (Bonelli et al., 2011; EEA, 2019a; Llasat et al., 2014).
- Coastal hazards like sea level rise and storm surges threaten coastal energy facilities (Azevedo De Almeida and Mostafavi, 2016; Brown et al., 2013).

**Current situation**

- Electricity grid interconnections and smart grid technologies are expanding (EC, 2016, 2018b; EEA, 2019a).
- Long-distance gas pipelines are being replaced by liquefied natural gas imports to enhance resilience (EEA, 2019a).
- Severe weather has caused blackouts and infrastructure damage (EEA, 2019a; Rübbelke and Vögele, 2011).

**Future situation**

- Grid expansion is needed to support the growing share of renewable energy (Becker et al., 2014; EEA, 2019a).
- Closer electricity-gas integration can aid energy storage solutions (Blanco and Faaij, 2018).
- Monitoring systems could improve resilience of grid to extremes (EEA, 2019a).
- Gas infrastructure may need to be rededicated to hydrogen in some areas (EEA, 2019a).

### *8.3.4 Subsystem: energy generation and conversion*

**What drives the impact**

- Higher temperatures reduce the efficiency and output of thermal power plants (Abdin et al., 2019; Cronin et al., 2018; Liu et al., 2020b).
- Water scarcity constrains cooling water availability for thermoelectric plants (Payet-Burin et al., 2018).
- Extreme weather events like heatwaves, droughts and floods cause plant shutdowns (Perera and Hong, 2023; Qvist, 2019).

- Coastal hazards disrupt cooling water flows at coastal plants (Brown et al., 2013).
- Solar power plants are affected by climate variables in different ways. Solar irradiation directly influences the output of solar modules, higher air temperatures decrease module efficiency slightly, and hailstorms can cause expensive damage to solar panels (Plaga and Bertsch, 2023; Solaun and Cerdá, 2019; EEA, 2019a).
- Wind turbines cannot operate efficiently in extremely low or high wind conditions, leading to reduced generation.

**Current situation**

- The share of fossil fuels and nuclear in electricity has declined since 1990 but remains significant (EC, 2022e).
- Heatwaves have forced shutdowns of nuclear reactors in France for cooling reasons (Qvist, 2019; Reuters, 2018; ASN, 2023).

**Future situation**

- Climate change could reduce usable cooling water capacity at power plants by over 15% by mid-century (Van Vliet et al., 2013b, 2013a, 2016b, 2016a).
- Water constraints in southern Europe will limit nuclear generation, raising costs (JRC, 2020a).
- Carbon capture systems may reduce power plant efficiencies and increase water needs (Mapes and Larsen, 2023; Singh et al., 2022).

### *8.3.5 Subsystem: primary energy carriers*

**What drives the impact**

- Warming temperatures in the Arctic could enable access to more fossil fuel resources but damage infrastructure (EEA, 2017c; Forzieri et al., 2018a; Huang et al., 2017).
- Permafrost thawing threatens pipelines (Forzieri et al., 2018a; Hjort et al., 2018).
- Population changes drive shifts in energy demand (EEA, 2019a).
- Land use changes affect resource availability (EEA, 2019a).

**Current situation**

- Fossil fuels meet 81% of Europe's primary energy needs, relying heavily on imports (EC, 2022e; EUROSTAT, 2018).
- Oil and gas are the main energy sources (EC, 2022e).
- Coal's share has declined since 1990 but remains significant (EC, 2022e).

**Future situation**

- Fossil fuel usage in Europe has been declining since 2005 and is expected to continue decreasing in the future, under all climate mitigation scenarios (EEA, 2019a; EC, 2021g).
- Renewables will see the fastest growth (EEA, 2019a; EC, 2021g).
- Natural gas can aid the transition from coal (EEA, 2019a).
- Low-carbon gases and e-fuels will replace natural gas over time (EEA, 2019a).

## 8.4 Risk assessment and evaluation

The major climate risks identified for the subsystems (1) energy demand, (2) energy transportation and storage, and (3) energy conversion and generation are:

Risk of energy disruption due to damage to energy transportation or storage infrastructure following coastal or inland flooding.

Risk of electricity disruption due to heat and drought impacts on energy production and peak demand.

### *8.4.1 Confidence*

There is considerable evidence on observed and projected impacts of climate change on the European energy system, including various reviews (EEA, 2019a; Bednar-Friedl et al., 2022b). Projections for some climate drivers (e.g. temperature) are robust, whereas considerable uncertainty remains for regional changes in others (e.g. droughts in some regions and wind speed). Further uncertainty results from rapid changes in the energy system itself, driven by the decarbonisation agenda, and technical and geopolitical developments.

There is wide agreement that southern European regions generally experience more adverse effects, whereas certain benefits have been observed alongside negative impacts in northern and central Europe (EEA, 2019a; Bednar-Friedl et al., 2022b).

### *8.4.2 Adaptation opportunities, constraints and limits*

The establishment of the energy union and the EU's long-term climate action strategy presents valuable opportunities to integrate climate change adaptation into the planning and implementation of a decarbonised energy system in Europe. To effectively tackle climate change impacts, all countries should incorporate the assessment of these impacts on both current and future energy systems into their national energy and climate plans, long-term strategies under the energy union, and into the development and revision of their national adaptation strategies and action plans (EEA, 2019a).

Indicative adaptation limits for the European energy sector can be distinguished between technical, socio-economic, environmental and regulatory limits:

- **Technical limits:** technical/operational measures not possible due to plant characteristics, limited efficacy of measures under rapidly changing and hardly protectable climate hazards and/or limits due to physical characteristics of building stock;
- **Socio-economic limits:** high installation costs for large-scale adaptation or new infrastructure, poverty, comfort and safety;
- **Environmental and regulatory limits:** competitive water uses, limited areas for expansion/space constraints for expanding new (green) infrastructures.

### *8.4.3 Overall assessment*

This section presents the outcomes of the structured risk assessment for the major climate risks identified in this factsheet. This assessment builds on information in this factsheet as well as other chapters of this report (e.g. Chapters 12 and 15 for the first risk). The initial risk assessment was conducted by the authors of this factsheet whereas the final assessment results reported here represent the consensus of the EUCRA risk review panel. Further methodological information is available in Annex 2.

**Table 8.1 Risk assessment for the risk of energy disruption due to damage to energy transportation or storage infrastructure following coastal or inland flooding**

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)**<br>• **high warming** |
|---|---|---|---|

| | | | |
|---|---|---|---|
| | | | • low warming |
| **Risk severity** | **Substantial**<br>Floods are already causing disruptions to energy supply in Europe, although they are generally short-lived (Karagiannis et al., 2017). | **Critical**<br>Climate change will increase flood risks in most parts of Europe, and flood risks to energy supply and transportation infrastructure are increasing significantly (Karagiannis et al., 2019b). | **Critical**<br>Further increase in flood risks to energy infrastructure. |
| **Confidence** | **Medium** | **Medium** | **Medium** |
| **Risk ownership** | **Co-owned**<br>The EU and its Member States share legislative responsibilities with respect to energy policy, including production, transmission/distribution and end-use (e.g. energy efficiency). While the EU can introduce legislation and targets regarding net-zero and energy security objectives, it is at the discretion of Member States to decide on policies to deliver against these targets.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>- Critical Entities Resilience Directive (2022/2557)<br>- Energy union strategy (2015/080)<br>- Regulation on Risk-Preparedness in the Electricity Sector (2019/941)<br>- Strategy for energy system integration (2020/299)<br>- Regulation on Guidelines for Trans-European Energy Infrastructure (2022/869)<br>- Trans-European Networks for Energy (TEN-E) Regulation (2022/869)<br>- European Green Deal's provisions on just transition<br>- REPowerEU<br><br>At the national level, the main policies of relevance include those relating to:<br>- Energy<br>- Transportation<br>- Spatial planning and infrastructure<br>- The environment (e.g. water governance) | | |
| **Policy readiness** | **Advanced**<br>Considerable EU legislation is in place to ensure the management of critical energy infrastructure, including the new Critical Entities Resilience Directive. | | |
| **Policy horizon** | **Long term** | | |
| **Urgency to act** | **Further investigation** | | |

**Source**: EEA.

## Table 8.2 Risk of energy disruption due to the impacts of heat and drought on energy production and peak demand: all Europe and southern Europe

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)**<br>• **high warming**<br>• **low warming** |
|---|---|---|---|
| **Risk severity** (all Europe) | **Limited** | **Substantial** | **Critical**<br>**Substantial** |
| **Confidence** (all Europe) | **Medium** | **Medium** | **Low** |
| **Risk severity** (Southern Europe) | **Substantial** | **Critical** | **Critical** |
| **Confidence** (Southern Europe) | **Medium** | **Medium** | **Medium** |
| **Risk severity: reasoning** | The European energy sector is already experiencing significant reductions and disruptions in power supply during exceptionally dry and hot conditions, in particular in southern Europe. | Heat and drought have multiple impacts on energy production, transmission and demand. These impacts increase the risks of energy disruption, in particular in southern Europe (EEA, 2019a; JRC, 2020a) | Risks of energy disruption is increasing in a warming climate. |

| | |
|---|---|
| **Risk ownership** | **Co-owned**<br>The EU and Member States share legislative responsibilities with respect to energy policy, including production, transmission/distribution and end-use (e.g. energy efficiency). While the EU can introduce legislation and targets regarding net-zero and energy security objectives, it is at the discretion of Member States to decide on policies to deliver against these targets.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Regulation on Risk-Preparedness in the Electricity Sector (2019/941)<br>• Strategy for energy system integration (2020/299)<br>• Clean energy for all Europeans package<br>• European Green Deal's provisions on just transition<br>• Just Transition Mechanism<br>• Energy union strategy<br>• Renewable Energy Directive<br>• Energy Efficiency Directive<br>• Energy Performance of Buildings Directive<br><br>At the national level, the main policies of relevance include those relating to:<br>• Energy<br>• Transportation<br>• Spatial planning and infrastructure<br>• The environment (e.g. water governance) |
| **Policy readiness** | **Medium**<br>Policy readiness is higher for safeguarding energy supply than for managing energy demand during extreme climatic events. |
| **Policy horizon** | **Medium term** |
| **Urgency to act** | **Further investigation (all Europe)**<br>**More action needed (southern Europe)** |

**Source**: EEA.

## 8.5 Relevant policies

Relevant policies and initiatives established by the European Commission to promote climate adaptation, enhance energy system reliability, and foster flexibility in response to the challenges of climate change include:

- **Energy union strategy:** this is a long-term strategy introduced in 2015, aimed at ensuring secure, sustainable, competitive and affordable energy in the EU. It consists of five mutually reinforcing dimensions: energy security, solidarity and trust; a fully integrated European energy market; energy efficiency contributing to moderation of demand; decarbonising the economy; and research, innovation and competitiveness.
- **Clean energy for all Europeans package:** launched in 2016, this is targeted at helping the EU to achieve its 2030 climate and energy targets. The package includes a range of measures, including new rules on electricity, energy efficiency, renewable energy and the governance of the energy union.
- **EU strategy on energy system integration:** this strategy, launched in July 2020, aims to make the energy system more integrated, flexible and interconnected. It sets out a vision to create a more circular energy system, harness the potential of renewable energy sources, and ensure more efficient use of resources.
- **Regulation on Risk Preparedness in the Electricity Sector** (2019/944): aims to ensure the security and reliability of electricity supply in the EU by requiring electricity operators to identify, assess and prepare for potential risks that could impact the electricity grid and supply, including risks related to extreme weather events.
- **Critical Entities Resilience Directive:** critical entities provide essential services in upholding key societal functions, supporting the economy, ensuring public health and

safety, and preserving the environment. Under this directive, which entered into force in January 2023, Member States will have to identify the critical entities for certain sectors by July 2026. To do this, they will use a list of essential services to carry out risk assessments. Once identified, the critical entities will have to take measures to enhance their resilience.

Many other EU policies also address the energy system, but with a focus on mitigation objectives.

# 9 Built environment

## 9.1 Key messages

- Key climate risks for the built environment are: damage to infrastructure and buildings due to slow-onset climate change and extreme climate events; and risks to human well-being from climate change impacts on buildings.
- Climate change is associated with risks to the built environment itself as well as to the services that buildings provide to their users and wider society.
- Damage from extreme weather events to the built environment is projected to increase up to 10-fold by the end of the 21st century as a result of the effects of climate change only. The most significant increases are expected for the energy and transport sectors, while the greatest damage in absolute terms is estimated for the industrial sector.
- Investment is needed in climate-proof design for new structures and in retrofitting and reinforcement of existing buildings, without diminishing the cultural or economic values of areas with historical significance or of properties with historical value.
- EU policies increasingly address climate risks to the built environment. Action at Member State level is vital. Policy action at both EU and Member State level is facilitated through, for example, updating construction standards, Eurocodes and European datasets.

## 9.2 Introduction

The built environment holds a central position in the European socio-economic landscape. It corresponds to everything people live in and around, such as housing, transport infrastructure, services networks and public spaces (EP, 2024). In general, all European cities face at least some vulnerability to climate-related events, increasing temperatures and changes in precipitation patterns, accentuated by climate change, requiring complex and grounded adaptation measures. In this context, EU renovation targets (EC, 2020e) offer a key opportunity to enhance resilience by upgrading the building stock. However, careful planning is essential to avoid unintended consequences or maladaptation.

In this chapter, the built environment has been investigated, from the perspective of buildings and civil engineering works. The former refers to residential (single and multiple residential dwellings) and non-residential (commercial, institutional and public) buildings. The latter includes 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 defenses, rockfall prevention measures, reforestation or landslide mitigation zones, etc.).

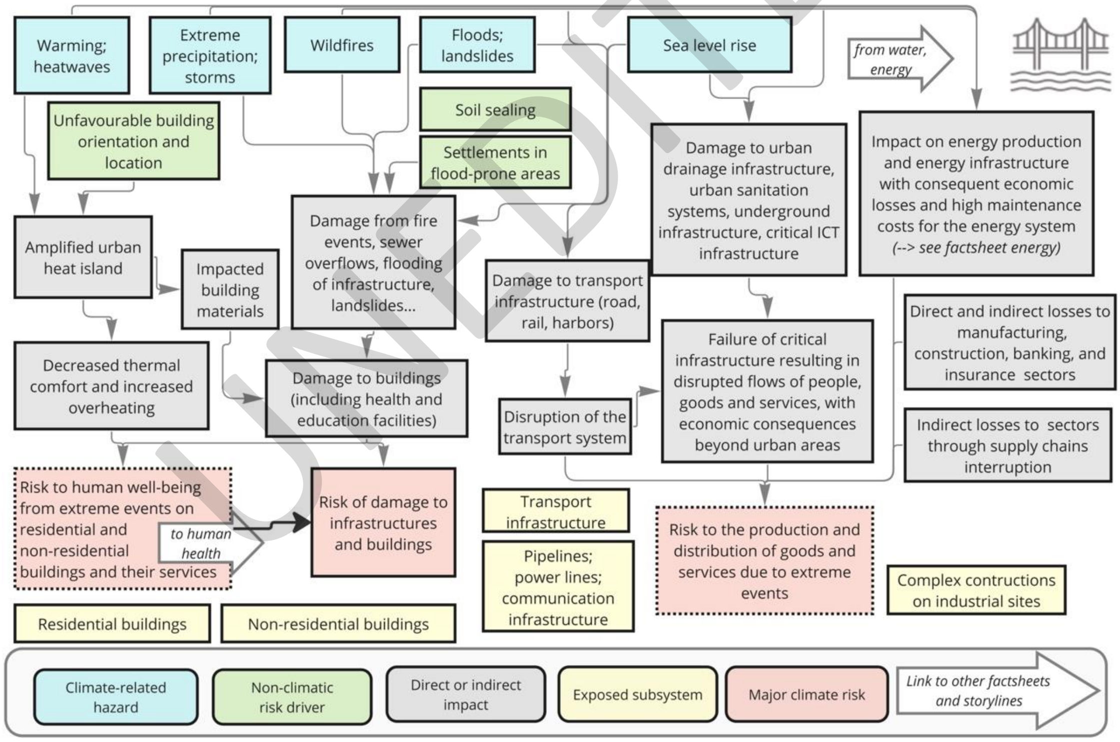
These subsystems are closely related to other sectors and systems. For example, the impact on buildings is connected to water security and marine and coastal ecosystems (see Chapters 4 and 5), especially concerning flood-related damage. Similarly, health facilities' susceptibility to heatwaves and the urban heat island (UHI) effect are of utmost importance, impacting human health (see Chapter 7). Direct damage to critical infrastructure has links to the critical infrastructure sector (see Chapter 15), while transport systems, energy generation plants, industry, and water supply networks have implications for energy and water security (see Chapter 5 and 8). Finally, the built environment, incorporating blue and green infrastructure, is closely tied to biodiversity and marine and coastal ecosystems (see Chapter 3 and4).

The interconnected nature of the built environment underscores the need for comprehensive risk management, with gaps in understanding of compound climate event dynamics. Indeed, direct impacts of extreme events on buildings and critical infrastructure, further intensified by climate change, have cascading effects on systems, livelihoods and economies. Rising urbanisation and interactions between severe weather events contribute to compound and cascading risks, impacting the flow of people, goods and services. These risks have economic consequences beyond urban areas and affect overall well-being (Moretti and Loprencipe, 2018; Markolf et al., 2019). Major policies promoting urban resilience, sustainability and climate adaptation highlight the built environment's critical role. Spatial planning not only influences the risk for all infrastructure, but also impacts the distribution of buildings, uses of space, social and economic development, energy matters, positive or negative environments, vegetation and green areas, public spaces, landscape and protected areas, Spatial planning also impacts strategic concepts, zoning plans, or density regulations that affect settlement configuration to better adapt to the hazards posed by climate change.

## 9.3 Risk drivers and impacts

### 9.3.1 Impact chain

**Figure 9.1 Impact chain for the built environment**






**Source:** ETC-CA, 2024.

### 9.3.2 Subsystem: residential buildings

**What drives the impact**

- Residential buildings are vulnerable to chronic and acute climate-related hazards, including extreme temperatures, high humidity, heavy rainfall, strong winds and solid mass impacts (EC DG CLIMA, 2023c).
- Climate change increases the risk of collapse and loss of value due to storms, snow, subsidence, water encroachment, soil degradation and deteriorating indoor climate;

these effects are aggravated by more, and more frequent and heavy, torrential rains, hail drops, and unusual snowfalls with much more devastating intensity and effects.

- Buildings experience decreased thermal comfort and increased overheating risks, influenced by factors like solar shading, ventilation, orientation and geographical location (Van Hooff et al., 2014; Dodoo and Gustavsson, 2016; Hamdy et al., 2017; Pérez-Andreu et al., 2018b; Dino and Meral Akgül, 2019). These factors negatively affect the health of occupants via heatstroke, dehydration, aggravation of chronic and respiratory diseases, and even death.
- Vulnerable groups of society often reside in older buildings, social housing, or structures with construction and energy standards that may be inadequate, rendering them more susceptible to the impacts of adverse climate events. Without appropriate retrofit measures, this situation could exacerbate social disparities in the future.
- Rising temperatures and uncontrolled humidity affect structural designs and accelerate corrosion processes in reinforced concrete and steel structures (Athanasopoulou et al., 2020; Bastidas-Arteaga et al., 2022).
- Urban areas, due to building arrangements and characteristics, cause the UHI effect, leading to temperature increases and severe heatwave effects. Heatwaves, in addition to causing large energy losses due to air-condition of buildings and negatively damaging building structures, as indicated previously, cause various health issues, including cramps, heat exhaustion and heatstroke, resulting in increased fatalities and illness rates (Ellena et al., 2020; Ballester et al., 2023c).
- Urban flooding risks are worsened by heavy precipitation, which is expected to become more frequent due to climate change, soil sealing as a result of urban expansion and land use changes, and insufficient or outdated stormwater infrastructure that does not assure proper drainage capacity.
- Coastal areas face flooding and sea level rise, impacting buildings, especially in densely populated subsiding regions (Dodman et al., 2022b).
- Settlement location near steep slopes and adherence to zoning laws significantly influence urban landslide risk (Mateos et al., 2020).

**Current situation**

- European cities exhibit varying degrees of vulnerability to drought, flooding and heatwaves (Tapia et al., 2017b). Western European cities are more exposed to flooding events, while those in southern Europe are more exposed to droughts. Cities in southern, western Europe and central-eastern Europe face significant exposure to heatwaves, partly due to limited solar shading and air conditioning installations.
- In northern Europe, buildings have been designed for cold winters and without any regard for exceptionally hot summers. Hence, the overheating of residential buildings is a severe issue threathening the health of vulnerable population groups also in northern Europe, even though heatwaves there are, in absolute terms, not as hot as in the warmer areas.
- Existing characteristic values from Eurocodes, a series of European standards for the design of buildings and civil engineering structures, often do not consider the potential effects of climate change (Croce et al., 2018; Rianna et al., 2023). In response to these limitations and the necessity to adapt to climate change, the second generation of Eurocodes (EC, 2023v) is currently under development. This new series aims to enhance the existing suite and broaden its scope. By incorporating new methods, materials,

regulatory and market requirements, as well as reinforcing robustness requirements, the updated standards will ensure full compliance with current practices. Additionally, the second generation of Eurocodes will introduce requirements for the assessment, reuse and retrofitting of existing structures to enhance building resilience, among other features.
- Extreme temperatures lead to issues like shrinking and swelling of clays, jeopardising the stability of houses in peri-urban environments.

**Future situation**

- Pluvial flooding risk is expected to increase significantly in northern European and some western-central European cities by 2030 (near term) (Komolafe et al., 2018).
- Heat risks will escalate in many cities by the end of the century (long term), especially in southern Europe, leading to a potential decrease of 74% in thermal comfort hours at 3°C of global warming by the end of the century (long term) (Jenkins et al., 2014; Hamdy et al., 2017; Heracleous and Michael, 2018; Dino and Meral Akgül, 2019; Shen et al., 2020).
- Urban landslide risks are expected to increase in regions experiencing higher extreme rainfall, necessitating comprehensive risk mitigation strategies (Gariano and Guzzetti, 2016).
- Heavy hailstorms are becoming more frequent, damaging building appliances and surfaces. The potential impacts of extreme heat, humidity, hail and heavy rain on construction materials, including damage to roofs, facades and insulation materials, and proliferation of mold, bacteria and insects, may become more prevalent in the future.
- Longer and more intense droughts will result in deeper desiccation, extending up to the first 2 metres of the soil surface exposed to evapotranspiration. This will necessitate more extensive and expensive reinforcement measures (Ighil Ameur, 2023).

### *9.3.3 Subsystem: non-residential buildings*

**What drives the impact**

- Non-residential buildings mainly refer to commercial, institutional and public buildings, with a specific focus on health and education facilities. They are affected by climate-related factors such as heat, flooding, water scarcity, drought and windstorms, both directly and indirectly.
- Climate impacts indirectly affect sectors through supply chains, transport and electricity networks, sometimes more significantly than direct effects (Koks et al., 2019d, 2019b; Knittel et al., 2020).
- Health facilities are particularly vulnerable to increasing climate-related shocks and stresses that could potentially causing significant damage to buildings that house them. This could have a knock-on effect on the provision of health services. Vulnerability depends on factors like building strength, design and the intensity of the event (EEA, 2020f).
- Health and social care facilities often lack air conditioning. Overheating of the buildings during heatwaves is a severe health risk for inpatients/residents (Kollanus et al., 2021) and challenges delivery of healthcare services.
- Overheating in office, industry and public buildings may affect lower learning attainment and worker productivity.
- Climate change poses a significant threat to cultural heritage, protected under the EU Civil Protection Mechanism (EU, 2013b), including tangible and intangible elements. For

instance, rising sea levels put building exteriors and indoor collections at risk, leading to potential income reduction due to the loss of tourism revenue (Phillips, 2015; Fatorić and Seekamp, 2017; Carroll and Aarrevaara, 2018; Sesana et al., 2018).

**Current situation**

- Health and education facilities are frequently damaged by floods and windstorms, accounting for 44% and 51% of the total Expected Annual Damage (EAD) (EUR 0.6 billion per year) for these sectors in the 2000s (Forzieri et al., 2018b).
- Floods cause the highest direct losses for the manufacturing and utilities sectors (Koks et al., 2019b; Sieg et al., 2019; Mendoza-Tinoco et al., 2020).
- It has been estimated that during, or at the end of, a single work shift in heat stress conditions, 35% of workers experience symptoms of physiological strain and 30% of workers report productivity losses (Flouris et al., 2018).

**Future situation**

- Structural damage from flooding and windstorms in health and education facilities is expected to increase significantly (Forzieri et al., 2018b), with knock-on effects on the provision of health and education services. These effects may be more significant on these types of buildings compared to others, such as offices or public buildings. Indeed, offices or public buildings may continue to operate, due to the evolution and increased development of teleworking, for example.
- Concerning health and education facilities, EAD related to flooding is projected to be two times higher in the 2080s (long term) (Forzieri et al., 2018b). Moreover, drought-induced subsidence damage could increase substantially, with EAD rising from EUR 10 million per year in the 2000s to EUR 460 million per year in the 2080s (long term) (Forzieri et al., 2018b).
- A warming climate leads to heightened occupational heat stress among workers, reducing their ability to engage in manual labour (Ioannou et al., 2022). This issue is strongest in southern Europe, but other regions may also see a decline in workers' capacity for physically demanding tasks (Kjellstrom et al., 2020).
- Business closures can be influenced by the effects of climate change as well as the local economy. Indeed, default probability for firms in particularly exposed locations might increase by up to four times that of an average firm in all sectors by 2050 (mid-term) (ECB, 2021). Additionally, the shift towards working from home has been favoured and increased post-COVID. This, along with other factors, may lead to a higher number of unused and disused buildings in future, rendering these structures obsolete and with potential for rehabilitation and conversion into other uses.

### *9.3.4 Subsystem: transport infrastructure*

**What drives the impact**

- Transport infrastructures are vulnerable to various weather-induced hazards, including changing precipitation patterns, temperatures, sea levels, coastal and river floods, droughts, erosion, marine heatwaves and ocean acidity.
- Climate change exacerbates risks, potentially disrupting normal functioning or leading to infrastructure failures during severe weather events.
- Heatwaves cause thermal expansion, buckling of roads and railways, and softening of road asphalt and pavement material.

- Rapidly changing temperatures around the freezing point of roads can lead to the deterioration of both the road surfaces and the main road structure.
- Urban roads and railways are vulnerable to extreme winds, while heavy rainfall impacts underground transport systems. Metro/subway systems face challenges from climate change, including heavy rainfall, storm surges and storms. Precipitation-induced landslides affect transport infrastructures in mountainous regions (Pregnolato et al., 2016).
- Droughts could reduce navigation capacity in rivers, impacting inland waterway transport (Jonkeren et al., 2014; Schweighofer, 2014).
- Airports and harbors, particularly in low-elevation coastal areas, are at risk due to sea level rise. Levee failures can trigger cascading failures in urban transport systems (Zaidi, 2018).
- Wildfire smoke storms and sand dust storms can disrupt airports, causing challenges for air operations and potentially damaging airport infrastructure and materials.

**Current situation**

- Current damage in the transport sector primarily results from river floods and heatwaves, accounting for approximately 51% and 27% of the total EAD (EUR 800 million per year) in the 2000s (Forzieri et al., 2018b).
- Heatwaves in western, central and northern Europe have led to road melting, railway asset failures and speed restrictions to prevent track buckling, causing significant disruptions in transportation infrastructure (Forzieri et al., 2018b).
- Adaptation measures are essential, integrating climate change considerations into planning and design phases (EEA, 2020a).

**Future situation**

- Costs associated with weather-induced hazards are projected to increase significantly by the 2080s (long term), potentially reaching over EUR 10 billion, a 20-fold increase from the current level. Heatwaves are expected to be the dominant factor, accounting for 92% of total damage by the 2080s (long term), particularly affecting roads and railways due to rutting and blow-ups (Forzieri et al., 2018b).
- Railways face double or triple the flood risk under different global warming level scenarios, potentially leading to substantial public expenditure increases (Bubeck et al., 2019a).
- Extreme rainfall induced by climate change could significantly increase landslide risks for natural and engineered slopes, disrupting transport infrastructure (Gariano and Guzzetti, 2016; Briggs et al., 2017; Tang et al., 2018; Powrie and Smethurst, 2019; Schlögl and Matulla, 2018; Rianna et al., 2020).
- Soil frost is a relevant phenomenon in cold regions of Europe affecting ecosystems and built infrastructures. For instance, permafrost degradation due to rising temperatures in high-altitude Alpine areas may affect ropeway transport infrastructure (Duvillard et al., 2019).
- Ports, especially in northern and western Europe, are vulnerable to sea level rise, storm surges and changes in wave agitation. Mediterranean ports may face non-operability hours due to wave changes (Christodoulou et al., 2018).
- Droughts are expected to lower water levels in inland waterways, thus hindering their use. For example, the Rhine in Germany has sometimes become more narrow and

shallow in recent years, meaning fewer vessels could pass and resulting in partial loading of vessels to reduce their gauge.

- The frequency of severe windstorms, hailstorms, tropical cyclones, sand and dust storms is expected to rise in various parts of the EU, posing additional challenges to transport infrastructure (EC DG CLIMA, 2023c).
- Wildfire smoke and sand dust storms may disrupt airports, affecting air operations and causing potential damage to infrastructure and buildings (Kwasiborska et al., 2023) .

### *9.3.5 Subsystem: pipelines, communication and electricity lines*

**What drives the impact**

- Electricity distribution lines and transmission towers are prone to failures during cold spells, heavy snow and rains, and extreme wind speeds (Panteli and Mancarella, 2015; Andrei et al., 2019; Karagiannis et al., 2019a).
- Heat stresses can cause expansion in oil and gas pipes, increasing the risk of rupture. Soil subsidence impacts underground assets, and rising temperatures could reduce the efficiency of steam and gas turbines.
- Disruptions in urban energy distribution, caused by events like flash floods damaging electricity substations, have cascading effects on social infrastructure, urban services and traffic management. Urban areas with high poverty rates are disproportionately affected (Gasbarro et al., 2019; Teotónio et al., 2020b).
- Storms, droughts and heatwaves can induce damage to information and communication technology assets and urban drainage systems, affecting telecomunications and water management (Dale and Frank, 2017).
- Sanitation systems face challenges with low flows during droughts, leading to sedimentation and blocking of sewer infrastructure networks.

**Current situation**

- Damage to energy distribution (total EAD of EUR 200 million per year in the 2000s) is primarily caused by river floods (33% of the EAD) and windstorms (56% of the EAD) (data elaborated from (Forzieri et al., 2018b).
- Wildfires have a considerable impact on gas pipelines, contributing to 40% of the total EAD (EUR 60 million per year) in the 2000s (data elaborated from (Forzieri et al., 2018b).
- Dry and hot periods in the past two decades have caused significant reductions and interruptions in power supply in European countries like France, Germany and Switzerland. These disruptions are primarily due to water cooling constraints on power plants (Van Vliet et al., 2016c; Abi-Samra, 2017; Vogel et al., 2019a).

**Future situation**

- The costs associated with weather-induced hazards on electricity lines and gas pipelines due to climate change could increase by approximately 50% and 20%, respectively, by the 2080s (long term). These increased costs are primarily linked to the same hazards as in the current period (Forzieri et al., 2018b).
- Indirect effects on transport and electricity networks (i.e. service disruption and its impact on productivity, job losses, lack of comfort, security issues, etc.) can be as high as, or substantially higher than, direct effects (Koks et al., 2019b, 2019d; Knittel et al., 2020).

- Intense storms can transport various pollutants including dust, trash, pesticides, particulates and oil from impermeable surfaces into nearby waters. This run-off compromises ecological ecosystems and impacts drinking water infrastructure (Delpla et al., 2009; Arnell et al., 2015; Miller and Hutchins, 2017).

### *9.3.6 Subsystem: energy and industrial infrastructure*

**What drives the impact**

- Fossil fuel, nuclear, and renewable energy production are vulnerable to droughts and heatwaves. Higher temperatures affect cooling system efficiency in power plants due to elevated water/air temperatures.
- Hydroelectric and thermal power plants are impacted by rising water temperatures and cooling water restrictions, leading to reduced energy production. Warmer water conditions can lead to water intake clogging due to excessive biological growth.
- Increasing temperatures affect the efficiency of solar energy technologies. While solar heating efficiency improves, photovoltaic panels become less efficient. Wind-blown sand and dust can further reduce power output, necessitating regular cleaning of solar energy plants. Solar systems are increasingly being integrated into buildings as façade or roof systems, known as building integrated photovoltaics or building integrated solar thermal systems. EU regulations mandate solar installations on new public and commercial buildings by 2026, residential buildings by 2029, non-residential buildings undergoing renovations by 2027, and existing public buildings in a stepwise approach by 2030. This highlights the need to consider the potential impact of climate change on these systems, given their crucial role in buildings (EU solar rooftop strategy, Energy Performance of Buildings Directive and REPowerEU plan).
- Extreme weather events significantly affect the extraction and refining operations of petroleum, oil, coal, gas and biofuels. Proximity to wildlands increases the risk of fires, particularly impacting built environments near these areas (EEA, 2020f).
- Drought and water scarcity directly impact chemical and plastic manufacturing industries in the EU, affecting production processes and resource availability (Gasbarro et al., 2019; Teotónio et al., 2020b).



**Current situation**

- River floods and storms accounted for approximately 47% and 27% of the total EAD (EUR 1.6 billion per year) in the industry sector in the 2000s. These climate-related events lead to significant economic losses (Forzieri et al., 2018b).
- Drought, floods and heat constituted about 61%, 18% and 17% of the total EAD (EUR 300 million per year) in the energy production sector in the EU during the same period. Droughts and heatwaves impact energy production, particularly affecting cooling systems in power plants (Forzieri et al., 2018b).

**Future situation**

- In the 2080s (long term), the EU is expected to experience a significant rise in damage to the energy production sector, due to sensitivity to droughts and heatwaves. Drought damage is projected to comprise 67% of all hazard impacts, and heatwave damage to account for 27% in the energy sector (Forzieri et al., 2018b).
- In the industry sector, damage from floods and windstorms is increasing. However, this damage will be surpassed by droughts and heatwaves in the coming decades. Drought-

related damage is projected to increase from EUR 300 million per year in the 2000s to EUR 9.1 billion per year in the 2080s (long term). Heatwave damage is expected to rise from EUR 100 million per year in the 2000s to EUR 5.2 billion per year in the 2080s (long term) (Forzieri et al., 2018b).

- Thunderstorms may disrupt solar photovoltaic plants, leading to halted electricity generation or damage to electrical equipment caused by lightning strikes (Zaini et al., 2016; Ahmad et al., 2021) .
- Climate change-related factors, such as acid rain and carbonation erosion, can accelerate the natural evolution of concrete in aggressive environments. Acid rain and carbonation erosion are both expected to be intensified by increased greenhouse gas emissions (Raposo et al., 2020; Guo et al., 2023; Rodríguez et al., 2023; Sousa et al., 2020).

### 9.3.7 Subsystem: green and blue infrastructure

This subsystem is closely related to Chapter 3, specifically to the 'Urban ecosystems' subsystem.

**What drives the impact**

- Green infrastructure ia vulnerable to droughts and extreme temperatures. In addition, it can be affected by water scarcity, extreme wind events, sea level rise, air pollution, fires, invasive species and diseases.
- Drought-induced reductions in soil moisture levels not only stress vegetation health, but also diminish the aesthetic appeal and recreational value of green spaces. Increasing demand for irrigation raises water consumption, potentially sparking conflicts over water resources.

**Current situation**

- Access to green and blue (water-based) spaces in the EU varies significantly. Northern and western European cities generally have more total green and blue areas compared to southern and eastern European cities (EEA, 2022o).
- On average, green and blue infrastructure make up 42% of the city area in the 38 EEA member countries. However, only 3% of the total city area consists of publicly accessible green spaces (EEA, 2022o).
- The provision of publicly accessible green spaces varies between cities and is often influenced by location and socio-economic status. This indicates disparities in access to natural amenities within urban areas (EEA, 2022o).
- Urban tree cover in these cities averages 30%. Finland and Norway have the highest proportion of tree cover, while Cyprus, Iceland and Malta have the lowest (EEA, 2022o).

**Future situation**

- Urban trees may face challenges due to increasing temperatures and decreasing water supply, affecting their fitness and potentially enabling more pests, leading to changes in growth trends (Dale and Frank, 2017).
- Increasing green spaces and integrating well-designed green facades and roofs in urban areas can help minimise the heat island effect and enhance environmental benefits (Mihalakakou et al., 2023).
- European beaches may experience reduced amenity due to sea level rise amplifying coastal erosion and inundation risks, particularly in southern Europe. Coastal settlements, especially in regions like Catalonia, Spain, are facing significant

infrastructure damage due to beach erosion and inundation (Toimil et al., 2018; López-Dóriga et al., 2019; Ranasinghe et al., 2021b).

- Acid rain and air pollution pose significant health risks, including eye irritation, respiratory illnesses and skin-related diseases. They also stress ecosystems, damage aquatic environments, lead to soil pollution and harm buildings (Tafazzoli and Sadoughi, 2021).
- Climate change leads to reduced oxygen levels, increased temperatures and water acidity, disrupting water bodies near urban areas, like rivers or lakes.

## 9.4 Risk assessment and evaluation

### *9.4.1 Confidence*

Risks related to direct impacts on residential and non-residential buildings and critical infrastructure would become severe with high warming, current infrastructure development design and minimal adaptation (high confidence). In some contexts, these risks would become severe even with low warming, current vulnerability and no additional adaptation (medium confidence). Indirect consequences of infrastructure failure on lives, livelihoods and economies also escalate in high warming scenarios with current vulnerability (medium confidence).

Transport and energy infrastructure along coasts and rivers is at risk, even with medium warming (high confidence), with damage leading to potential long-lasting disruption, if there is no additional adaptation (medium confidence).

In disaster situations, infrastructure-related risks can exacerbate capacity issues with emergency response (limited evidence, high agreement). Climate-related impacts on transport and energy infrastructure reach far beyond the direct impacts on physical infrastructure, triggering indirect impacts on health and income (medium confidence). Power outages triggered by heat, flood and drought have substantial health implications, particularly among low-income populations.

### *9.4.2 Adaptation opportunities, constraints and limits*

The main adaptation opportunities identified for the built environment are:

- Many EU policies and strategies (see Section 9.5) address climate risks to, and climate proofing of, infrastructure, and include both short- and long-term risk mitigation.
- Implementing climate-responsive design in buildings and urban settlements involves sustainable spatial planning, strategic densification, walkable neighborhoods, low-mobility transport infrastructure, and the effective use of passive climate strategies, including ventilation, solar irradiation and shading techniques. This should be combined with renewables, energy-efficient measures for net zero energy consumption, biodiversity enhancement, waste reduction, recycling initiatives and community engagement.
- Energy efficiency and smart technologies focus on enhancing building efficiency standards, utilising energy-efficient technologies like lighting and heating, ventilation and air conditioning systems (HVAC ), and incorporating smart city technologies such as smart grids, sensors and data analysis.
- The concept of resilient infrastructure includes the development of sustainable drainage systems, flood-resilient buildings, and integrated green spaces to enhance overall climate resilience in urban areas.
- Green roofs, facades and other vegetated spaces act as natural sponges, absorbing rainwater upon contact and allowing it to infiltrate into the ground or evaporate. This natural mechanism serves as flood prevention, while also cooling buildings, promoting biodiversity and enhancing air quality, thereby contributing to citizens' wellbeing .

- Spatial planning is crucial, especially in considering areas at risk due to climate change, which may differ from what is currently outlined in regulations and sectoral plans for improving and relocating areas. Continuously updating data with maps and tools to enable this, as well as considering new construction standards focused on the safety and robustness of buildings, is essential.
- Planning strategies for green and blue infrastructure elements offer potential solutions for adapting to ongoing climate change. However, in certain cases, high temperatures can increase the risk, resulting in difficulties in managing and maintaining these infrastructures. While they offer environmental benefits, they can also lead to increased economic expenditure for maintenance and management, particularly in countries and periods experiencing drought and water scarcity.

The main gaps identified for the built environment are:

- Insufficient understanding of the long-term effectiveness, economic costs and trade-offs of adaptation options.
- Need for more comprehensive studies on urban resilience and ecosystem-based approaches.
- Lack of research on the interactions between climate change, urbanisation and socio-environmental factors.
- Increased collaboration needed for effective and context-specific adaptation strategies.
- Limited studies examining the risks from hailstorms and lightning.

One of the knowledge gaps identified involves the necessity of providing Member States with up-to-date climatic data and with design maps for use in designing new structures and renovating existing ones. Additionally, the development of readily available tools for data post-processing and statistical modelling could assist designers in using continuously updated data for climatic actions. The availability of such data and tools in georeferenced formats, hosted on authoritative platforms, could simplify and expedite the retrieval of reliable characteristic values for climate-responsive design (CDS, 2022; Climate ADAPT, 2022).

There is a need for more comprehensive studies about sectoral risks and cascading risks for vital sectors such as transport. For example, the German research projects KLIWAS (KLIWAS, 2015) and BMDV Network of Experts (BMDV, 2016) deliver detailed knowledge about cascading risks of climate change for transport infrastructure in Germany.

More research is also needed on overheating of residential and non-residential buildings, as well as on the effectiveness of passive and active cooling solutions and UHI reduction solutions in mitigating this overheating. Effective adaptation and mitigation measures for buildings must be resilient against multiple risks and be guided by technical expertise across various climatic zones in Europe (EC DG CLIMA, 2023b, 2023c).

### *9.4.3 Overall assessment*

This section presents the outcomes of the structured risk assessment for the major climate risks identified in this factsheet. This assessment builds on information in this factsheet, and possibly in other chapters of this report. The initial risk assessment was conducted by the authors of this factsheet whereas the final assessment results reported here represent the consensus of the EUCRA risk review panel. Further methodological information is available in Annex 2.

The following major risks assessed in other chapters are also relevant for this factsheet, but they are not presented here to avoid duplication:

- Risk of energy disruption due to damage to energy transportation or storage infrastructure following coastal or inland flooding (Chapter 7).
- Risk of electricity disruption due to the impacts of heat and drought on energy production and peak demand (Chapter 7).

- Risk to the population and built environment from wildfires facilitated by drought and heat (Chapter 11).
- Risk to the population, infrastructure and economic activities from inland flooding (Chapter 12).
- Risk to the population, infrastructure and economic activities from coastal flooding (Chapter 12).
- Widespread disruption of marine transport (Chapter 15).
- Widespread disruption of land-based transport (Chapter 15).

### Table 9.1 Risk assessment for the risk of damage to infrastructures and buildings due to slow-onset climate change and extreme climate events

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)**<br>• **high warming**<br>• **low warming** |
|---|---|---|---|
| **Risk severity** | **Substantial**<br>High vulnerability in ageing buildings and infrastructures | **Substantial**<br>Increasing risk if no adaptation is adopted in the design of new structures and retrofitting of existing structures | **Critical**<br>Further increasing risk levels<br>**Substantial**<br>See mid-term |
| **Confidence** | **Medium** | **Medium** | **Medium** |
| **Risk ownership** | **Co-owned**<br>The EU and Member States share legislative responsibilities with respect to policies relating to spatial planning and infrastructure. Since the EU does not have an explicit competence on spatial planning, zoning and spatial planning policies generally reside at Member State level. However, the EU can exert considerable influence on spatial planning through other sectoral competences (e.g. via the environment, energy and maritime affairs) and different funding instruments (e.g. Cohesion Fund).<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Critical Entities Resilience Directive (2022/2557)<br>• Floods Directive (2007/60)<br>• Technical guidance on the climate proofing of infrastructure in the period 2021-2027 (2021/C373/01)<br>• Taxonomy Regulation for Sustainable Activities (2020/852)<br>• European standards: second generation of Eurocodes<br>• Construction Products Regulation (05/2011)<br>• Energy Performance of Buildings Directive (revision provisionally agreed in December 2023)<br>• Renovation wave<br>• Green public procurement<br><br>At the national level, the main policies of relevance include those relating to:<br>• Spatial planning and infrastructure<br>• Energy<br>• Transportation | | |
| **Policy readiness** | **Medium**<br>• Many EU policies and strategies address climate risks to, and climate proofing of, infrastructure, and include both short- and long-term risk mitigation.<br>• There are currently no obligatory requirements to incorporate climate scenarios into building plans, and there is a lack of incentives to climate proof the existing building stock. However, the revised Energy Performance of Buildings Directive (foreseen to be adopted in spring 2024) includes provisions on adaptation.<br>• Future climate risks are not sufficiently addressed in the current Eurocodes. | | |
| **Policy horizon** | **Long term** | | |
| **Urgency to act** | **More action needed** (assuming a high warming scenario)<br>**Further investigation** (assuming a low warming scenario) | | |

**Source**: EEA.

**Table 9.2 Risk assessment for the risk to human wellbeing from climate change impacts on residential and non-residential buildings**

| | Current/near term (2021-2040) | Mid-term (2041-2060) | Long term (2081-2100)<br>• high warming<br>• low warming |
|---|---|---|---|
| **Risk severity** | **Substantial**<br>The European population is increasingly affected by overheating of buildings during summer heatwaves | **Substantial**<br>Overheating and summer energy poverty will further increase across Europe | **Critical**<br>The built environment is increasingly operated outside its design climate envelope<br>**Substantial**<br>See mid-term |
| **Confidence** | **Medium** | **Medium** | **Medium** |
| **Risk ownership** | **Co-owned**<br>The EU and Member States share legislative responsibilities with respect to policies relating to spatial planning and infrastructure and to public health. Since the EU does not have an explicit competence on spatial planning, zoning and spatial planning policies generally reside at Member State level. However, the EU can exert considerable influence on spatial planning through other sectoral competences (e.g. via the environment, energy and maritime affairs) and different funding instruments (e.g. Cohesion Fund).<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Critical Entities Resilience Directive (2022/2557)<br>• Technical guidance on the climate proofing of infrastructure in the period 2021-2027 (2021/C373/01)<br>• European standards: second generation of Eurocodes<br>• Energy Performance of Buildings Directive (revision provisionally agreed in December 2023)<br>• Renovation wave<br><br>At the national level, the main policies of relevance include those relating to:<br>• Spatial planning and infrastructure<br>• Public health<br>• Energy | | |
| **Policy readiness** | **Medium**<br>• Human well-being linked to the built environment (including residential buildings, hospitals and schools) is often not explicitly addressed in EU policies, despite them identifying vulnerable buildings and assets as being subject to climatic risks.<br>• There are currently no obligatory requirements to incorporate climate scenarios into building plans, and there is a lack of incentives to climate proof the existing building stock. However, the revised Energy Performance of Buildings Directive (foreseen to be adopted in spring 2024) includes provisions on adaptation. | | |
| **Policy horizon** | **Long term** | | |
| **Urgency to act** | **More action needed** (assuming a high warming scenario)<br>**Further investigation** (assuming a low warming scenario) | | |



**Source**: EEA.

## 9.5 Relevant policies

EU adaptation strategy and nature-based solutions: the EU's adaptation strategy emphasises the importance of enhancing preparedness and resilience in both buildings and infrastructure. It promotes the development of nature-based solutions, such as urban green spaces and green roofs, to combat heat-induced stress and reduce the need for mechanical air conditioning.

EU Taxonomy and sustainability criteria: the EU Taxonomy sets criteria for construction and renovation projects, requiring substantial contributions to climate adaptation in buildings. These criteria aim to ensure the sustainability of economic activities and guide the construction industry towards climate-resilient practices.

Cohesion Policy (2021-2027): the EU's Cohesion Policy addresses climate change adaptation in the built environment sector. Under Policy Objective 2 of the European Regional Development Fund, it promotes climate change adaptation and disaster risk prevention and resilience, emphasising ecosystem-based approaches. Policy Objective 3 focuses on enhancing mobility through developing climate-resilient transport networks.

Trans-European transport corridors (TEN-T): this is the main EU policy defining standards for transport infrastructure and establishing a network of core transport infrastructure corridors in the EU; it is of critical importance for connectivity in Europe and vital transport infrastructure in the EU context. Revisions of the trans-European transport corridors (TEN-T) regulations will put a stronger focus on climate resilience and climate proofing transport infrastructure.

Level(s) framework for sustainable buildings: Level(s) is the European framework for sustainable buildings, enabling designers to assess and report on buildings' sustainability features. It includes indicators related to climate change adaptation, maximising thermal comfort and reducing water consumption to minimise risks related to droughts.

EU Missions and Covenant of Mayors: the EU Missions, particularly the Mission on Adaptation to Climate Change, aim to assist European regions in becoming climate resilient by 2030. The Covenant of Mayors initiative collaborates with cities to achieve the EU's climate targets, focusing on climate change mitigation and adaptation at the local level. These initiatives play a significant role in driving transformative change and sustainable development in European cities.

The InvestEU Fund supports private and public investments in four policy areas of importance for the EU, one of which is sustainable infrastructure (EUR 9.9bn in guarantee). These include transport, energy, nature and other environment, infrastructure and other assets and equipment. The EU adaptation strategy also states that the European Commission (EC) will explore better alternatives to predict climate-induced stress on buildings by introducing climate resilience criteria through green public procurement (GPP) for public buildings. Use of the GPP guidance is voluntary for authorities. Updated guidance is currently under development: it aims to cover health and thermal comfort, extreme weather risks, sustainable drainage and water consumption.

The renovation wave focuses on adaptation measures for existing building stock and aims for the protection and adaptation of buildings to various temperature-, wind-, water- and solid mass-related climate hazards. It also pays attention to vulnerable groups.

Energy Performance of Buildings Directive: the revised version (expected to be formally adopted in spring 2024) includes provisions on adaptation and resilience, including requirements to address resilience in renovation and in new buildings, as well as the option of including information on the adaptive capacity of buildings in the Building Renovation Passports.

The New European Bauhaus (NEB) initiative connects the European Green Deal with living spaces, and promotes projects and practices that are aesthetically beautiful, in harmony with nature and the environment, and inclusive, by encouraging a dialogue between cultures, disciplines, genders and ages. As part of the initiative, it is stressed that reconnecting with nature through the promotion of nature-based solutions in cities can mitigate flood risks and other extreme weather events. The NEB is delivered through identifying synergies among existing funding instruments and policies, as well as through specific and dedicated actions. Projects that advance the NEB objectives are conducted within the NEB Lab, where actions to create enabling conditions for green transitions (including new tools, frameworks and policy recommendations), and to trigger tangible transformation on the ground, are implemented.

The Critical Entities Resilience Directive (2022/2557) adopts a broader scope to identify critical entities which are now understood as those that provide essential services crucial for the wellbeing of EU citizens and functioning of the internal market. Extreme weather events are identified as physical risks. The critical entities include both the digital infrastructure sector and the transport sector. By January 2026, EU Member States are obliged to formulate strategies to enhance the resilience of critical entities.

The Floods Directive (2007/60/EC) aims to reduce flood impacts on infrastructure, communities and the environment. The directive constitutes an effort to streamline flood risk assessments and management across Member States. It does not specifically address the groups or assets that are most vulnerable to the impacts of floods. However, Member States are obliged to identify areas of potential significant flood risks, assess in detail the flood hazard, prepare flood maps and generate flood risk management plans. As part of this exercise, Member States should identify and map vulnerable assets and people.

The Construction Products Regulation (No 305/2011) (CPR) provides harmonised rules for the marketing of construction products in the EU. An EC evaluation found that the CPR is currently unable to deliver on broader policy priorities, such as the green transition, and hampers the promotion of climate performance-oriented information on construction products. A revision was proposed in 2022, aimed at enhancing the sustainability of construction products and contributing to the objectives of the green transition.

The second generation of Eurocodes will improve standards by promoting harmonisation and ease of use, and requiring assessment and retrofitting of existing structures. Additionally, it will advance pre-normative work on structural elements, strengthening robustness and ensuring infrastructure resilience in the face of climate change impacts.

# 10 EU outermost regions

## 10.1 Key messages

- All EU outermost regions will be heavily impacted by climate change, with effects on key sectors including tourism, the blue economy and agriculture.
- The existing socio-economic conditions of the outermost regions — including social inequalities, fragile infrastructure and unsustainable land use practices — are exacerbated by climate change and made particularly vulnerable.
- Martinique, Guadeloupe, Saint Martin, Réunion and Mayotte face high risks to both natural (biodiversity) and human (infrastructure, health, tourism and agriculture) systems due to tropical cyclones, sea level rise, marine heatwaves and ocean acidification.
- French Guiana faces high risks to human infrastructure due to floods, sea level rise and coastal erosion.
- The Macaronesian islands face high risks due to marine heatwaves, tropical cyclones and sea level rise.
- Many EU policies take the outermost regions' needs and challenges into account. However, they do not focus specifically on climate adaptation, for which the main responsibility lies with these regions and their associated Member States. Successfully implementing these EU policies would help alleviate future climate impacts.

## 10.2 Introduction

The EU outermost regions are an integral part of the EU despite being geographically remote from the European continent. These regions are governed by individual EU Member States and include the French islands of Martinique, Saint Martin and the Guadeloupe Archipelago in the Caribbean Basin; the Spanish Canary Islands, and the Portuguese Azores and Madeira Archipelagos in the Atlantic Ocean; French Guiana in South America; and the French islands of Mayotte and Réunion in the Western Indian Ocean. The remote nature of all EU outermost regions implies that they present different climatic and socio-economic characteristics from mainland Europe, and that most climate impacts in these regions will differ in terms of both hazard and impact types. Overall, the regions are characterised by unique ecosystems and biodiversity which may boost key sectors like agri-food, tourism and the blue economy. At the same time, the regions face socio-economic challenges like high unemployment (especially among young people), an ageing population, youth leaving school early, non-qualified populations and lack of infrastructure. Therefore, it is crucial to assess climate change drivers and impacts for these regions separately from those in mainland Europe.

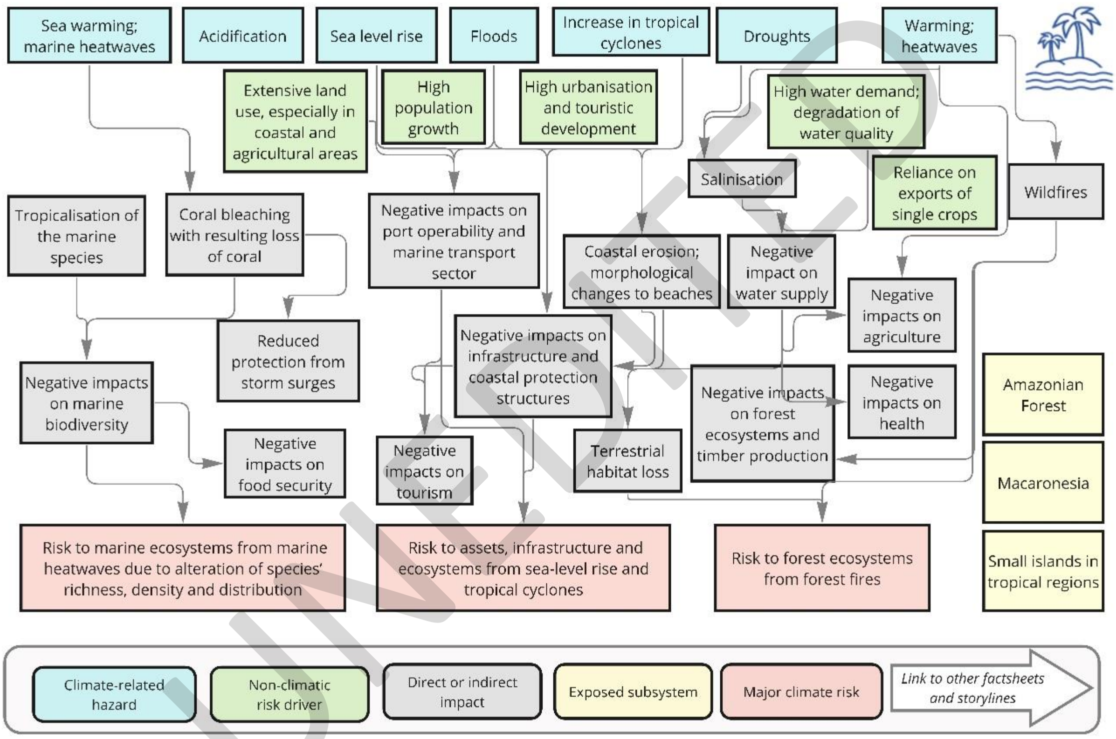
Overall, in the EU outermost regions there has been, and will be, significant pressure to develop new buildings and infrastructures along the coast. This inevitably increases the anthropic pressure on coastal ecosystems, potentially increasing their vulnerability to climate change. Also, this will further increase exposure to coastal flooding in a context where sea level and the frequency of high-intensity hurricanes are expected to increase. In turn, this will amplify the potential for human and economic losses. This factsheet highlights these dynamics and shows that both human and ecological systems in the EU outermost regions are vulnerable to climate change due to rising atmospheric and marine temperatures, ocean acidification, sea level rise and increased exposure to hurricanes. Socio-economic vulnerabilities (e.g. reliance on tourism, poverty) as well as land use (e.g. location of human settlements, location and nature of crops) magnify the risks. The factsheet will focus on three subregions formed by grouping the EU outermost regions according to their climatic and non-climatic similarities. The identified subregions are:

- *small islands in tropical regions* (subregion 1), encompassing Saint Martin, Guadeloupe, Martinique, Mayotte and Réunion;
- *coastal regions in the Amazon Forest* (subregion 2), which comprises French Guiana;
- *Macaronesia region* (subregion 3), covering the Azores, Madeira and the Canary Islands.

## 10.3 Risk drivers and impacts

### *10.3.1 Impact chain*

**Figure 10.1 Impact chain of the main climate risks to the EU outermost regions**






**Source:** ETC-CA, 2024.

### *10.3.2 Subregion: small islands in tropical regions*

**What drives the impact**

The climatic impact drivers are (Mycoo et al., 2022):

- tropical cyclones;
- heavy rain events;
- marine heat stress and ocean acidification;
- sea level rise;
- droughts.

Non-climatic impact drivers are:

- social capital, health and livelihood (Mycoo et al., 2022);
- extensive land use, especially in coastal and agricultural areas.

**Current situation**

- Tropical cyclones represent a major threat to the region. For example, Hurricanes Irma and Maria caused a USD 3 billion loss to Saint Martin in 2017, and Bejisa had significant impacts on the natural and built environments of Réunion in 2014 (Duvat and Magnan, 2019);
- Rising trends in sea temperatures in low salinity zones which affect tropical cyclone intensification in the eastern Antilles (e.g. Guadeloupe, Martinique) have been detected, increasing heat stress on marine ecosystems;
- The Caribbean region is also experiencing droughts (a drying trend of 0.18 mm/year reduction in rainfall has been observed in the region) and sea level rise (Mycoo, 2018);
- Extensive and severe coral bleaching has been observed in Réunion (Gudka et al., 2020) and in the Caribbean Basin (Muñiz-Castillo et al., 2019), degrading marine ecosystems and reducing protection from tropical cyclone surges;
- The Caribbean region has experienced massive inundations of *Sargassum* seaweed floating in coastal waters and landing on beaches since 2011, with huge adverse impacts on tourism, fisheries and human well-being (McConney et al., 2023). Climate change appears to be one of the drivers of the *Sargassum* crisis, but its exact role is still not clear (Marsh et al., 2023).

**Future situation**

- The number of intense tropical cyclones in the Atlantic region is expected to increase (Bhatia et al., 2019; Knutson et al., 2020);
- Sea levels will rise further and ocean acidification will continue;
- Droughts and extreme rainfall events will increase, as will average temperature (Stennett-Brown et al., 2017). This will raise the risk of flooding;
- There is evidence that coral reef bleaching events may occur annually in some regions, including the Caribbean. This would exacerbate related impacts, such as marine ecosystem services loss, biodiversity loss and reduced protection from tropical cyclones;
- This situation poses serious risks to human and natural systems, affecting human health, infrastructure, their intersection (e.g. water security) and economic systems. This is especially potent for tourism and agriculture, and in particular the sectors that rely on the services provided by terrestrial and marine ecosystems.

### *10.3.3 Subregion: coastal regions in the Amazon*

**What drives the impact**

The climatic drivers are:

- Extreme heat events;
- Rainfall variability and extreme precipitation events;
- Reduction of mean annual precipitation;
- Sea level rise;
- Increased sea surface temperature.

The non-climatic drivers are:

- Land use and land use planning (gold mining);
- Dependency on limited and specialised resources and ecosystem services.

**Current situation**

- Most of French Guiana's population lives on the coast and is exposed to sea level rise, coastal erosion and flood. Population growth is high;

- Gold mining poses serious threats to the ecological stability of the region, which is characterised by the largest intact tropical forest worldwide;
- Droughts, precipitation and rising temperatures are key climatic drivers of impacts on biodiversity and timber production (Aubry-Kientz et al., 2015; Aguilos et al., 2018).

**Future situation**

- All current climate drivers can be expected to increase;
- Urban areas in the Amazonian Delta region will be at higher risk of flood due to climate change and rapid population growth;
- Risks to natural systems, especially the biodiversity provided by mangroves and tropical forests, will increase due to extreme heat events and land use;
- The climatic and non-climatic drivers of this subregion pose serious risks to human infrastructure systems, especially due to floods, sea level rise and coastal erosion;
- Changes in forest composition due to temperature and mean rainfall variation as well as land use will pose a risk to timber production, which French Guiana's economy heavily relies on.

### *10.3.4 Subregion: Macaronesia*

**What drives the impact**

The identified climatic drivers are:

- Sea surface temperatures;
- Tropical storms;
- Extreme heat events;
- Wildfires;
- Increase in humidity;
- Precipitation deficits;
- Sea level rise.

The non-climatic drivers are:

- Land use and land use planning (e.g. extensive construction in coastal areas, extensive construction of roads);
- Unsustainable tourism practices (e.g. massively more tourists than locals);
- Unsustainable fishing practices.

**Current situation**

- There is an increase in moderate to extreme heatwaves (Bernal-Ibáñez et al., 2022) leading to tropicalisation of the region, i.e. the arrival of algal species, fishes and crabs that normally live in warmer waters. This is a clear risk to biodiversity (Ribeiro et al., 2019; Castro et al., 2021; Schäfer et al., 2019);
- Observed climate impacts on ecosystems and society include wildfires, tropical storms and floods. For example, wildfires occurred in Madeira in 2012, 2016 and 2017, and they occur regularly in the Canary Islands. Several tropical storms hit the subregion, including storms Gordon (2012), Alex (2016), Helene (2018) and Lorenzo (2019) that hit the Azores, and storms Delta (2005) and Hermine (2022) in the Canary Islands. Several floods have occurred in the Azores (2009, 2018 and 2019), Madeira (2010, 2013) and the Canary Islands (2009, 2010, 2013, 2014 and 2015);
- Extensive urbanisation and touristic development has destroyed habitats, degraded water quality and led to the disappearance of continuous coastal shores, endangering

the unique terrestrial and marine flora of the region (Bernal-Ibáñez et al., 2021; Medail and Quezel, 1997; Rendeiro Martín-Cejas and Pablo Ramírez Sánchez, 2010).

**Future situation**

- In addition to the ongoing tropicalisation, increasing marine heatwaves will reduce the productivity of marine flora species (Bernal-Ibáñez et al., 2021, 2022; González et al., 2021). It is likely there will be a contraction in the distribution of bryophytes, vascular plants and arthropod species in the Azores (Ferreira et al., 2019);
- The number of extreme heat events accompanied by high humidity will increase (González et al., 2021);
- Overall, there will be a transition to drier conditions, with less precipitation and more arid periods (González et al., 2021);
- This transition will intensify wildfires, with the end-of-century Fire Weather Index ranging from medium (under the RCP2.6 scenario) to high (under RCP8.5) in the Canary Islands;
- Sea level rise will continue to rise, likely leading to more coastal flooding and a progressive retreat of the coastline (González et al., 2021);
- These climate drivers will have direct and profound impacts on the economy. The region may lose its attractiveness to tourists if its biodiversity declines because of marine heat stress, if humidity is persistently above bearable levels, or usable sandy beach areas are extremely limited or absent;
- Sea level rise and an increase in coastal flooding may also significantly impact the marine transport sector. These factors would compromise ports' operability and potentially lead to cascading impacts on trade, tourism and the islands' overall accessibility.



## 10.4 Risk assessment and evaluation

### *10.4.1 Confidence*

Confidence in the risk assessment depends on the quality and quantity of the evidence used to support it. While there are several projects aimed at investigating and improving the resilience of the EU outermost regions (e.g. SOCLIMPACT, NetBiome-CSA), research on vulnerabilities, exposure and hazards in this region is still lagging behind research on mainland Europe.

The most developed evidence found for this region comes from Global Climate Models (GCMs), in particular the components related to atmospheric dynamics and sea level rise. However, GCMs cannot simulate the small-scale topographic and coastal features of the islands, which are responsible for most of their observed microclimate variation. This requires downscaling techniques, which most studies do not adopt. Instead, those that employ regional climate models only use a limited number of scenarios, and usually only RCP8.5.

Targeted studies that focus on vulnerabilities, exposure and impacts for individual islands of the outermost regions are sparse and, in many cases, qualitative due to the nature of the study or availability of modelling resources. This also compromises confidence in the risk evaluation for the EU outermost regions.

### *10.4.2 Adaptation opportunities, constraints and limits*

In the EU outermost regions, as elsewhere, successful adaptation planning needs to consider multiple scenarios and stakeholders' views (Sousa et al., 2023). Successful climate adaptation planning in the outermost regions requires integrating adaptation options into the local context, with accountable, transparent and coordinated governance that is equitable and participatory

(Poti et al., 2022). Flexible regional planning is essential to mainstreaming adaptation at the regional and insular levels (Ribalaygua et al., 2019).

In the Caribbean, several adaptation measures are important for coastal adaptation, including planned retreats (i.e. migration to more elevated areas), hard protection measures, and education, training and public awareness.

In the Western Indian Ocean (i.e. in Réunion and Mayotte), ecosystem-based measures such as conservation and coral reef restoration are extremely important adaptation measures.

For French Guiana, research stresses the importance of community-based adaptation. This suggests that incorporating local knowledge in adaptation policy measures is key for enhancing the resilience of both human and natural systems in the region.

For Macaronesia, the establishment of protected areas has led to advantages for local communities and supported a sustainable commercial sector, including businesses like diving centres, restaurants and lodging sites, suggesting that this should be continued. Specific recommendations for the region include sustainable urbanisation; promoting the efficient and sustainable use of natural resources; and implementing ecosystem-based management principles.

### *10.4.3 Overall assessment*

This section presents the outcomes of the structured risk assessment for the major climate risks identified in this factsheet. The initial risk assessment was conducted by the authors of this factsheet whereas the final assessment results reported here represent the consensus of the EUCRA risk review panel. The assessment in this factsheet follows the same general approach as for other factsheets (see Annex 2 for details). However, the thresholds for risk severity classes have been adjusted to the small population, economic output and area of the EU outermost regions. Therefore, the results are not directly comparable with the assessments in the other factsheets and storylines, which cover all of Europe.

**Table 10.1 Risk assessment for the threats to marine ecosystems from marine heatwaves (EU outermost regions)**

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long-term (2081-2100)**<br>• **high warming**<br>• **low warming** |
|---|---|---|---|
| **Risk severity**<br>All EU outermost regions | **Critical**<br>Observations of coral bleaching and alien species, and indications of occurring tropicalisation, suggest a possible change to the current ecosystem. | **Critical**<br>Increasing warming and marine heatwaves trigger further coral bleaching and facilitate further invasions of alien species; endemic species might suffer or disappear. | **Catastrophic**<br>**Critical** |
| **Confidence** | **High** | **High** | **Medium** |
| | Observations of marine heatwaves and impacts have been extensive in the recent past, and ocean warming will continue in the foreseeable future. However, there is little forward-looking research on the impacts of changes to the frequency and intensity of marine heatwaves on marine ecosystems for EU outermost regions. | | |
| **Risk ownership** | **Co-owned**<br>Marine ecosystem affairs reside largely under the shared policy remits of the EU and Member States. However, the EU may have greater legislative responsibilities if the risk falls under the common fisheries policy, such as the management of marine biological resources. | | |

| | |
|---|---|
| | At the EU level, the main relevant policy frameworks and initiatives include:<br>• Marine Strategy Framework Directive (2008/56);<br>• Maritime Spatial Planning Directive (2014/89);<br>• Common fisheries policy (2023/103);<br>• Action plan on protecting and restoring marine ecosystems;<br>• EU principles on integrated coastal zone management.<br><br>At the national level, the main policies of relevance include those relating to:<br>• The environment (e.g. marine ecosystems);<br>• Industry (fisheries and aquaculture);<br>• Tourism;<br>• National adaptation funding. |
| **Policy readiness** | **Medium**<br>It partly falls under the EU biodiversity strategy, the European Maritime, Fisheries and Aquaculture Fund and the LIFE programme, but clear targets on how to deal with adapting to marine biodiversity changes are missing. |
| **Policy horizon** | **Medium-term** |
| **Urgency to act** | **Urgent action needed** |

**Source**: EEA.

### Table 10.2 Risk assessment for the threats to assets, infrastructure and ecosystems from sea level rise and tropical cyclones (EU outermost regions)

| | Current/near term (2021-2040) | Mid-term (2041-2060) | Long-term (2081-2100) |
|---|---|---|---|
| **Risk severity** Small islands in tropical regions | **Catastrophic** | **Catastrophic** | **Catastrophic** |
| | Risk severity corresponds to islands in the Caribbean region, whereas the risk is lower for islands in the Western Indian Ocean (Réunion and Mayotte). | | |
| **Risk severity** (Macaronesia) | **Substantial** | **Substantial** | **Critical** |
| **Risk severity** (French Guiana) | **Limited** | **Substantial** | **Substantial** |
| **Confidence** | **High** | **High** (for small islands in tropical regions and Macaronesia)<br>**Medium** (for French Guiana) | **Medium** |
| **Confidence reasoning** | Projections on rising sea levels are robust, even though there are uncertainties at the regional scale. While projections of future cyclone frequency, intensity and paths have considerable degrees of uncertainty, there is increasing evidence of an intensification of the strongest tropical cyclones. Uncertainty is higher for French Guiana because it is currently outside, but close to, the regions affected by tropical cyclones. | | |
| **Risk ownership** | **Co-owned**<br>The EU and Member States share legislative responsibilities in relation to infrastructure and the environment.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Critical Entities Resilience Directive (2022/2557);<br>• Technical guidance on the climate proofing of infrastructure in the period 2021-2027 (2021/C373/01);<br>• Floods Directive (2007/60);<br>• EU biodiversity strategy for 2030 (2020/380); | | |

| | |
|---|---|
| | • Forthcoming EU Nature Restoration Law (adoption expected for spring 2024);<br>• Birds Directive (2009/147) and Habitats Directive (92/43);<br>• Water Framework Directive (2000/60);<br>• EU Solidarity Fund;<br>• Union Civil Protection Mechanism.<br><br>At the national level, the main policies of relevance include those relating to:<br>• Spatial planning and infrastructure (e.g. protection of coastal areas);<br>• The environment;<br>• Industry;<br>• Civil protection and emergency preparedness;<br>• National insurance and disaster payments;<br>• National adaptation funding. |
| **Policy readiness** | **Medium**<br>The EU Solidarity Fund supports EU countries or regions with recovery after severe natural disasters, but is not aimed at risk prevention and management. Most other policies are also reactive after a catastrophe happens and preventive adaptation measures are lacking. Impacts on ecosystems can be mitigated through green infrastructures financed by the EU biodiversity strategy via the European Regional Development Fund, the European Maritime, Fisheries and Aquaculture Fund, InvestEU and LIFE programme grants. |
| **Policy horizon** | **Long-term** |
| **Urgency to act** | **Urgent action needed** (Small islands in tropical regions) |
| | **More action needed** (Macaronesia) |
| | **Further investigation** (French Guiana) |

**Source**: EEA.



## Table 10.3 Risk assessment for the threats to forest ecosystems from wildfires (EU outermost regions)

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long-term (2081-2100)**<br>• **high warming**<br>• **low warming** |
|---|---|---|---|
| **Risk severity**<br>Macaronesia | **Critical** | **Critical** | **Catastrophic**<br>**Critical** |
| **Risk severity**<br>Small islands in tropical regions, French Guiana | **Limited** | **Limited** | **Substantial**<br>**Limited** |
| **Confidence** | **Medium** | **Medium** | **Medium** |
| | Current observations document the extent of the impacts of wildfires on forest ecosystems fairly well. However, regional projections of key climatic drivers have considerable uncertainty at the scale of most EU outermost regions. There is little research on non-climatic drivers and vulnerabilities. | | |
| **Risk ownership** | **National**<br>Member States have the primary legislative responsibility for forest management. They have fewer opportunities to draw on resources from the Union Civil Protection Mechanism, such as RescEU, due to the geographical remoteness of the EU outermost regions.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• EU biodiversity strategy for 2030 (2020/380); | | |

| | |
|---|---|
| | • Forthcoming EU Nature Restoration Law (adoption expected for spring 2024);<br>• EU forest strategy for 2030 (2021/572);<br>• Common agricultural policy (2021/2116);<br>• Birds Directive (2009/147) and Habitats Directive (92/43);<br>• Union Civil Protection Mechanism;<br>• EU Solidarity Fund.<br><br>At the national level, the main relevant policies include those relating to:<br>• The environment (e.g. forest management and natural disturbances);<br>• Civil protection and emergency preparedness;<br>• National adaptation funding. |
| **Policy readiness** | **Medium**<br>There is limited focus on long-term preparedness in relevant EU policies. |
| **Policy horizon** | **Long-term** |
| **Urgency to act** | **More action needed**<br>(Macaronesia) |
| | **Further investigation**<br>(Small islands in tropical regions, French Guiana; assuming a high warming scenario) |
| | **Watching brief**<br>(Small islands in tropical regions, French Guiana; assuming a low warming scenario) |

**Source**: EEA.

## 10.5 Relevant policies

The EU recognises that the outermost regions have very different geographic, social, economic and climatic characteristics than those of continental Europe. Thus, the EU requires programmes, policies and initiatives tailored to these regions' specific needs, which are outlined in the communication 'Putting people first, securing sustainable and inclusive growth and unlocking the potential of the EU's outermost regions' (EC, 2022b).

Most of the EU's policy initiatives do not explicitly to reduce the harmful impacts of climate change. They do, however, aim to support strategic economic sectors (e.g. agri-food, tourism, the blue economy) and improve key socio-economic indicators, all of which would be compromised by climate change. Thus, although indirectly, their successful implementation would alleviate the future impact of climate change.

In terms of development goals, relevant policies are the cohesion policy instruments (EC, 2022h, 2022k), under which the EU will provide the outermost regions with the highest contribution rate of 85%. They will receive an allocation of EUR 1.514 billion (EUR 1.142 billion under the European Regional Development Fund and EUR 372 billion under the European Social Fund Plus).

The agri-food sector is supported by the POSEI scheme (programme of options specifically relating to remoteness and insularity). An annual budget of EUR 653 million is allocated to support these regions in the supply of essential agricultural products and to support the marketing and production of local products.

Concerning the blue economy, under the maritime and fisheries policy, EUR 315 million is allocated for structural investments and compensation of additional costs. Up to 100% of financing is provided for small-scale coastal fishing and for ecosystem protection measures.

Some EU funds support climate adaptation, such as the LIFE programme and the European Union Solidarity Fund (EUSF). LIFE has four sub-programmes, one of which focuses on climate change mitigation and adaptation. It grants bonus points to projects in the outermost regions and provides a 95% co-financing rate to projects protecting biodiversity and ecosystems in these regions. LIFE also co-finances projects in urban and land-use planning; infrastructure resilience; sustainable flood, drought and coastal risk management; and preparedness measures for extreme weather events. The EUSF aims to provide aid to Member States to support recovery in the aftermath of disasters. It has undergone substantial reforms over the years. One such reform took place in 2014, introducing a lower regional disaster threshold for the outermost regions.

# Part C Risk storylines

The following chapters complement the thematic factsheets presented in Part B by presenting climate risks and risk pathways for Europe in the form of risk storylines. These storylines are narratives that explore dynamic interdependencies and feedback loops among risk drivers and trace the propagation of risks through risk pathways. In its simplest form, storytelling of climate risks considers how climate hazards may compound (e.g. when they occur simultaneously or consecutively), how their impacts may cascade or spill over across geographic or functional boundaries, or how the interplay of risk drivers may unfold in specific situations. These narratives integrate insights from environmental and social sciences, anecdotal evidence, counterfactuals, and locally contextual or culturally embedded knowledge to identify plausible interconnections, challenges and potential courses of action. The Intergovernmental Panel on Climate Change's Sixth Assessment Report defines storylines as a means of 'making sense of a situation or a series of events through the construction of a set of explanatory elements'. In a more specific way, storylines refer to 'self-consistent unfolding of past events or of plausible future events or pathways' or 'a combination of qualitative and quantitative information which ensures that data can be meaningfully interpreted' (Shepherd and Lloyd, 2021).

The storyline narratives start by drawing attention to recent and memorable events, explaining why these events qualify as risks that require a coordinated European response. Subsequently, the storyline sections delve into various aspects, including the roles of climatic and non-climatic risk drivers in observed events, the understanding of related atmospheric and physical processes, their integration into risk assessments, and their predictability in forecasts and early warning systems. They explore the impacts and vulnerabilities associated with these events and processes, considering different elements at risk, such as human health, ecosystems, critical infrastructure and value chains. Lastly, the subsections examine how climate change and societal development could either exacerbate or mitigate the propagation of risks.

Extreme weather and climate-related events have triggered many crisis situations recently, prompting regulatory responses, solidarity payments and reforms to the Union Civil Protection Mechanism. These and other crises have stressed the importance of strategic crisis management capabilities. The Group of Chief Scientific Advisors' 2022 report (EC, 2022m) is one among many initiatives drawing attention to this critical field. Since 2022, the European Parliamentary Research Service publishes an annual review of future risks the EU may face (European Parliamentary Research Service, 2023). These range from geopolitics and climate change to health, economics and democracy. The review also elaborates on how the EU's risk governance capabilities could be further improved. Other initiatives include the World Economic Forum's *Global Risk Report* (WEF, 2023), the Institute for Economics and Peace's *Ecological Threat Reports* (e.g. IEP, 2023) and AXA's *Future Risks* report (AXA, 2022).

Climate storylines favour understanding of resilience and capacity to cope with climate-induced disasters and crises. The storyline approach can be complemented by other risk anticipation tools, including stress tests and strategic foresight, to inform the establishment of resilience goals and the enhancement of management capabilities in the face of interconnected and enduring crises. The focus and structure of the storylines in this report have been chosen to enhance the understanding of the evolving risk landscape and how the practice of strategic risk assessment can better align with increasing demands and requirements. The evolution of climate risk theory and practice is also associated with the inclusion of a wide range of risks beyond climate hazards and shocks. For the climate risk community, this means broadening the boundaries of risk assessment to include not only environmental factors but also financial, social and geopolitical risk drivers.

Storyline authors were invited to identify major climate risks and assess them using the same structured risk assessment approach that was applied in the thematic factsheets of this report (see Annex 2 and the introduction to Part B for further information). This approach was applied in most, but not all, storylines. When a major climate risk draws on information from a factsheet as well as a storyline, the structured risk assessment was preferably presented in the factsheet, considering also evidence from the respective storyline. The findings from factsheets and storylines are fully integrated in Part D of this report.

# 11 Extreme heat and prolonged drought

## 11.1 Key messages

- Europe is the fastest warming continent on Earth. Extreme heat, once relatively rare, is becoming increasingly common, particularly in southern and western Europe. The record-hot summer of 2022 has been linked to 60,000-70,000 premature deaths.
- Drought is a growing problem, driven by the combination of higher temperatures with reduced and more irregular precipitation. Prolonged droughts cause severe economic damage across many sectors. They can severely degrade the water resources that people, agriculture, industry and ecosystems depend on, as well as hamper transport via inland waterways.
- Management practices, infrastructure investments and other factors can either mitigate or exacerbate the impacts of a changing climate.
- Southern Europe is particularly vulnerable, but countries in central and northern Europe are also at risk and not prepared for prolonged droughts.
- Heat and drought are creating conditions for wildfires that threaten health, the built environment, ecosystems and the carbon sink. Wildfire risks are already critical in southern Europe and are projected to increase further.
- Europe faces the growing risk of a megadrought that spans large regions and lasts for several years, with severe impacts on crop production, food security, drinking water supplies and energy production.
- Enhanced policies to mitigate drought and heatwave risks are needed at EU, Member State and subnational levels. Water scarcity could also trigger conflicts.



## 11.2 Introduction

The world is witnessing its highest temperatures on record – and most likely the highest for about 125,000 years – and Europe is warming faster than the planet as a whole. In the period 2018-2022, the average surface temperature worldwide was about 1.2°C higher than in the period 1850-1900, but in Europe it was about 2.2°C higher. Europe's five warmest years on record have all occurred since 2014, and the summer of 2022 was the hottest ever recorded (C3S, 2023e).

Extreme heat, once relatively rare, is increasingly common, and so is heat stress. Between June and August 2022, most of Europe experienced at least 10 days of strong heat stress (C3S, 2023e). Much of the southern and western Europe had at least 5 days of very strong heat stress ([7]), and parts of the southwest, close to 50 days. Across Europe, that summer's heat has been linked to at least 60,000 and possibly more than 70,000 premature deaths (Ballester et al., 2023d, 2023e).

Snow amounts are decreasing in much of Europe while rainfall patterns have changed, and drought is a growing problem, particularly when temperatures are high. Northern countries that historically had ample water supplies have experienced water stress (Toreti et al., 2023a), and parts of southern Europe are increasingly at risk of desertification (Barbiroglio, 2022). A persistent lack of precipitation starting in the winter of 2021-2022, combined with above-

([7]) 'Days with very strong heat stress' refers to days where the Universal Thermal Climate Index, which describes weather-induced outdoor thermal stress in humans and represents a 'feels-like' temperature, exceeds 38°C (Di Napoli et al., 2018).

average temperatures and heatwaves, led to a severe drought that, at its peak in summer 2022, affected more than a third of Europe (C3S, 2023e).

This recent experience has made drought and extreme heat risks one of the top concerns as Europe confronts future climate change. This chapter delves deeper into these risks, looking at the interaction of climatic and non-climatic drivers; key impacts on people, ecosystems and the economy; the potential for future crises; and the role of EU policies in building resilience.

## 11.3 Recent experience with heat and water stress in Europe

Europe has experienced several extreme drought and heatwave events in recent years, most notably in 2003, 2007, 2018, 2019, 2022 and 2023. A Europe-wide temperature record of 48.8°C was set in August 2021 in Sicily (Prior, 2023), followed by a European record for July at 48.2°C set in July 2023 in Sardinia (WMO, 2023a). During the 2018-2019 drought, Paris set its own record of 42.6°C in July 2019 and, alarmed by recent trends, has begun to prepare for potential 50°C days by mid-century (Cazi and Garric, 2023). Several studies have shown that climate change is increasing the likelihood of heat records in Europe (Robinson et al., 2021), as well as the likelihood of increasing daily maximum temperatures and the frequency and intensity of heatwaves (Seneviratne et al., 2021b).

As noted in the introduction, many Europeans have also experienced severe drought conditions in recent years. The combination of heat and drought has caused crop failures, created water stress, and harmed forests and other ecosystems in Europe (Bednar-Friedl et al., 2022b).

Definitions for drought differ depending on the context. The EU Water Framework Directive defines drought exclusively as precipitation deficits (meteorological droughts), but risks of drought and water scarcity are driven by multiple factors. Meteorological droughts can be exacerbated by increased evapotranspiration losses due to high temperatures, which can lead to soil moisture deficits (agricultural droughts); these can limit evapotranspiration, thereby increasing surface temperatures and strengthening heatwave events. Low flows in rivers (hydrological droughts) are further influenced by seasonal changes in snow cover (e.g. low snow meltwater contribution due to low snow cover in mountains) and glacier meltwater.

The 2022 drought began with a persistent lack of precipitation in the latter part of 2021, especially in France, Italy and Spain. The lack of rain continued into the spring and summer of 2022, and the drought was exacerbated by hot temperatures and several heatwaves starting in May, linked to a persistent anticyclonic anomaly over western Europe (Faranda et al., 2023). River discharges in Europe were the second lowest on record (since 1991), and local minimum discharge records were broken (Copernicus, 2022; Montanari et al., 2023). In certain areas, the drought was among the worst in 500 years (Zhang et al., 2023).

Climate change has intensified hydrological droughts in the Mediterranean region (Seneviratne et al., 2021b). Other parts of Europe have seen some reductions in river flow as well, often linked to decreases in snow cover during the winter and to glacial retreat. In 2022, for example, the Alpine glaciers received very little winter snow and experienced an unusually warm summer, leading to record ice loss from these glaciers in the Alps (C3S, 2023e; see also Chapter 2). In some parts of northern Europe, a shorter snow season, a decrease in accumulated snow and earlier snowmelt have contributed to a decrease in summertime river flows and soil moisture, which is exacerbated by heat (Veijalainen et al., 2019).

### *11.3.1 How non-climatic factors affect heat and drought risks*

As with all climate risks, the extent to which Europeans are harmed by extreme heat and drought depends greatly on factors unrelated to the hazards themselves (see also Chapter 2 and Chapters 5 and 7). These include differences in the geography, land use patterns, environmental conditions, economies and demographics of Member States (and within them); disparities that make some groups more vulnerable than others; and policies and institutions – most crucially, in the context of drought, how water resources are managed.

As of 2021, about 75% of Europe's population lived in urban areas (EC, 2022n), and this exposes them to higher temperatures during heatwaves due to the urban heat island effect and building characteristics (Ward et al., 2016). Buildings and other urban infrastructure absorb heat during the day, increasing the overall ambient temperature, and limit how much cities cool down at night. Urban green spaces help offset this effect, but studies in several Member States have found lower-income neighbourhoods tend to have smaller and lower-quality green spaces (C3S, 2023i). Socio-economic conditions also affect the quality of housing and people's access to air conditioning and other protective measures (see Chapter 9 for more information).

Underlying chronic diseases and old age greatly increase vulnerability to extreme heat (see also Chapter 7). The heat mortality rate in the summer of 2022, for example, was 16 per million for ages 0-64, but 160 per million for ages 65-79 and 1,684 per million for those aged 80 and older (Ballester et al., 2023d). This is a concern given Europe's ageing population. In many cities, hospitals and schools are also concentrated in areas that are hotter than the city as a whole, increasing the exposure of vulnerable groups as well as teachers and healthcare workers (EEA, 2022e; Bednar-Friedl et al., 2022b).

One factor in drought vulnerability, meanwhile, is how scarce water is to begin with. Water resources are not uniformly distributed around Europe. In 2017, for example, Austria had 8,444 $m^3$ of water available per inhabitant, while Spain had 2,042 $m^3$ and Italy had 1,320 $m^3$ (EEA, 2021i). Conditions vary annually, but in southern Europe, the most water-stressed region, about 30% of the population faces permanent water stress, and up to 70% faces seasonal water stress. In 2019, water scarcity affected 29% of EU territory, but over 50% of the area of Cyprus, Malta, Greece, Portugal and Italy (EEA, 2023o). However, even more water-abundant regions can be significantly affected by prolonged drought, especially since communities, economies and ecosystems are not used to, or prepared for, water scarcity.

Use of irrigation for agriculture also varies in different parts of Europe. Agriculture is the most water-demanding sector in southern and eastern Europe (accounting for up to 76-79% of use), while water allocation in northern Europe is more balanced (i.e. 18-36% among the agriculture, cooling, industrial use and household sectors) (MedECC, 2020b). On average, water use in Europe has decreased since the 1990s in most economic sectors, especially agriculture, as efficiency has improved (EEA, 2019d), but there are regional differences, and there is room for further improvement (European Court of Auditors, 2021). Industrial use trends vary, while water use in some urban areas has risen with population growth and higher consumption (Caretta et al., 2022b).

In some places, households, industry and agriculture are already competing for the same scarce water resources (Garrick et al., 2019b). National policies and legislation about prioritising water use have been implemented, but approaches vary (EurEau, 2020). Drinking water supply is usually considered critical infrastructure and thus given priority, but this is not legally mandated in many countries.

In many EU Member States, water distribution and irrigation infrastructure is old and in need of upgrades. The losses due to leakage can be substantial, in the range of 10-72% (EurEau, 2020; ERM, 2013b). Another concern is that groundwater abstraction rates in parts of Europe exceed recharge rates, leading to groundwater depletion and increasing the impacts of water scarcity in southern Europe (Bednar-Friedl et al., 2022b). Unsustainable groundwater pumping already threatens environmental flow requirements in many areas, especially in southern Europe. Saltwater intrusion is also affecting water supplies in many coastal regions in southern Europe, with saltwater reaching up to 40 km inland in Italy's Po delta in 2022, a new record (Faranda et al., 2023).

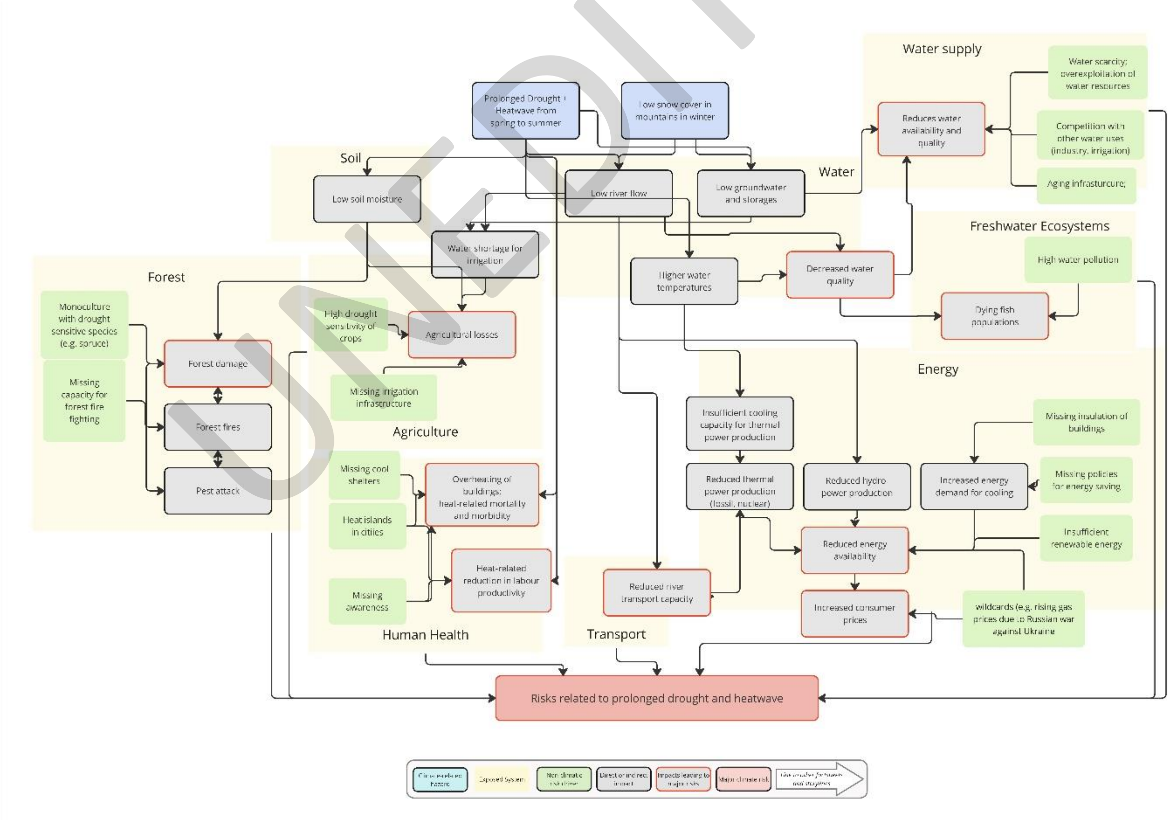
Lastly, land use patterns, land degradation, ecological conditions and straightening of free-flowing rivers, including the reduction of natural flood areas, can also affect the severity of a drought's impacts. Drought conditions can be exacerbated by artificial impermeable surfaces and soil compaction, and pollution and eutrophication can amplify the impacts of droughts on ecosystems and recreational areas.

### *11.3.2 How extreme heat and prolonged droughts affect different sectors*

Extreme heat and droughts can trigger a complex chain of cascading and compounding impacts on human and natural systems alike, as illustrated in Figure 11.1. Not all these impacts can be quantified in economic terms, in particular irreversible damage to terrestrial and aquatic ecosystems. In the period 1981-2010, annual economic losses from droughts have been estimated at around EUR 9 billion for the EU and the UK (Cammalleri et al., 2020b). The largest impacts were found in agriculture (39-60% of total damage, depending on region) and the energy sector (22-48%), as well as public water supply (9-20%). The greatest losses were seen in Spain (EUR 1.5 billion per year), Italy (EUR 1.4 billion) and France (EUR 1.2 billion). Loss data for more recent years suggest the averages would be much higher now. The 2022 compound drought and heat events in Europe, for instance, caused an estimated EUR 40 billion of economic losses (EEA, 2023e), with the largest losses in Italy, Spain and France (AON, 2023). Figure 11.2 illustrates key impacts on different sectors.

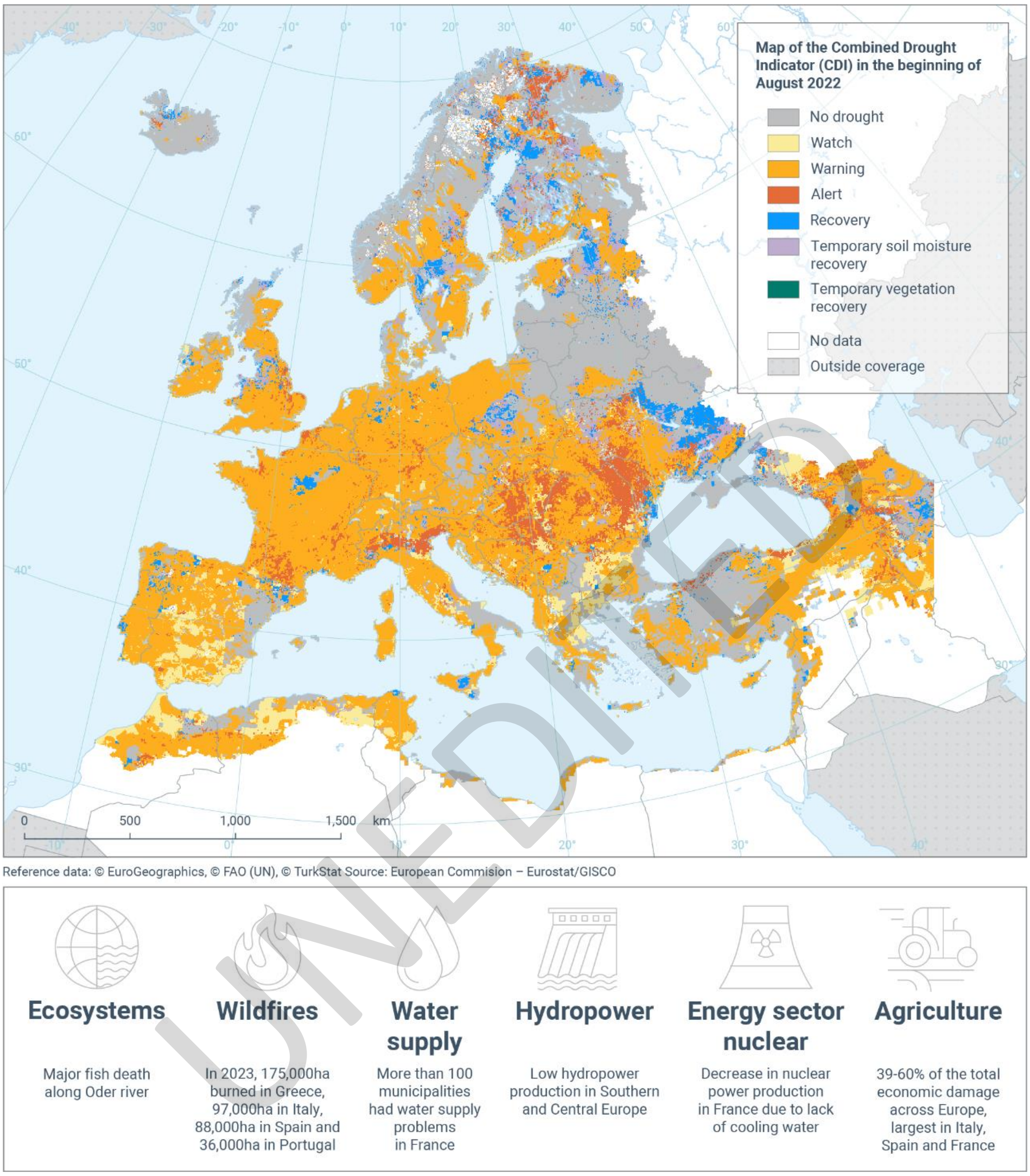


**Figure 11.1 Example of impact chain on droughts**




**Source**: ETC-CA, 2024.

**Figure 11.2 Map of extent of drought at the beginning of August 2022**






**Source**: Based on the Combined Drought Indicator of the JRC European Drought Observatory (Toreti et al., 2022) and some key impacts in different sectors (see text for references).

As highlighted in the Chapter 6, heat and drought stress on crops can cause significant crop losses and yield reductions, affecting food security. Only a small fraction of Europe's cropland is irrigated (5.6% in 2016) though there are very large regional variations, with irrigation widely used in southern Europe, and far less in northern, central and eastern Europe ([8]). Rainfed agriculture may be more vulnerable to drought than irrigated agriculture. In 2018, for example, extremely low rainfall and warm spring and summer temperatures sharply reduced yields of major cereal crops, below the 10th percentile (Beillouin et al., 2020). This, in turn, drove up

([8]) See https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_irrigation.

prices, by an estimated 34% for soft wheat and 48% for barley (EC DG AGRI, 2018; EC, 2018a; Brás et al., 2021).

Irrigated agriculture, on the other hand, is adversely affected when droughts lead to water shortages and competition with other sectors for scarce resources, as was seen in 2022 when growth of winter and summer crops was compromised by water shortages (Toreti et al., 2022). Saltwater intrusion during droughts exacerbates the integrity of water supplies in delta areas and along coasts (Tarolli et al., 2023).

Heat stress harms crops, and it is increasingly occurring in the summer in central and southern Europe, and even in the spring in southern Europe, as well as in the southern boreal zone recently (Fontana et al., 2015; Ceglar et al., 2019b; Seneviratne et al., 2021b). The 2022 heat and drought imposed high costs on farmers for reseeding and irrigation, combined with crop losses. In Italy, 11% of farms were forced to suspend activities, and total agricultural costs were estimated at EUR 9 billion (Legambiente, 2022). Heat and drought can also affect livestock production through thermal stress on livestock and reduced forage production (Bednar-Friedl et al., 2022b). Wildlife has suffered as well, with heat and water scarcity driving excess mortality of fish, birds and mammals in western and southern Europe in the summer of 2022, for example (Delacroix, 2022).

The combined effects of low flows and high water temperatures during droughts and heatwaves can also amplify the impacts of water pollution, such as eutrophication due to nutrients flowing into water bodies and resulting algal blooms. One of the largest ecological disasters in Europe in recent memory was the Oder River disaster in July and August 2022, when over 360 tonnes of fish died along more than 500 km of the river (EC, 2023a). A large toxic algal bloom has been identified as the cause. It was triggered by salt pollution from industrial activities, plus high nutrient concentrations and low water discharge due to prolonged drought.

As the Chapter 13 highlights, heat and drought are also major drivers of tree mortality in Europe, incrementally and through wildfires (Bednar-Friedl et al., 2022b). Water scarcity and high temperatures can harm tree regeneration, increase mortality rates, induce crown dieback and defoliation (Carnicer et al., 2011), and alter forest structure and composition (Hember et al., 2017; Senf et al., 2020a). This affects the ecosystem services provided by forests, including the carbon sink, water storage and filtering, and temperature regulation, as well as impacts on Europe's wood-based industry (Knutzen et al., 2023; Wolf and Paul-Limoges, 2023) and the functioning of several nature-based solutions (NBS).

Water security is discussed in detail in the Chapter 5, but it is important to note here that it is not only arid areas in Europe that have experienced water stress in recent years, but also places with generally abundant water resources. In 2022 in France, more than 100 municipalities had water supply issues and drinking water was delivered by truck (Toreti et al., 2022). In some small municipalities in Finland and Sweden, droughts in 2003 and 2018 led to temporary water scarcity (Ahopelto et al., 2019; Silander and Järvinen, 2004).

Water also plays an important role in the energy sector, so droughts can be highly disruptive. Limited river flows decrease hydropower production and can reduce cooling water availability for thermal power plants. During the summer of 2022, nuclear power production in Europe had to be reduced due to low flows and high temperatures in rivers; hydropower production was also low across most of Europe (Toreti et al., 2022). The impacts of heat and drought on transport can be severe, too (see Chapter 15 for a detailed discussion).

Lastly, it is important to highlight the impacts of extreme heat on people's health (see also Chapter 7). Extreme heat is the greatest direct climate change-related threat to human health, with 86-91% of deaths linked to weather or climate extremes in Europe in the period 1980-2020 (EEA, 2022e), though the lack of consistent reporting of heat-related mortality makes precise estimates challenging. The number of people who are exposed to extreme heat and are particularly vulnerable is rising, due to Europe's ageing population, the prevalence of chronic diseases and the increased frequency, length and intensity of heatwaves, combined with growing urbanisation (EEA, 2022e).

Exposure to extreme heat can cause heat exhaustion and potentially deadly heatstroke; it also affects cardiovascular and respiratory systems and can exacerbate pre-existing health problems (EEA, 2022e). At work, it can lead to dehydration, impair cognitive abilities and slow reflexes, increasing the risk of injury. It can also affect pregnancy outcomes, cause kidney problems, worsen sleep and affect mental health. Extreme heat affects health indirectly, too, due to worsening air quality and by restricting people's capacity to work and exercise outdoors (Ebi et al., 2021; WHO, 2018).

Europe has experienced several heatwaves with large death tolls. The 2003 heatwave set a record of 70,000 excess deaths, which may have been broken in 2022; estimates range from 60,000 to more than 70,000 excess deaths (Ballester et al., 2023d, 2023e). In Italy, the extreme heat in July 2022 increased the mortality rate for people over 65 by 29% (Ballester et al., 2023d).

Increased heat exposure is already affecting Europe's labour force, especially in sectors where many people work outdoors, with working hours and productivity both affected (van Daalen et al., 2022b; EEA, 2022e). In the period 2016-2019, the agriculture, construction, forestry, and mining and quarrying sectors are estimated to have lost an average of 16 hours per worker per year relative to 1965-1994, with the largest losses found in southern Europe (EEA, 2022e).

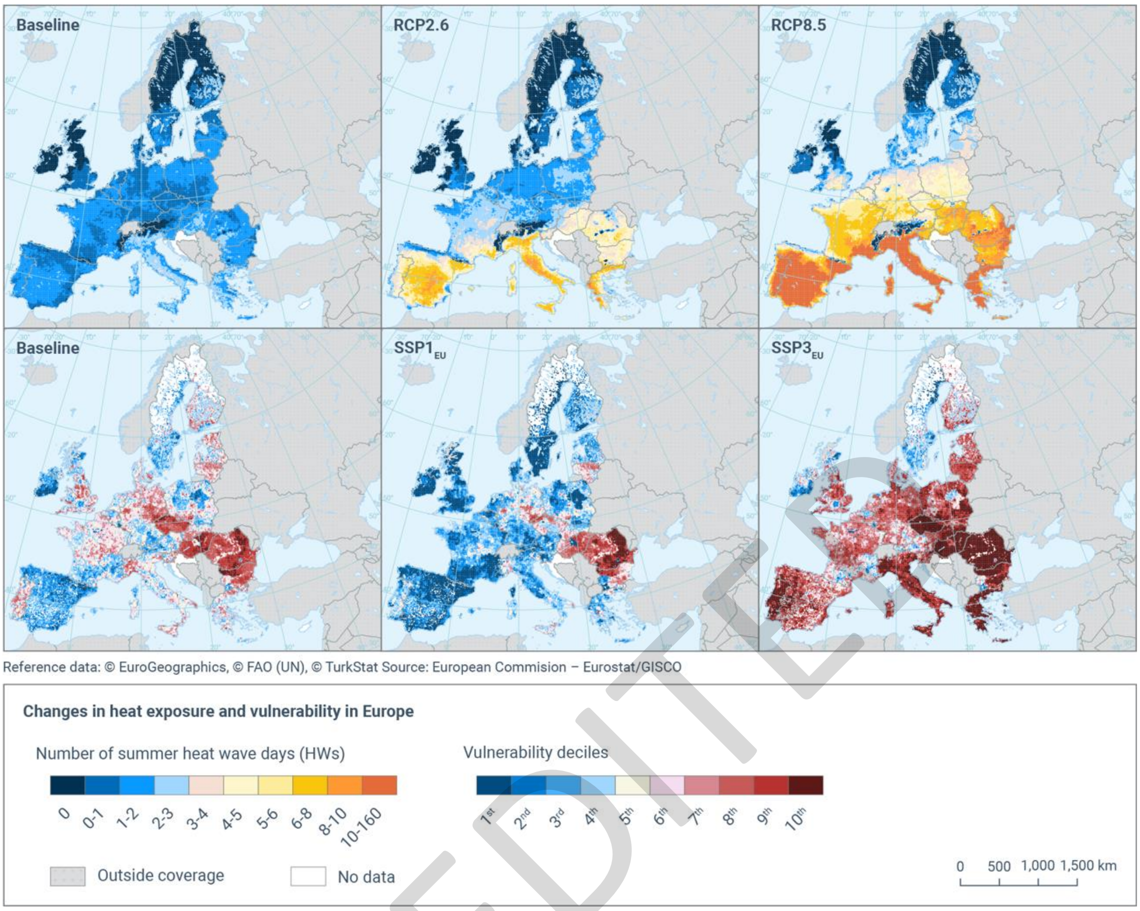
## 11.4 Potential for future crises

The Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report identifies four key risks from climate change for Europe in the coming decades, three of which are linked to heat and drought: mortality and morbidity of people and ecosystems disruptions due to heat; loss in agricultural production due to combined heat and droughts; and water scarcity across sectors (Bednar-Friedl et al., 2022b; the fourth key risk is flood impacts). The risk of heat stress is particularly high if global temperatures increase by 3°C or more, in which case the IPCC warns, with high confidence, of limits to the adaptation potential of people and health systems, particularly in southern and eastern Europe.

The IPCC also projects, with high confidence, that the combination of heat and drought will cause substantive agricultural production losses in most of Europe (Bednar-Friedl et al., 2022b). The risk of water scarcity is already identified as high at 1.5°C of warming, and very high at 3°C, in southern Europe, with risks also increasing, but at lower levels, in western and central Europe. At 3°C, adaptation would become increasingly difficult, with southern Europe likely to be the first to reach hard limits.

Globally, the likelihood of record-breaking heat extremes is estimated to increase significantly already in the period 2021-2050 and even more dramatically in the period 2051-2080 (week-long heat extremes becoming 3-21 times more likely in a high-emission scenario) (Fischer et al., 2021a). However, heat extremes in western Europe are increasing faster than simulated by climate models because of missed atmospheric circulation trends in the models (Vautard et al., 2023). Future projections may therefore underestimate the changes in extreme heat. Figure 11.3 shows projections for future heat exposure and vulnerability across Europe (Rohat et al., 2019a).

### Figure 11.3 Changes in heat exposure and vulnerability in Europe




**Note:** Top row: mean number of summer heatwave days (HWDs) for the baseline (1986-2005) and future (2041-2060) conditions under two Representative Concentration Pathways (RCPs) (ensemble median). Bottom row: vulnerability index in Europe for the baseline socio-economic conditions (2015) and for the year 2050 under the two Shared Socioeconomic Pathways (SSPs). The vulnerability index measures socio-economic vulnerability to heat stress determined by income, education, ageing, artificial surfaces, social isolation and pre-existing medical conditions (Table 1, **(Rohat et al., 2019a)**).
**Source:** Adapted from **(Rohat et al., 2019a)** (Fig. 1 and 3).



As discussed in the previous section, the severity of water stress depends not only on water supplies, but also on demand and resource management practices (see also Chapter 5 and Chapter 2). Future changes in water demand depend on population and demographic change, urbanisation, changes in agriculture, efficiency and industrial use. Regional and local differences in these trends within Europe are expected to be large. Further improvements in water efficiency are needed in the regions with high water stress, with significant adaptation efforts required in agriculture in particular.

Economic damage from droughts is expected to increase with climate change (Cammalleri et al., 2020b), though estimates are difficult and contain large uncertainties. Assuming no socio-economic change relative to 2015, drought damage is projected to be EUR 9.7 [range of 7.4-13.8] billion per year at 1.5°C of global warming, up from EUR 9 billion in the period 1981-2010; at 2°C it could reach EUR 12.2 [range of 9.7-18.6] billion per year, and at 3°C, EUR 17.2 [13.4-27.6] billion per year. These projections consider only drought impacts, however, not how prolonged heat might exacerbate the impacts. In addition, as noted in Section 11.3, much higher losses in recent years suggest that these may be underestimates.

A 2020 analysis as part of the PESETA IV project found that by the end of this century, at 3°C of global warming, the number of citizens in the EU and the UK exposed to heatwaves in any given year would rise from an average of 10 million in the period 1981-2010 to 300 million, or more than half the population (Naumann et al., 2020). With no further adaptation, this could result in 96,000 excess deaths per year from extreme heat, up from an average of 2,750 in the period 1981-2010. The analysis also found that, in a 3°C scenario, what is now a 50-year heatwave may occur almost every year in Spain and parts of Portugal, every 3 years in most other southern European areas, and at least every 5 years in other regions of Europe. All these risks would be significantly lower in a 1.5°C scenario; the analysis finds mortality from extreme heat, for instance, would decline to about 30,000 deaths per year. As recent experience shows, however, annual averages can conceal very large shocks.

It is difficult to quantify the likelihood of a severe multi-year drought combined with prolonged extreme heat, for example, but there is scientific agreement that this likelihood will increase with further warming (Bevacqua et al., 2022a; Tripathy and Mishra, 2023). The rate of increase depends on the future warming scenario. A recent study suggested that extreme heat and drought events typical of an end-of-century climate could occur over Europe sooner, and already before 2040 (Suarez-Gutierrez et al., 2023). Megadroughts have occurred in the past, are influenced by climate change and have the potential to strain modern water management systems (Cook et al., 2022). The crises experienced by several Member States in recent years show that it is important to prepare for such extremes. The larger changes in observed heat extremes compared to projections (Vautard et al., 2023) also highlight the risk of underestimating the changes.

### *11.4.1 Potential for acute crises*

Severe heatwaves and droughts could lead to acute crises, with the potential for extreme heat, raging wildfires and critical infrastructure failures to cause severe health and economic impacts. As noted above, heatwaves are becoming more frequent and more severe in Europe (Bednar-Friedl et al., 2022b). Older people, those with pre-existing medical conditions and outdoor workers would be disproportionately affected by extreme heat, while all water-dependent economic sectors, especially agriculture, would be under stress from drought conditions. Also, drinking water supply, which is a basic human need, would be under stress in a severe drought situation.

During a severe drought, an unprecedented wildfire situation could arise as well. Indeed, in 2023, very large and severe fires occurred in Europe, including the largest seen since at least 2000, in Greece’s Alexandroupolis region (DG-ECHO, 2023). In 2022, an estimated 900,000 hectares were burnt in EU countries (C3S, 2023e). Increasing wildfires can cause substantial damage to forests and nearby human settlements, require large-scale evacuations, spread smoke that can cause serious air quality issues even far away from the actual fire, and sometimes kill people. Large-scale wildfires may also overwhelm the capacity of rescue and recovery operations and deplete emergency response capacity.

The likelihood of a severe heatwave is greater under already prolonged drought conditions (Miralles et al., 2014), and a severe heatwave amid a drought could cause even worse water shortages than Europe has seen so far. Water demand often increases during heatwaves, but water supply systems could fail under extreme stress. Vulnerabilities such as ageing infrastructure, overconsumption of ground water and salt intrusion also increase the risks. Competition among water users will increase during droughts and could require strict restrictions on water use to avoid leaving some users with no water (see also Chapter 5). As discussed in the Chapter 15, extreme heat and drought are very disruptive to energy systems and could cause system failures. Power outages during a severe heatwave could leave people without the ability to use the cooling systems they need to survive, driving up mortality and morbidity rates, and potentially create crises in healthcare facilities.

It is important to stress that acute crises may persist for longer periods in a changing climate. Even in the lower of the two emissions scenarios assessed (RCP4.5), the number of heatwave days would increase from about 5 days per year in 2000 to 13 days in France, 20 days in Greece and 24 days in Italy, according to the heatwave definition in the WHO EuroHEAT project (C3S, 2019b).

### 11.4.2 Potential long-term impacts

The acute crisis caused by a severe heatwave can last weeks or months, but droughts can stretch out for years. Moreover, the cumulative effects of several heatwaves and droughts can overwhelm systems if they are not resilient enough.

The agricultural sector, which is already vulnerable to acute crises, could be profoundly affected by large-scale, severe droughts that go on for a long time or occur several times within a few years. After a prolonged dry period, stored water resources in either soil and groundwater or reservoirs and other man-made storage systems would be depleted, and this could result in major crop losses in large parts of Europe. The continued reduction of snowmelt and glacial melt flowing into rivers is likely to exacerbate water stress (Bednar-Friedl et al., 2022b). More frequent droughts and decreasing water resources may drive farmers out of business unless they can adapt significantly.

Persistently dry and hot conditions, together with land degradation, may also increase desertification risks in parts of southern Europe (UNEP, 2016). At 2°C of global warming, 8% of Europe's territory is characterised as having a high or very high sensitivity to desertification (UNEP/UNECE, 2016). See Chapter 6 for a discussion of the implications on food availability and costs. The cumulative effects of extreme heat and droughts on forest ecosystems and on biodiversity could be very severe as well, as discussed in Chapter 13 and Chapter 3.

The heat impacts on labour are also expected to increase (van Daalen et al., 2022b) and adaptation measures will be crucial to keep workers safe, healthy and productive (EEA, 2022e). Several other economic impacts are possible. Since industry needs water for cooling and other parts of industrial processes, some operations may have to move or shut down – and others that might have been set up in certain parts of Europe may choose more water-secure sites instead.

Tourism could be severely affected by extreme heat as well as wildfires, particularly in southern Europe and in cities that experience repeated heatwaves. Projections of future tourism demand show a clear pattern, with northern regions benefiting from milder conditions while southern regions face significant reductions in tourism demand, especially in a high-emission scenario (Matei et al., 2023).

A final concern to raise here is that the severe water scarcity that prolonged droughts could create might lead not only to conflicts among different water-using sectors, but also among countries that share water resources. Cooperation is needed in transboundary river basins to assess these potential tensions. Political disputes can arise both during an acute crisis and in the long-term management of water resources. Application of drought management plans (DMPs) and cross-sectoral management of water resources are important to ensure fair distribution of the water resources.

### 11.4.3 Adaptation and resilience

While the challenges posed by extreme heat and prolonged droughts are significant, there are multiple ways to mitigate these risks. As noted in Section 11.3.1 it matters greatly how water resources are managed, for instance. Effective adaptation measures in the context of drought include promoting efficient water use and conservation; restoring catchments; increasing water supplies through wastewater reuse, desalination and water harvesting techniques; renewing and improving the existing infrastructure for water supply and irrigation, including to minimise losses; creating or improving early warning and alert systems; and raising public awareness among stakeholders (Vogt et al., 2018; Cammalleri et al., 2020b). Farmers can also switch to more drought-resistant crops, improve water holding capacity in their soils, change cropping patterns and timing, and adopt other climate-smart agriculture techniques (EEA, 2019d).

Restoring the sponge function of soil and NBS can help retain water in soil and the watershed area and alleviate both droughts and floods. Relevant NBS include conservation agriculture, groundwater recharge, sand dams and water harvesting structures (UN Environment-DHI, UN Environment and IUCN, 2018). NBS can also be used to enhance habitats and ecosystems' well-being. River restoration (e.g. maintaining and restoring wetlands, restoring natural little streams and closing ditches, establishing riparian vegetation) can be used to increase water retention in river catchments. In many places, unsustainable water consumption and excessive groundwater abstraction need to be addressed (see Chapter 5).

Early warning systems, improved forecasts and planned measures for wildfires, droughts and heatwaves can help ensure timely responses and mitigate harm (van Daalen et al., 2022b). Increasing the resilience of critical infrastructure is crucial to reduce the risk of cascading effects (e.g. power outages during a severe heatwave resulting in more health issues). It is important to develop national heat-health actions plans that cover both short- and long-term measures to mitigate the health impacts of heat (Martinez et al., 2019).

City planning with more trees and green spaces can be used to lower the temperature in cities. Limited soil sealing and desealing, more green spaces, better building design, better building design and resilient cooling solutions are needed (EEA, 2022e). To avoid severe negative impacts on health, adaptation methods such as raising awareness, early warning systems, adaptation of working times and putting in place ready-to-go actions at health and social care centres are needed. Special emphasis should be given to vulnerable groups. For instance, a substantial proportion of hospitals and schools need to improve their preparedness for heatwaves. Conditions for outdoor workers also require special attention and adaptation.

Some adaptation measures may be equally necessary and effective across Europe, but solutions will need to be tailored to specific contexts. For example, the adaptations needed in mostly rainfed agriculture in northern Europe are different to those needed on irrigated farms in southern Europe. Investments should also take into account differential vulnerabilities and inequalities.

## 11.5 Role of EU policies

Prolonged heat and drought affect many policy domains: water, agriculture, biodiversity, forestry, health, energy, transport and infrastructure. Recognising that several factsheets address specific sectors, and Chapter 15 discusses several adaptation deficits as well, this section focuses mainly on policies related to water and agriculture, urban infrastructure and human health risks.

### *11.5.1 Water and agriculture*

Since 2000, the main policy regarding water management has been the EU Water Framework Directive (WFD) (EC, 2000), last updated in 2014, which aims to preserve water quality and ensure there is enough water for both human needs and ecosystems. It uses the river basin approach, so that bodies of water shared between countries or other borders are managed in cooperation. Member States have the obligation to implement river basin management plans (RBMPs), revised every 6 years.

Droughts are directly mentioned under Article 6. When a drought occurs, the WFD calls for steps to be taken to prevent further deterioration of water bodies. RBMPs must also include the conditions to declare exceptional circumstances such as droughts, the adoption of indicators, and the measures taken to deal with said droughts. The effects of droughts are to be reviewed annually.

While the WFD recognises and sets out some specific conditions on how to manage drought conditions, more can be done. In 2007, the EU released a communication on addressing the challenge of water scarcity and droughts, highlighting the benefits of water pricing and drought management plans (Commission of the European Communities, 2007). In 2015, the Global Water Partnership Central and Eastern Europe released a guidance document (Global Water Partnership Central and Easter Europe, 2015) to help Member States develop drought management plans as part of their updated RBMPs. For the 2021 revision of the RBMPs, the European Commission in its follow-up (EC, 2019c) encouraged Bulgaria, Germany, Finland, Croatia, Hungary and Sweden to implement drought management plans and recommended that Italy and Spain update their DMPs.

The common implementation strategy was launched in 2001 to work towards a successful implementation of the WFD in Member States and associated countries. Its 2022-2024 work programme includes several tools to address water scarcity, including by promoting water reuse in agriculture, reducing leakage in water supply networks, and establishing an ad hoc task group on water scarcity and droughts. Within the ad hoc task group, a report on drought management policies and an in-depth assessment of drought management plans in the EU was published in October 2023 (EC DG ENV, 2023). The assessment is supported by the EDORA project, which recently released the first multi-sectoral drought Risk Atlas, complemented by the European Drought Impact Database.

The new common agricultural policy (CAP) for 2023-2027 has several provisions relevant to drought resilience, including the requirement that a minimum of 25% of direct payments to farmers be allocated to eco-schemes and a minimum of 35% of European Agricultural Fund for Rural Development (EAFRD) funding be ring-fenced for environmental and climate objectives (EC, 2023w; EC DG AGRI, 2022a). This can be for agri-environmental climate interventions and investments relevant for water resilience. Eco-schemes and agri-environment climate interventions will be mandatory for countries to include in their CAP strategic plans (CSPs), but voluntary for farmers. To accelerate adaptation to droughts, inclusion of relevant adaptation measures in CSPs for regions most at risk could be made binding in future.

The new CAP calls for each Member State to develop a CAP strategic plan. In one of the letters to Member States, the Commission highlighted the need for coherence with the WFD: 'how the interventions under coupled income support are consistent with the Water Framework Directive (EC, 2000) are in most cases judged insufficient; Member States should in particular clarify how the different situations in river basins were taken into account, and based on the respective river basin management plan, how the most sensitive interventions – in light of their potential impact – are consistent with the aim of reaching (or maintaining) "good status"'(EC DG AGRI, 2022b).

The risk of heat, independent from droughts, is also important for agriculture, with impacts on animal welfare as well as farmers' ability to work in heatwave conditions. The CAP does not take this risk into account sufficiently, with only one eco-scheme measure referring to animal welfare to cope with heat stress (EC, 2021j).

### *11.5.2 Energy and infrastructure*

The consideration of climate adaptation in general and the risk of prolonged heat and droughts in particular varies across EU energy policies. Regulation 2019/941 on risk-preparedness in the electricity sector explicitly recognises heat and droughts as a cross-border risk. Furthermore, the amendments and recast of the directives on energy performance of buildings and energy efficiency mention climate change adaptation in the context of improving air quality and insulation of buildings, which would advance heat and drought resilience.

The EU renovation wave (EC, 2020a) is an important policy that recognises heatwaves as a risk enhancing energy poverty, productivity and health issues. Another policy that shows awareness of the risks caused by heat and droughts is the urban agenda for the EU (Climate Adaptation Partnership, 2018), a part of the Climate Adaptation Partnership. Furthermore, the proposal for a recast Urban Wastewater Treatment Directive would promote innovative multi-benefit, highly efficient and cost-effective green solutions through the requirement to develop integrated urban wastewater management plans.

Lastly, the Communication on Green Infrastructure — Enhancing Europe's Natural Capital (EU COM/2013/0249 final, 2013) (EC, 2013) calls for integrating green infrastructure considerations into river basin management. It also highlights the dangers of the urban heat island effect, encouraging the use of green infrastructure in cities, for example by incorporating biodiversity-rich parks, green spaces and fresh air corridors in urban areas.

### *11.5.3 Health and heat*

The EU strategy on adaptation to climate change, 'Forging a climate-resilient Europe', adopted in 2021, explicitly recognises climate risks to human health and calls for new efforts to understand these risks, including through the European Climate and Health Observatory. Managed jointly by the European Commission and the EEA, the observatory brings together expertise from multiple European and international organisations; fosters information exchange and cooperation with Member States, subnational and non-governmental actors; and hosts a resource hub accessible to all ([9]).

The primary responsibility for public health and the provision of health services in the EU lies with the Member States, but EU health policies provide additional support and facilitate cooperation. For example, Regulation 2022/2371 on serious cross-border threats to health gives the EU a strong mandate to coordinate responses to cross-border health threats, at the EU and Member State levels. While the main focus now may be on infectious diseases, similar coordination on shared heat- and drought-related health risks might be appropriate as well.

The EU4Health programme, which will invest EUR 5.3 billion into actions with an EU added value, could also support enhanced action on these risks. One of EU4Health's objectives is to contribute to tackling the negative impact of climate change and environmental degradation on human health. The European Health Emergency Preparedness and Response Authority, established in 2021 with a budget of EUR 6 billion for the period 2022-2027, is another important resource for helping Member States improve their preparedness for crises linked to heat and drought, and respond more effectively.

The EU renovation wave, which aims to make buildings more energy efficient, can help reduce vulnerability to extreme heat by improving insulation (so homes do not get as hot to begin with) and energy efficiency (so keeping homes cool is less expensive).

## 11.6 Aggregated risk assessment

This section presents the outcomes of the structured risk assessment for the major climate risks identified in this storyline. This assessment builds on information in this storyline, and possibly in other chapters of this report. The initial risk assessment was conducted by the authors of this storyline whereas the final assessment results reported here represent the consensus of the EUCRA risk review panel. Further methodological information is available in Annex 2.

([9]) See https://climate-adapt.eea.europa.eu/en/observatory.

The following key risks assessed in other chapters are also relevant for this storyline, but they are not presented here to avoid duplication:

- Risk to human health from heat stress increased by climate change (Chapter 7).
- Health risks to outdoor workers due to increased heat stress (Chapter 7).
- Risk to human well-being from climate change impacts on residential and non-residential buildings (Chapter 9).
- Risk to rainfed and irrigated crop production in Europe from heat, drought and other adverse weather conditions (Chapter 6).
- Risks of water scarcity to population and economic sectors (Factsheet 'Water security').
- Risk of energy disruption due to the impacts of heat and drought on energy production and peak demand (Chapter 8).

In addition, drought and/or heatwaves are linked to risks presented in Chapter 3 (risk to biodiversity and carbon sinks from increased frequency and intensity of wildfires, and risk to soil health related to direct impacts on soil parameters and soil erosion) and Chapter 15 (risk of widespread disruption of land-based transport).



**Table 11.1 Risk assessment for the risk to the population and built environment from wildfires facilitated by drought and heat: all Europe and southern Europe**

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)**<br>• **high warming**<br>• **low warming** |
|---|---|---|---|
| **Risk severity (all Europe)** | **Substantial**<br>Recent wildfires have reached unprecedented levels in some European countries, with large impacts on the population. | **Critical**<br>European regions that are not currently prone to fire, could become risk areas for wildfires. | **Catastrophic**<br>Increased wildfire activity possible in further European regions depending on climate development and forest management.<br>**Critical**<br>See mid-term |
| **Confidence (all Europe)** | **High**<br>Risks are strongly linked to increasing temperatures, heatwaves and drought events, with ongoing and expected intensification over the near term. | **Medium**<br>Risks are strongly linked to increasing temperatures, heatwaves and drought events, with ongoing and expected intensification over the near term. | **Medium**<br>More common occurrence of heatwaves and drought events, and high-end risks are expected by many projections, although varying according to different emission scenarios. |
| **Risk severity (southern Europe)** | **Critical**<br>Recent wildfires have reached unprecedented levels in some southern European countries, with large direct and indirect impacts on the population. | **Critical**<br>A combination of more frequent and more intense droughts will increase the length and intensity of wildfires across southern Europe. | **Catastrophic**<br>More frequent and severe wildfires lead to further increased impacts of wildfires on the population in southern Europe.<br>**Critical**<br>See mid-term |
| **Confidence (southern Europe)** | **High**<br>Risks are strongly linked to increasing temperatures, heatwaves and drought | **High**<br>The intensification of heatwaves and drought events, over most of Europe, | **High**<br>More common occurrence of heatwaves and drought events, and high-end risks are |

| | | | |
|---|---|---|---|
| | events, with ongoing and expected intensification over the near term. | but especially in southern and western Europe, are confirmed by many studies and projections. | expected by many projections, although varying according to different emission scenarios. |
| **Risk ownership** | **Co-owned**<br>The EU can provide support and guidelines for fire risk management, but risk management and prevention measures are implemented at national level. However, the EU can take greater action in cases where the risk proves difficult to manage nationally.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Proposed revision of the Energy Performance of Buildings Directive (2021/0426)<br>• Critical Entities Resilience Directive (2022/2557)<br>• EU renovation wave (2020/662)<br>• EU biodiversity strategy for 2030 (2020/380)<br>• Forthcoming EU Nature Restoration Law (adoption expected for spring 2024)<br>• EU forest strategy for 2030 (2021/572)<br>• Union Civil Protection Mechanism<br>• European Forest Fire Information System<br>• Emergency Response Coordination Centre<br><br>At the national level, the main policies of relevance include those relating to:<br>• Spatial planning and infrastructure<br>• The environment<br>• Civil protection and emergency response<br>• National adaptation funding | | |
| **Policy readiness** | **Medium**<br>Wildfire management is established in all European countries, but with a near-term focus. Long-term planning and fire prevention are insufficient, as evidenced by the large number of fires that are intentionally ignited. | | |
| **Policy horizon** | **Medium term** | | |
| **Urgency to act** | **More action needed (all Europe)** | | |
| | **Urgent action needed (southern Europe)** | | |

**Source**: EEA.

# 12 Large-scale flooding

## 12.1 Key messages

- In the past 30 years alone, floods in Europe have affected 5.5 million people, killing almost 3,000. Floods caused more than EUR 170 billion in economic damage in the same period.
- Climate change is significantly increasing flood risks across Europe. Heavy precipitation is occurring more often in most areas, and river flooding is becoming more common in some areas.
- Extreme sea level rise is accelerating, increasing the risk of coastal floods and storm surges.
- Compounding risk factors exist, such as unaffordability of flood insurance, collapse of housing prices, stress on banking systems and government budgets, impacts on European disaster recovery funding, displacement of people, and impacts of floods outside Europe on trade, security and finance.
- Risks from inland and coastal flooding will become more severe over time. Without additional protection measures, annual damage from coastal floods could exceed EUR 1 trillion by the end of the century.
- Key measures for managing flood risks include stopping further construction in future flood-prone areas, upgrading coastal protection, including nature-based solutions where appropriate, and giving streams and rivers more space by restoring natural flood plains, and improved early warning systems.

## 12.2 Introduction

Floods are common and costly natural hazards. The Historical Analysis of Natural Hazards in Europe (HANZE) database shows 2,521 floods with significant socio-economic impacts between 1870 and 2020 (Paprotny et al., 2023). In the past 30 years alone, floods in Europe have affected 5.5 million people, and killed almost 3,000. They also caused more than EUR 170 billion in economic damage in the same period (Paprotny et al., 2023).

Floods can occur for different reasons and take different forms: sea level rise and storm surges can cause coastal floods; heavy or prolonged rainfall can result in pluvial floods; rivers can swell, causing fluvial floods; and groundwater can rise above the surface or flood basements. Infrastructure such as dams and dikes can fail, often with catastrophic outcomes.

Management efforts have already prevented many flood losses across Europe, as described in this chapter, but flood disasters still occur – and, with climate change, flood risks are increasing (Feyen et al., 2020b). The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report identifies flooding as a key risk for Europe (Bednar-Friedl et al., 2022f), and the impacts are projected to increase throughout the 21st century and beyond. Within just a few months in 2023, severe floods occurred in Italy, Norway, Slovenia and along the Mediterranean coast. Moreover, between 2007 and 2023 the number of Union Civil Protection Mechanism (UCPM) activations in response to floods was the second highest natural hazard after fires. In 2023, the UCPM was activated six times for floods, and maps were produced by the Copernicus Emergency Management Service for 27 different events. Proactive climate adaptation and disaster risk management, including early warning systems, are crucial to contain the growth in flood risks.

This chapter examines Europe's recent experience with floods; how climate change might amplify flood risks; how climatic and non-climatic drivers might exacerbate those risks and lead to a crisis; and the role of EU policies in mitigating flood risks, across the EU and within individual countries.

## 12.3 Flood risks in Europe today

Extreme rainfall has caused several major floods in Europe in recent years. On 13-14 July 2021, for instance, one of the largest floods in western Europe in decades took place in the uplands of the Eifel-Ardennes region in Germany, Belgium and the Netherlands. Over 200mm of rain fell within 2 days, causing pluvial floods upstream as well as river flooding downstream (Kreienkamp et al., 2021b). In some regions, entire towns and villages were submerged by several metres of water. At least 222 people died, 134 in the Ahr valley in Germany alone. Economic damage was estimated at EUR 44 billion, with extensive damage to towns and villages, including to critical infrastructure, which disrupted the electricity supply and transport links (Kreienkamp et al., 2021b; EEA, 2023d). Road closures significantly hampered relief deliveries and clean-up work in the affected regions (Mohr et al., 2022a).

Extreme rainfall also triggered devastating floods and landslides in the north Italian region of Emilia-Romagna in May 2023. There were three consecutive deluges, which in some areas brought about half as much rain in 36 hours as normally falls in a year. This caused pluvial flooding and led to some rivers overflowing their banks. The rainfall seen in the region over the first 21 days of May 2023 marks the wettest event of this type on record, with an estimated return period of about 200 years (Barnes et al., 2023). The floods may have been exacerbated by a long period of drought prior to the intense rainfall. This drought had compacted the soil, reducing its capacity to absorb rainfall. Moreover, land use changes over the last 50 years, such as urbanisation, altered farming practices and narrowing of riverbeds, had limited space for water drainage (Sabelli, 2023). The floods claimed at least 16 lives, displaced more than 15,000 people and caused extensive damage. There was also extensive loss of turnover due to business interruption (ARUP, 2021). The agricultural sector was hard hit, with 12,000 businesses affected and damage of at least EUR 1.5 billion; the tourism sector was also heavily affected (BusinessWeekly, 2023).

In August 2023, Slovenia experienced devastating floods that forced it to activate its national flood protection and rescue plan. The floods came after several wetter-than-usual months, particularly July (Bezak et al., 2023b). Hence, soil moisture was already relatively high. When cold Atlantic air moved southwards across the Alps on 3 August 2023, it met a low-pressure cyclonic area over the Mediterranean. This generated storms over Slovenia between 3 and 6 August, with rainfall totals exceeding a 250-year return period at many locations (Bezak et al., 2023b). The downpours caused river floods and extensive landslides; in many locations river discharge was between 100- and 500-year return periods. At least seven people were killed, and almost 90% of all municipalities in Slovenia reported damage. The government estimates the total direct damage was EUR 9.9 billion (16% of GDP). There was severe damage to local and regional road networks and to supply networks (drinking water, electricity, gas), 16,000 hectares of agricultural land were flooded, and topsoil was polluted (Bezak et al., 2023b). Indirect impacts have also been reported. For example, in September 2023, it was reported that Volkswagen planned to temporarily reduce production at plants in Germany and Portugal due to a disruption of car part deliveries as a result of the floods (Ralev, 2023a, 2023b).

Several catastrophic floods in Europe in recent years have been triggered by coastal storms. In February 2010, for example, the exceptionally violent Storm Xynthia swept across western Europe, killing about 65 people and leaving devastation in its wake. France was particularly hard hit, with the storm surge causing extensive coastal flooding. The centre of the storm passed over the Loire-Atlantique department on 28 February 2010, with average wind speeds in some areas of 110-120 km/hour and gusts up to 160 km/hour. The public was prepared for the winds, but not for the storm surge. The surge coincided with high tide and raised the water 1.5 metres above the expected tide level. In Faute-sur-Mer, the worst-hit area, the water rose as much as 4.7 metres above average sea level, overtopping dikes and causing extensive floods. The rainfall during the events was actually very low, and discharge in the adjacent rivers was not high, or else the impacts could have been worse (Vinet et al., 2012).

Floods are common in Norway, particularly along the country's west coast, which is known as Europe's wettest region and is frequently flooded due to a combination of steep terrain, spring snowmelt, summer convective precipitation and atmospheric rivers. Still, the impact of Storm Hans, in August 2023, was particularly devastating. More than 4,000 people were evacuated from their homes, and floods and landslides caused extensive damage to transport infrastructure. A major rail bridge collapsed, and so did a hydroelectric river dam.

In September 2023, Storm Daniel combined with low-pressure systems that were already bringing torrential rains that triggered pluvial and fluvial flooding across the Mediterranean region. In Europe, thousands were left homeless, and floods killed at least four people in Bulgaria, six in Spain, seven in Türkiye and 17 in Greece. In Libya, Storm Daniel brought record amounts of rainfall to parts of the country's northeast. Two dams collapsed, releasing a 7-metre wave of water that hit the city of Derna and swept people and buildings into the sea. The death toll was estimated at 4,000 people, with more than 10,000 missing (Zachariah et al., 2023).

### *12.3.1 Climatic and non-climatic drivers of flood risk*

It is important to understand how climate change is affecting flood risks across Europe and how non-climatic factors affect floods' severity, and the resulting human and economic losses. The disaster in Libya is a prime example: a rapid World Weather Attribution study found that climate change made heavy rainfall up to 10 times more likely in Greece, Bulgaria and Türkiye, and up to 50 times more likely in Libya (Zachariah et al., 2023). On top of that, the study found that factors such as poor dam maintenance and construction in floodplains further exacerbated the problem, which contributed to the humanitarian disaster in Libya.

Overall, climate data show that heavy precipitation is becoming more frequent in Europe, with high confidence in northern Europe and Alpine regions, but less clear patterns in western and central Europe (Bednar-Friedl et al., 2022f). Changes in the frequency of river flooding are less unequivocal. The IPCC states that there is high confidence of an observed increasing trend of river floods in western and central Europe, and medium confidence of a decrease in northern and southern Europe (Bednar-Friedl et al., 2022f). A recent study by (Blöschl et al., 2019), based on the largest river flow database available, found an increase in flood frequency in north-western Europe over the period 1960-2010, a decrease in medium and large catchments in southern Europe, and a decrease in eastern Europe.

A climate attribution study of the Eifel-Ardennes floods found that climate change had increased the intensity of the maximum 1-day summer rainfall by about 3-19% (Kreienkamp et al., 2021b). The role of climate change in the Emilia-Romagna floods remains uncertain (Barnes et al., 2023), but warming is expected to make consecutive days of extreme rainfall more frequent (Du et al., 2022).

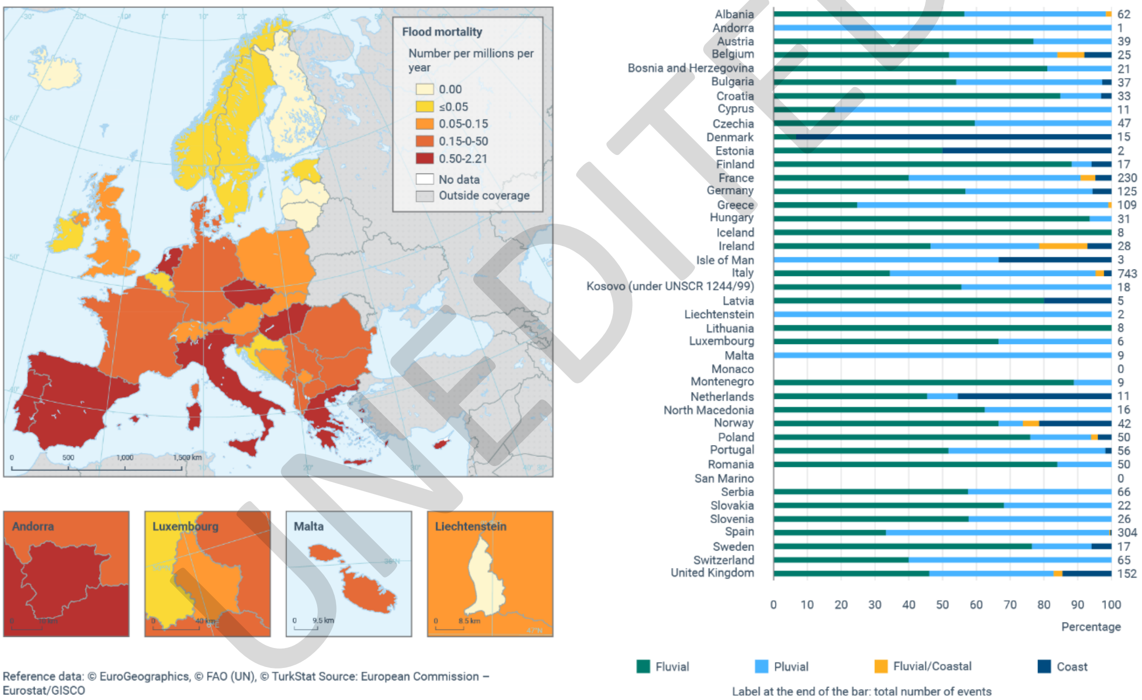
Sea level rise, which increases the risk of coastal floods and storm surges, has also accelerated. Over the period 1993-2018, regional mean relative sea level rise in the subpolar North Atlantic reached on average 2.17 (ranging between 1.66 and 2.66) mm per year (Frederikse et al., 2020). Present-day extreme sea levels translate into a present-day 1-in-100-year extreme total water level of 0.5-1.5 m in southern Europe; 2.5-5.0 m along the western Atlantic European coasts, around the UK and along the North Sea coast; and 1.5-2.5 m along the Baltic Sea coast (Kirezci et al., 2020).

With population growth, an increase in the total number of households and a massive rise in GDP, there are more people, more homes and far more valuable assets exposed to floods than

150 years ago ((Paprotny and Mengel, 2023); see Chapter 2). The European PESETA IV project estimates that, at present, more than 170,000 people in the EU and the UK are exposed to river floods (Feyen et al., 2020b), which cause annual economic damage of EUR 7.8 billion. The same study estimates that about 100,000 people per year are exposed to coastal flooding, and economic damage is EUR 1.4 billion.

A database of 2,500 past floods with significant socio-economic impacts in Europe between 1870 and 2020 (Paprotny et al., 2023) found that almost 49% of events were caused by short but intense rainfall (pluvial floods), and that these were responsible for 56% of fatalities (see Figure 12.1). To improve our understanding of these kinds of pluvial floods, a dataset was recently developed on behalf of the Copernicus Climate Change Service, which evaluates the spatial distribution of pluvial flood risk at high resolution for 20 cities in Europe (C3S, 2020b). Slow-onset floods, caused mainly by long-duration rainfall, snowmelt or ice jam, accounted for 46% of events, with coastal and coastal-river floods constituting 4% and 2%, respectively. Although 56% of fatalities were caused by pluvial floods, the vast majority of economic losses and flooded houses were due to fluvial floods (Paprotny et al., 2023).

**Figure 12.1 Flood events by type and mortality per year**




Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO



**Note:** Total number of flood events with significant socio-economic impacts by type (bar chart) and the mortality rate per year (cartogram), 1870-2020.
**Source**: HANZE database.

### *12.3.2 How Europe has protected itself from floods*

One of the most visible ways in which flood risk is managed in Europe is through infrastructure, such as levees and dikes. European countries have among the top flood protection standards in the world (Scussolini et al., 2016). Several iconic flood protection schemes were developed after the 1953 coastal flood that killed more than 2,100 people and caused extensive damage in the Netherlands, Germany, Belgium and the UK (e.g. Dutch Delta Works, Thames Barrier). These defences have since avoided countless losses and casualties. For example, on 5-6 December 2013, Storm Xaver caused water levels on the North Sea that exceeded those of 1953 (Wadey et al., 2015), but the flood measures greatly reduced the consequences.

It is important to note that the construction of flood protection measures can lead to increased exposure, as people and businesses move into protected areas, and/or result in more vulnerability, as those located in areas protected by dikes and levees may be less well prepared if a flood occurs. These are examples of the 'levee effect' and emphasise the need to consider flood management in an integrated manner.

Increasingly, countries are turning towards nature-based solutions (NBS), which can reduce flood risk while also providing valuable ecosystem services and remaining more robust to future changes in climate. Examples of such NBS include restoring wetlands, old river channels and floodplains, developing water retention areas and installing green roofs (Ruangpan et al., 2020; Sørup and Arnbjerg-Nielsen, 2021).

Less visible, but also critically important, are effective forecasting and early warning systems – though these are not foolproof and require constant updating to include state-of-the-art new scientific and operational knowledge. Storm Xynthia provides a case in point. The storm surge was not included in the alert message, so many people were caught by surprise. Many fatalities were attributed to victims becoming trapped in single-storey buildings as homes' electric shutters failed (Cunge and Erlich, 2014).

In Germany, Belgium and the Netherlands in 2021, while the floods were forecast in advance, the unprecedented nature of the extreme precipitation revealed several limitations with current systems. For example, official weather radars in the Netherlands underestimated precipitation by a factor of three (Imhoff et al., 2021), showing that there are potentially gains to be made by also using unofficial stations and citizen science observations (De Vos et al., 2019). The Ahr valley in Germany, where 134 people died, witnessed systemic failure of its early warning and emergency management systems (Fekete and Sandholz, 2021; Apel et al., 2022). Underlying causes of this failure include fragmentation of institutional responsibilities, data sharing constraints, limited information during the flood, and poor risk awareness and preparedness among the general public (Fekete and Sandholz, 2021; Thieken et al., 2023). Moreover, much of the flooding occurred on smaller rivers, which have received less attention in the modelling community than the larger rivers (e.g. Meuse and Rhine) over recent decades.

## 12.4 How future climate change could intensify flood risks

Both mean sea level and extreme sea levels are expected to increase as a result of sea level rise throughout this century, which would lead to an increased likelihood of coastal flooding (Vousdoukas et al., 2017). Even if greenhouse gas emissions are rapidly reduced, sea level rise will continue well beyond 2100, necessitating the need to adapt to long-term sea level rise (Haasnoot et al., 2021). Changes in storm patterns could also make coastal floods more frequent. For example, post-tropical cyclones, which can cause severe autumn storms and significant risk in Europe (Sainsbury et al., 2020), may become more common (Baatsen et al., 2015). Medicanes, tropical cyclone-like storms in the Mediterranean, will likely decrease in frequency, but they may become more hazardous with warmer temperature (Romera et al., 2017; González-Alemán et al., 2019).

There is high confidence that extreme precipitation will increase in the northern, central, eastern and Alpine European regions. For the Mediterranean basin, there is medium confidence of increases for the middle and the end of the century under the RCP4.5, RCP8.5 and SSP5-8.5 scenarios and for 2°C of warming and higher, with a negative gradient towards the south (MedECC, 2020c). This means that the frequency and magnitude of pluvial floods is expected to increase in the future (Kundzewicz and Pińskwar, 2022).

In terms of river flooding, extreme peak flow events above a 100-year return period are projected to increase in most regions of Europe (Alfieri et al., 2015, 2017a; Rojas et al., 2012; Hirabayashi et al., 2013; Dankers et al., 2014; Forzieri et al., 2016; Roudier et al., 2016; Thober et al., 2018; Ward et al., 2017; Winsemius et al., 2016). The exceptions are southern (due to reduction of precipitation) and north-eastern European regions (due to reduced snowmelt-induced river floods) (Bednar-Friedl et al., 2022f). For lower peak flows, the picture is more mixed across different parts of Europe.

### *12.4.1 Future flood damage projections at the European scale*

Without additional adaptation, studies projecting changes in fluvial and coastal flood risk at the European scale project increases in annual economic damage and the number of people affected in the near term, and more in the medium and long term (see Section 12.6). For pluvial flooding, European-scale assessments are currently lacking, although the impact of climate change and recent urban development patterns on exposure to pluvial flooding has been assessed in a study for the cities of Odense, Vienna, Strasbourg and Nice (Skougaard Kaspersen et al., 2017). This study found a projected increase in exposure to pluvial floods until 2100 under both the RCP4.5 and RCP8.5 scenarios. As extreme precipitation is expected to increase in large parts of Europe, those regions may also expect more pluvial flooding.

Yet, as the examples in Section 12.3 make clear, natural hazards are only part of the picture. It also matters greatly how many people and how much infrastructure and property are exposed to floods, and how vulnerable they are. Europe's overall population is projected to peak at 453.3 million in 2026, and then gradually decrease to 419.5 million in 2100, but with large differences across countries ((Eurostat, 2023f); see Chapter 2). Even so, construction of new homes and buildings in flood-prone areas could lead to an increase in risk. Studies projecting changes in flood risk in Europe (both river and coastal) project an overall increase in expected annual damage and expected annual affected population in the near, mid- and long term (see Section 12.6), if there is no additional adaptation on top of what is done today.

In absolute terms, flood damage and losses may be greater in highly prosperous industrial areas than in economically depressed areas – including agricultural regions where climate change has reduced productivity prior to the floods. Lack of prosperity might also affect adaptive capacity and people's ability to recover from a flood. Fatality rates may be higher in places with high levels of social and economic vulnerability and/or ageing populations. More broadly, vulnerability varies greatly between different groups in society, and more research is needed to understand how flooding disproportionately affects people based on aspects such as age, gender, education, ethnicity, caste and employment status (UNDRR, 2019).

Investing in adaptation and disaster risk reduction measures across Europe could significantly reduce flood risks (Vousdoukas et al., 2020; Steinhausen et al., 2022; Dottori et al., 2023). The PESETA4 project found, for example, that retention areas can be used to reduce river flood peaks in a cost-efficient way in most EU countries (Feyen et al., 2020b). Implementing this strategy across the EU could reduce annual economic damage by the end of the century by 64-82% and the number of people affected by similar rates. Retention areas also have other benefits, such as restoring natural floodplain functioning and enhancing ecosystem services.

The PESETA4 study found that strengthening existing dike systems in an economically favourable way could reduce annual economic damage by 41-68%. However, dikes can transfer risk downstream and, in the event of dike failure, this could lead to catastrophic impacts. Implementing flood-proofing measures for buildings could halve annual economic damage. For coastal flooding, raising dikes to a level of protection that maximises the economic benefits per section could reduce economic damage by about 90% and the number of people exposed by 59-63% by the end of the century. Overall, while the investment costs are relatively high (EUR 1.3-1.9 billion per year), they are about two orders of magnitude lower than the damage they would prevent, the study found.

### 12.4.2 Envisioning future floods – and critical constellations of flood risk

Climate projections can be difficult to use in planning and decision-making, due to the large uncertainties and challenges associated with understanding projections. To overcome these challenges, storylines of future conditions in specific contexts are increasingly used to engage with stakeholders and consider adaptation options (Hazeleger et al., 2015). This approach has been taken in Norway, for example, to discuss flood risks (Hegdahl et al., 2020; Schaller et al., 2020).

Similarly, following the floods in 2021 in the Netherlands, a 3-day hackathon was held to assess what could have happened if this exceptional rainfall event had occurred elsewhere in the country (De Bruijn and Slager, 2021). It found that water levels on local and regional water systems could have exceeded design levels for extended periods, which could have led to potentially fatal breaches of regional or even primary flood defences (while in the 2021 event, no one died in the Netherlands). Vulnerabilities were also found in residential areas, with water entering buildings, electricity outages and interruptions to road, rail and water transport. Such analyses could inform future risk assessments in a way that is more comprehendible to decision-makers.

Below, several examples are briefly explored of how future floods could lead to crises in Europe at different scales, through various transmission pathways.

*Compound and multi-risk impacts*

Within Europe, there is increased attention on compound climate events, defined by (Zscheischler et al., 2018) as '*… the combination of multiple drivers and/or hazards that contributes to societal or environmental risk*'. Several recent flood disasters fall into this category. For example, the floods in Germany, Belgium and the Netherlands in 2021, and across the Mediterranean region in September 2023, were caused by a combination of pluvial and fluvial flood drivers; the flood impacts in the Mediterranean region in 2023 and those in Slovenia the same year were fuelled by successive rainfall events; and the flooding from Storm Xynthia was exacerbated by a combination of high tide and storm surge. While in the case of Storm Xynthia the rainfall and river discharge were not high, compound coastal and inland floods have the potential to cause devastating impacts, as occurred with Hurricane Harvey in the United States and Cyclone Idai in Mozambique. The same could happen in Europe, and indeed Paprotny et al. (2018) found a high probability of joint occurrence of storm surge and precipitation and/or river discharge across large parts of Europe. Given that relative sea level, extreme precipitation and extreme peak flows are projected to increase in many regions under future climate change, it is likely that the frequency of compound floods will increase. For example, models show increases in compound flood frequency in Europe in the period 2070-2099 compared with the period 1970-2004 (Bevacqua et al., 2019b, 2020).

Spatial dependence between flood events is also important: ignoring the spatial dependence in flooding between different regions (i.e. the fact that if one area is flooding, the chance of a nearby area flooding is also elevated) can severely underestimate the likelihood of exceeding key loss thresholds in a given year. For example, a simulation to determine the likelihood of aggregated river flood damage in the EU and the UK exceeding EUR 100 billion in a given year found that it was extremely unlikely if no dependence in flood risk between different individual river basins was assumed (Jongman et al., 2014). When this spatial dependence in risk between basins was included, however, the probability increased significantly, to 0.0085 in 2000 and 0.022 in 2050 (return periods of 118 and 46 years, respectively).

More broadly, there is growing attention to the need to assess risk related to natural hazards in a more holistic way, by looking at total risk from different types of natural hazard, physical interactions among different natural hazards, and potential interactions across all risk drivers – i.e. hazard, exposure and vulnerability (Ward et al., 2022). The potential role of the droughts preceding the floods in Emilia-Romagna in 2023 are a case in point. A framework was recently developed in the Horizon 2020-funded MYRIAD-EU project to guide scientists and practitioners in the steps needed to carry out a multi-risk assessment (Hochrainer-Stigler et al., 2023). An accompanying database (MYRIAD-HES) allows users to explore when and where flood events have occurred in the same space and time as hazard events (Claassen et al., 2023). With climate change and socio-economic change, the likelihood of multiple hazards and risks affecting a single place at the same time or in sequence is expected to increase, and this could lead to more catastrophic floods and/or chains of disasters that include floods, with potentially devastating impacts at European scale.

*Financial impacts*

An increase in flood risk can lead to a rise in the price of insurance and reinsurance coverage, and premiums increasing for customers. A severe flood, or several severe floods in succession, can impact the affordability of flood insurance, even if the floods occur outside the EU. Floods can trigger 'hard' international capital markets, in which investors raise the price of capital, meaning that reinsurers (and primary insurers who reinsure on international markets) may need to raise premiums. Annual insurance premiums for EU countries could be EUR 1,380-3,220 higher by the end of the century under a hard reinsurance capital market compared with a soft market (Tesselaar et al., 2020a). In EU countries, this could create financial hardship for households and lead a larger share of the population to forgo insurance. This, in turn, would reduce the financial resilience of households, with particular impacts on lower-income people.

Floods may also become a major source of financial vulnerability for European small and medium-sized enterprises (SMEs); flood risk is priced into higher interest rates on new loans to SMEs only to a limited extent, and flooding has a significant impact on the occurrence of loan default (Barbaglia et al., 2023b). More broadly, De Nederlandsche Bank (the central bank of the Netherlands) carried out a stress test of the Dutch banking system to flooding (Caloia and Jansen, 2021), and concluded that major floods could put severe stress on its soundness.

Floods also have macro-fiscal implications for the financial liabilities of governments. For flood events with a return period of 100 years, the fiscal impacts of government liabilities can exceed 7-17% of GDP for some EU Member States (World Bank, 2021).

Increased flood risk could lead to tipping points where house prices collapse abruptly. A stylised case study based on Rotterdam in the Netherlands found that tipping points in house prices occur under scenarios of very high and rapid sea level rise, if the market responds to sudden changes in perceived flood risk rather than gradually adjusting prices to changes in flood risk in an economically rational manner (Van Ginkel et al., 2022). The likelihood of such sudden price collapses is compounded by either a reactive 'wait-and-see' policy, a failure to manage flood risk perceptions, or delayed implementation of a crucial flood protection measure. The study also concluded that such tipping points may happen earlier, and also in less extreme sea level scenarios, in other cities with weaker institutional settings and/or fewer resources for adequate response.

*Regional economic impacts*

Floods can cause notable economic effects in affected areas, such as local economic downturns, material and service shortages, and price inflation. In the short run, temporary scarcities of essential services and goods (e.g. water and food) can lead to price inflation, while in the long run, a shortage of construction materials can have a similar effect. Regional governments can experience reduced/delayed tax revenues and increased repair costs for public infrastructure and buildings.

Floods also have micro-economic impacts on individual firms over short and medium timeframes, which can have knock-on effects on society, such as job losses and economic downturns. For example, flooding significantly and persistently worsened the performance of European manufacturing firms in the period 2007-2018 (Fatica et al., 2022).

### *Impacts on European disaster recovery funding*

The European Union Solidarity Fund (EUSF) was set up in response to the severe floods in Central Europe in 2002, with the aim of providing financial assistance to countries for recovery from natural hazards. From its launch until the end of 2022, the EUSF has been mobilised 107 times in the context of natural hazards, funding payouts of over EUR 7.6 billion (EU, 2023a). Of these, 59 events were floods, with payouts of EUR 3 billion. The EUSF is an important mechanism for ensuring financial stability and disaster relief to Member States hit by natural hazards. Several studies have examined potential transmission pathways that could stress the EUSF. The depletion risk from river floods alone (i.e. the probability of claims in a given year exceeding the fund size of EUR 1 billion) was estimated to be close to 5% under conditions in the year 2000, rising steeply to 9% by 2050 (Jongman et al., 2014). A future storyline approach was used to examine whether the EUSF could be depleted by a combination of tropical cyclones and other hazards (Ciullo et al., 2021; Van Den Hurk et al., 2023). The trigger for this study was the active Atlantic hurricane season of 2017, which had major economic impacts in EU outermost regions in the Caribbean. In the same year, EUSF payouts of over EUR 1.2 billion were made following earthquakes in central Italy. This led to the question of whether alternative, unprecedented yet plausible, realisations of past tropical cyclones could have compromised the EUSF. The study found that if a major disaster occurs in mainland Europe in the same year that large payouts are required due to tropical cyclones, the EUSF could experience severe stress.

### *Temporary displacement and migration of people*

Currently, millions of people are displaced globally due to natural hazards, with 50% of all displacements caused by floods (IDMC, 2023). An increased number of flood events in the future may lead to more displacement and more permanent migration, both within and from outside Europe. Recent research shows the limits for future flood adaptation in coastal areas in France and how many people may migrate internally to safer areas (Tierolf et al., 2023). It used an agent-based model to simulate different adaptation choices of 260,000 residents living in the current 100-year floodplain in coastal areas of France. The research found that more than 10,000 of these inhabitants may choose migration towards inland areas as their preferred adaptation option.

It appears that when coastal areas remain attractive for socio-economic reasons (e.g. jobs) people will still move to low-lying areas, even under sea level rise. However, how many people will continue to move to coastal regions also depends on whether governments have invested in coastal flood protection. This is exemplified in a study by (Reimann et al., 2023), which projects up to 20 million people in Mediterranean countries migrating to higher ground, related to sea level rise. It found that the number of internal migrants could be reduced by a factor of 1.4 to 9 by implementing adaptation strategies, depending on the type of strategies pursued. As mentioned earlier, given that sea level will continue to rise well beyond 2100, more research is needed on areas that may become uninhabitable in the long run, and how this may affect displacement and migration.

### *Remote impacts*

Within Europe, and around the globe, there is increasing recognition that climate impacts may cascade into focal ([10]) countries from overseas. Hence, these remote impacts are becoming more prominent in both national and European risk assessments. Several of these remote impact chains have already been examined in this chapter. In an increasingly interconnected world,

([10]) Focal Countries (dutchculture.nl) such impact chains are expected to become more prominent in the future, especially given the anticipated impact on compound and multi-hazard events.

## 12.5 The role of EU policies in mitigating flood risks

The Floods Directive (2007/60/EC), introduced in 2007 as a response to the devastating central European floods of 2002, aims to minimise impacts on communities, infrastructure and the environment. Under the directive, Member States are required to assess all areas where significant floods could take place; map the flood extent and the assets and people at risk in these areas; and take adequate and coordinated measures to reduce this flood risk. A comprehensive assessment of the directive's effectiveness is yet to be conducted as it is too early for a full evaluation (EC, 2019a). However, the directive did establish a holistic risk governance framework and levelled the playing field for flood risk assessment (EC, 2021q). It enhanced coordination among authorities and stakeholders, built awareness and, to some extent, mainstreamed climate adaptation. However, the risk assessment the directive requires does not address risk propagation pathways or mandate a breakdown of the social groups that are most vulnerable and in need.

Floods are among the most frequent and disruptive risks identified in the national (and regional) disaster risk assessments under the Union Civil Protection Mechanism (UCPM). Most national disaster risk assessments identify and assess, at least qualitatively, the impacts of climate change on flood severity and frequency. The UCPM enhances collective capacity for managing various hazards, such as natural, technological and health emergencies. It prioritises cross-border risks, disasters with transboundary effects, and low probability, high impact events, necessitating priority prevention and preparedness measures. It encourages Member States and participating states to improve risk assessments and risk management planning.

Floods are also addressed in sectoral legislation, such as Directive 2012/18/EU on the control of major-accident hazards involving dangerous substances (Seveso Directive) and the Critical Entities Resilience Directive (2022/2557), which focuses on critical entities' resilience and the provision of essential services.

Cohesion policy plays an important role in making regions more resilient to the effects of climate change, including the increased risk of flooding. In the period between 2014 and 2020, cohesion policy funded almost 6,000 projects that contributed to climate change adaptation measures and improved the management of climate-related risks (EU, 2022b). More than 1,500 projects were implemented to improve flood resilience, including urban stormwater management systems, construction and reinforcement of dykes, rehabilitation of rivers and floodplains, and integrated flood management. Cohesion policy efforts to reduce the flood risks associated with climate change will be further strengthened in the 2021-2027 period.

Finally, the need for a more holistic approach to the assessment of natural hazard risk is at the heart of the United Nations Sendai Framework for Disaster Risk Reduction 2015-2030, which advocates for multi-sectoral, multi-hazard and systemic risk approaches to support risk reduction. This is taken up in several EU policies, strategies and frameworks, and is a key element for reducing risks in an increasingly connected world.

## 12.6 Aggregated risk assessment

This section presents two major climate risks for Europe linked to this storyline:

- Risk to the population, infrastructure and economic activities from pluvial and fluvial flooding.

- Risk to the population, infrastructure and economic activities from coastal flooding.

The risk assessment for these two broad risks follows the approach outlined in Annex 2. The initial risk assessment was conducted by the authors of this storyline, based largely on quantitative projections of economic damage presented in the tables below. The final assessment results reported here represent the consensus of the EUCRA risk review panel, which considered further evidence not listed in the tables below, including the occurrence and impacts of recent flood events in Europe (as described in this chapter), information on increases in cloudbursts that can lead to pluvial flooding, potential underestimation of flood risks in current quantitative impact models, and indirect and cascading impacts of floods (e.g. on business operations).

Tables 12.1 and 12.2 show a summary of the projected aggregated risk of river and coastal flooding in Europe, in terms of expected annual economic damage and expected annual affected people at the European scale, assuming no additional adaptation or disaster risk management. Such large-scale assessments are not yet available for pluvial flooding, although a recent dataset developed on behalf of the Copernicus Climate Change Service evaluates the spatial distribution of pluvial flood risk at high resolution for 20 cities in Europe. While the absolute values and relative changes between the present day and the future show large ranges depending on model set-up, scenarios and assumptions, overall the numbers show large increases in severity. The ranges provided are taken from the following studies: for river flood risk (Feyen et al., 2020b; Steinhausen et al., 2022; Rojas et al., 2013; Dottori et al., 2023; Alfieri et al., 2015; Jongman et al., 2014; World Bank, 2021); and for coastal flood risk (Feyen et al., 2020b; Vousdoukas et al., 2020; Hinkel et al., 2010; Mortensen et al., 2023). As previously mentioned, these kinds of projections are not yet available for pluvial flooding at the European scale.



### Table 12.1 Risk assessment of the risk to the population, infrastructure and economic activities from pluvial and fluvial flooding

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)**<br>• low warming<br>• high warming |
|---|---|---|---|
| **Risk severity** | **Substantial**<br>Projected increases in annual economic damage (EAD) of 70-110% in the near term due to climate change only, to EAD values of around EUR 10-23 billion, depending also on exposure change. Projected increases in expected annual affected population (EAAP) of 130% in the near term due to climate change only, to EAAP of around EUR 0.5 million | **Critical**<br>Projected increases in EAD of 110-150% in the mid-term due to climate change only, to values of EAD of around EUR 13-29 billion. Additional 200% increase due to exposure change. Projected increases in EAAP of 150% in the mid-term due to climate change only, to EAAP of around EUR 0.5 million. | **Catastrophic**<br>Projected increases in EAD of 200-1,700% in the long term depending on the climate change scenario and inclusion/non-inclusion of exposure change, to values of EAD of around EUR 23-98 billion. Projected increases in EAAP of up to 220% in the long term depending on the climate change scenario and inclusion/non-inclusion of exposure change, to EAAP of up to EUR 0.7 million.<br>**Critical**<br>See mid-term |
| **Confidence** | High | High | Medium |
| **Risk ownership** | **Co-owned**<br>The EU and its Member States share legislative responsibilities to manage climate risk relating to coastal flooding due to the wide scope of the affected systems (e.g. infrastructure, industry and public health), which all fall under the policy remits of the EU and national governments. | | |

| | |
|---|---|
| | At the EU level, the main relevant policy frameworks and initiatives include:<br>• Critical Entities Resilience Directive (2022/2557)<br>• Seveso-III Directive (2012/18)<br>• Floods Directive (2007/60)<br>• Water Framework Directive (2000/60)<br>• EU Solidarity Mechanism: Social Cohesion Fund<br>• Union Civil Protection Mechanism<br><br>At the national level, the main policies of relevance include those relating to:<br>• Spatial planning and infrastructure (e.g. protection of coastal areas)<br>• River basin management<br>• Civil protection and emergency preparedness<br>• National insurance and disaster payments<br>• National adaptation funding |
| **Policy readiness** | **Medium**<br>At EU level, policies leave large regulatory discretion with regard to objectives and measures for the assessment and management of flood risks; there is a lack of binding and measurable flood risk standards and targets. The objectives are not quantified and measurable, hindering estimation of the level of effort, of costs and the cost-effectiveness of measures. There is still limited funding, insufficient implementation of measures, and insufficient integration of adaptation objectives and river basin management plans' objectives with sectoral plans. Current and future climate risks are not sufficiently addressed in river basin management plans. |
| **Policy horizon** | **Long term** |
| **Urgency to act** | **Urgent action needed**<br>• Need to better integrate river basin management plans, flood risk management plans and adaptation objectives and measures with sectoral plans.<br>• Need to improve flood monitoring and early warning systems to prevent risks for infrastructures and cities.<br>• The resilience to deal with floods in a changing climate can be enhanced by nature-based solutions (NBS), such as natural retention, as this reduces the peak level of an inland flood and the exposure of flood defence infrastructure (e.g. dikes).<br>• Apart from grey measures (levees, dikes) and NBS, non-structural measures could also be taken (e.g. land use limitations in future flood-prone areas, urban and spatial planning, and relocation). |

**Source**: EEA.



### Table 12.2 Risk assessment of the risk to population, infrastructure and economic activities from coastal flooding

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)** |
|---|---|---|---|
| **Risk severity** | **Substantial**<br>Projected increases in annual economic damage (EAD) of 50-80% in the near term due to climate change and exposure change, to values of EAD of around EUR 4.7-5.7 billion. | **Critical**<br>Projected increases in EAD of 110-3,200% in the mid-term due to climate change and exposure change, to values of EAD of around EUR 7-39 billion. Projected increases in expected annual affected population (EAAP) of 200-3,500% in the mid-term due to climate change and exposure change, to EAAP of around EUR 0.03-0.7 million. | **Catastrophic**<br>Projected increases in EAD of 450-80,000% in the long term due to changes in climate change and exposure, to EAD of EUR 14.3-961 billion. Projected increases of 1,300-7,900% in EAAP in the long term due to climate change and exposure change, to EAAP of EUR 0.2-3.6 million. |
| **Confidence** | High | High | High |
| **Risk ownership** | **Co-owned** | | |

| | |
|---|---|
| | The EU and its Member States share legislative responsibilities to manage climate risk relating to coastal flooding due to the wide scope of the affected systems (e.g. infrastructure, industry and public health), which all fall under the policy remits of the EU and national governments.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Critical Entities Resilience Directive (2022/2557)<br>• Floods Directive (2007/60)<br>• Seveso-III Directive (2012/18)<br>• Maritime Spatial Planning Directive (2014/89)<br>• EU principles on integrated coastal zone management<br>• Water Framework Directive (2000/60)<br>• EU Solidarity Mechanism: Social Cohesion Fund<br>• Union Civil Protection Mechanism<br><br>At the national level, the main policies of relevance include those relating to:<br>• Spatial planning and infrastructure (e.g. protection of coastal areas)<br>• Civil protection and emergency preparedness<br>• National insurance and disaster payments<br>• National adaptation funding |
| **Policy readiness** | **Advanced**<br>At EU level, policies leave large regulatory discretion with regard to objectives and measures for the assessment and management of flood risks to coastal areas, and there is a lack of binding and measurable flood risk standards and targets.<br>At the national level, coastal countries have made substantial investments in coastal protection in recent decades, and none of the coastal floods in Europe during the last 50 years led to considerable loss of life or had very large economic impacts. However, there is limited information on sea level rise planning and policies for most countries in the EU, and future climate risks may not be sufficiently addressed in coastal management plans. |
| **Policy horizon** | **Long term** |
| **Urgency to act** | **More action needed**<br>• Reduction of greenhouse gas emissions is essential to limit sea level rise and the increase in coastal flooding risks.<br>• Enhance coastal protection, including through nature-based solutions and non-structural measures (e.g. land use limitations, land use change, relocation).<br>• Support science to reduce uncertainties in future sea level rise, associated flood risks and potential adaptation options. |

**Source**: EEA.

# 13 Forest disturbances and carbon sinks

## 13.1 Key messages

- Europe's forests provide vital ecosystem services, including carbon storage, with an estimated annual removal of 281 million tonnes of $CO_2$ equivalent (Mt $CO_2e$/year) from the atmosphere in 2021 across the EU, or about 7% of total emissions.
- By 2030, as part of the EU's climate commitments, carbon removals in the Land Use, Land Use Change and Forestry sector are expected to rise to 310 Mt $CO_2e$/year, but they have actually been declining over the past 10 years due to increased wood harvest rates, climate-driven forest disturbances and other factors.
- Major wildfires, storms, droughts and insect outbreaks, exacerbated by climate change, have caused widespread tree mortality in several European countries. This has reduced carbon sinks and even turned some forest areas into $CO_2$ sources, while also affecting biodiversity, water regulation and other ecosystem services.
- Climate-related forest disturbances are projected to increase, effectively constituting a positive feedback to climate change and potentially undermining the carbon removal target.
- Climate-adapted afforestation, reforestation and forest preservation can contribute to climate change mitigation while providing complementary benefits such as biodiversity preservation and sustainable development, but trade-offs need to be accounted for.
- Since feedbacks between more frequent/intense extreme events, forest disturbances and carbon stocks are only partially represented in future projections, current estimates of future land carbon sinks and of nature-based solutions for climate change mitigation may be overly optimistic.
- Europe's climate strategies should prioritise emissions reductions, without relying so heavily on forest-based mitigation, with urgent action required to avoid crossing temperature thresholds that can destabilise the European carbon sink further.



## 13.2 Introduction

Forests play an important role in Europe's plan to reach net-zero greenhouse gas (GHG) emissions by 2050, while supporting adaptation and providing many vital ecosystem services such as water recycling, timber and employment. In 2021, forests removed 281 million tonnes of $CO_2$ equivalent (Mt $CO_2e$/year) from the atmosphere, enabling the Land Use, Land Use Change and Forestry (LULUCF) sector as a whole to be a significant carbon sink even after accounting for agriculture and other emissions sources (EEA, 2023b, 2023i).

Altogether, the LULUCF sector removed 230 Mt $CO_2e$ in 2021, almost 7% of the EU's GHG emissions in other sectors (EEA, 2023b, 2023i). By 2030, the LULUCF Regulation (Regulation (EU) No 2018/841) calls for annual LULUCF carbon removals to rise to 310 Mt $CO_2e$/year. However, $CO_2e$ removals have decreased in the past 10 years, as more wood is being harvested, ageing forests in some EU countries are sequestering less carbon, the conversion of land to forest has slowed, and natural disturbances have taken a growing toll on forests (Korosuo et al., 2023b).

Regionally, wildfires, windstorms and insect outbreaks may turn some forests from carbon sinks into sources of GHG emissions. In some European countries, the LULUCF sector has become a net source of $CO_2$ during such exceptional events (EEA, 2023b).

Future climate change is projected to bring higher temperatures, water scarcity, more compound heat and drought events and associated disturbances, all of which increase the strain on Europe's forests (Bednar-Friedl et al., 2022d). These add to human pressures from wood harvest (Senf and Seidl, 2021a) and other management practices that tend to reduce forest resilience to climate-driven disturbances (Forzieri et al., 2022b). While the magnitude of these effects remains uncertain, there is a high risk that forests will be unable to deliver the levels of carbon sequestration now expected of them (Roebroek et al., 2023), and changes in management practices will be needed (Korosuo et al., 2023b).

Given the key role of forests in LULUCF removals towards climate change mitigation targets, this chapter examines the climatic and non-climatic factors driving forest loss and degradation in Europe, the potential for future crises, and the implications for the EU's climate policies.

## 13.3 Europe's forests under pressure

Forests in the EU cover an estimated 160 million hectares, or about 35% of the total land area, but they are very unevenly distributed, with large forests in the north and very little forest cover in parts of western and southern Europe (Eurostat, 2021).

Forest cover across the continent has increased by about 37% since 1950, as a consequence of reforestation and afforestation following land abandonment, while forest conservation measures have contributed further to the forest carbon pool. Forest cover increases were highest in southern and central Europe. At the same time, increased atmospheric $CO_2$ and deposition of nutrients from fossil fuel burning and agriculture stimulated forest productivity, resulting in over a three-fold increase in the European forest carbon sink until the 2000s.

However, afforestation and reforestation activities in many countries were directed towards economic gains, favouring fast-growing species and homogeneous stands. Primary forests, already scarce, have continued to diminish, in great part due to logging, with only a few scattered patches left in several western European countries (Sabatini et al., 2021). In general, forests in most EU Member States are highly fragmented, even-aged and with limited biodiversity, which limits the ecosystem services they can provide and makes them more vulnerable to disturbances (Auffret and Svenning, 2022; Mauri et al., 2023; Seidl et al., 2014).

The EU biodiversity strategy for 2030 puts forward a roadmap for adding at least 3 billion additional trees across Europe by 2030 to protect and enhance biodiversity. The EU forest strategy for 2030 also highlights forests' economic value and their key role in climate change mitigation and adaptation However, successful implementation of these strategies requires quantification of future risks to forests from climate change, and particularly of carbon sequestration and disturbance dynamics, short- vs long-term effects, and economic benefits vs biodiversity and ecosystem services.

With so much at stake, it is crucial to understand why Europe's forests are under so much pressure, and what it will take to protect them. This section examines the key drivers of risk and recent trends in forest disturbances.

### *13.3.1 Climatic and non-climatic risk drivers*

Climate change affects forests and their carbon sink through multiple interacting processes. In the long term, rising temperatures increase the growing season length and productivity of many European forests (Luyssaert et al., 2010), but reductions in precipitation and soil moisture partly offset these gains (Montibeller et al., 2022). Soil moisture droughts affect forest productivity and growth and, especially when combined with heat extremes, can weaken and even kill trees (Hartmann et al., 2022; Hammond et al., 2022b; Bednar-Friedl et al., 2022d).

Direct drought mortality is difficult to quantify but droughts are often a predisposing factor for both fire and insect outbreak mortality, and are likely to contribute the most to the volume of timber damaged by other abiotic disturbances, which account on average for 6% of damage and have increased six-fold since 1950 (Figure 13.3). A significant correlation between excess tree mortality and drought has been reported across continental Europe, with an estimated 500,000 ha of forest loss associated with drought over the period 1987-2016 (Senf and Seidl, 2021a), and the IPCC reported with high confidence that climate change has potentially contributed to tree mortality in Europe (Bednar-Friedl et al., 2022d). Furthermore, climate change may shift suitable ranges for plant species faster than their dispersal can keep up with, potentially leading to long-term biodiversity loss (Auffret and Svenning, 2022; Mauri et al., 2022b).

Climate change can also increase the risk of other forest disturbances, such as fires, insect outbreaks and windthrow events in some regions (Seidl et al., 2017). Warmer temperatures are associated with an increase in atmospheric aridity, increased wildfire risks and longer fire seasons (Seneviratne et al., 2021a; Jones et al., 2022; Rossi et al., 2023b). Furthermore, warmer conditions make it easier for insects to survive and reproduce, increasing the risk of large outbreaks (Seidl et al., 2017). Climate-driven disturbances can also interact with each another and create impact cascades: trees weakened by drought become more susceptible to insect outbreaks or fire, for instance (Seidl et al., 2011).

Forest management is a key non-climatic driver of the European carbon sink and of natural forest disturbances. It alters forest composition, structure, age distribution and productivity, all of which affect carbon sequestration and resilience to disturbances such as droughts, insect infestations, pathogens and wildfires (Forzieri et al., 2020b; Ciais et al., 2008; Luyssaert et al., 2010) (see also Box 13.1).

A third of Europe's forests are dominated by a single tree species, naturally or due to monocultures (Forest Europe, 2021; see also Chapter 3). For decades, forest expansion in central Europe favoured even-aged conifer monocultures outside of their natural ranges (e.g. Norway spruce, Scots pine) over native and mixed species (Patacca et al., 2023b; Seidl et al., 2011). These forests are especially vulnerable to heat-drought events (Hartmann et al., 2022) and to bark beetle infestations (Hlásny et al., 2021a). Conversely, there is substantial evidence that biodiversity can enhance ecosystems' productivity and resilience to disturbances (Loreau et al., 2021; Isbell et al., 2015). A recent meta-analysis found that more biodiverse young growing forests also store more carbon than monocultures (Warner et al., 2023).

A complex case in this context is forest on peatland. Peatland contains around 25% of the terrestrial carbon pool (Loisel et al., 2021b). Available data suggest that a warming climate on average will reduce peatland build-up and the corresponding carbon sink (Gallego-Sala et al., 2018). This is exacerbated by non-climatic drivers such as drainage and cultivation. In Europe, peatland is largely confined to temperate, boreal and Arctic regions, and covers approximately 5% of the land area. Roughly half still qualifies as active 'mire', but the rest is drained for agriculture or forestry (Tanneberger et al., 2017). In Sweden, a major European wood-producing country, stands on drained peatland make up 14% of total production forest (Laudon and Maher Hasselquist, 2023).

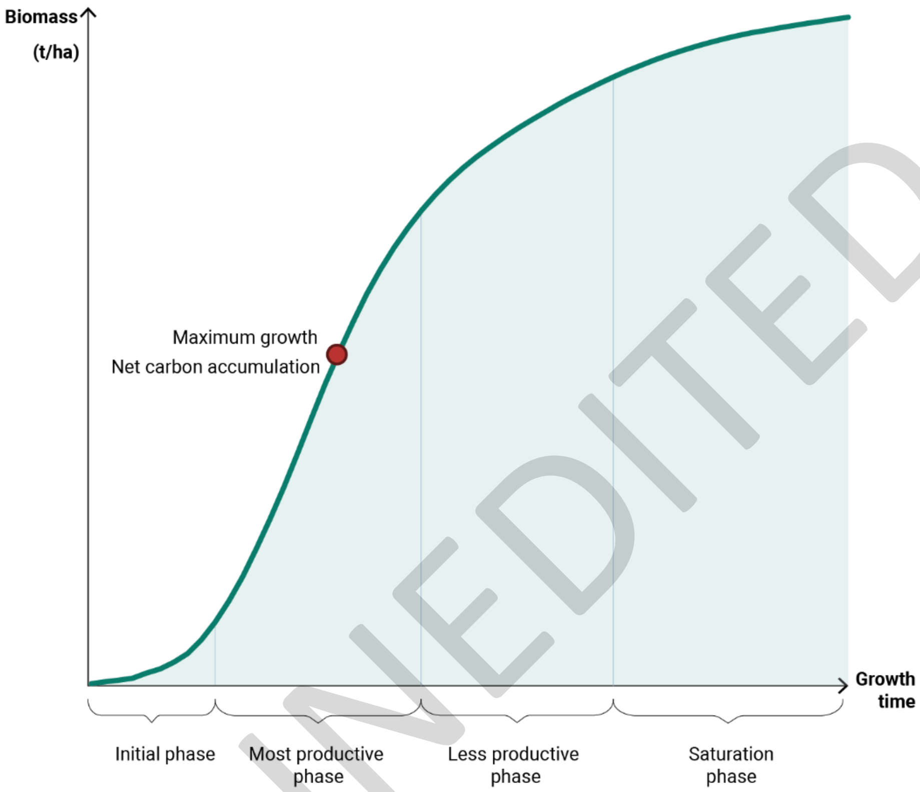
The overall carbon balance of a drained forest is dependent on local conditions, maturity of the stand and management (Loisel et al., 2021b; Mäkipää et al., 2023; Morison, 2012; Günther et al., 2020; Minkkinen et al., 2020; Alm et al., 2022). In general, however, lowered groundwater levels lead to peat oxidation and increase the fire risk of the surface layer, whereas increased above-ground biomass adds to the fuel load (Loisel et al., 2021b). As peatland is largely irrecoverable in a policy-relevant timeframe, maintaining and rewetting peat soils are a high priority (Loisel et al., 2021b; Günther et al., 2020; Mäkipää et al., 2023; Noon et al., 2022).

Given the complex interactions between risk drivers, there can be significant trade-offs in forest management. These entail not only economic vs environmental considerations, but also trade-offs between disturbance prevention, carbon storage and other ecosystem services (Adams, 2013; Schmitt et al., 2020; Anderegg et al., 2020).

### Box 13.1. Biomass growth and sink-pool dynamics in forests

Growth of a tree or forest stand in principle follows an S-curve (Figure 13.1), with accumulation of carbon being highest at an intermediate size/age (IPCC, 2019). At the climax stage, annual regrowth and decay rates average out. The ultimately decreasing growing capacity is due to multiple factors, including availability of nutrients, hydrological factors, changing photosynthesis-respiration balance, and damage from wind, lightning, fire, flooding and infections (Köhl et al., 2017). Trees can get very old and net carbon uptake by an individual tree can continue over hundreds of years (Köhl et al., 2017).

**Figure 13.1 Biomass growth curve**






The shape of the S-curve is site- and ecosystem-specific and can be modified through management (drainage, fertilisation, thinning and tree choice). At any point on the curve, however, the standing crop will decline if the harvest rate exceeds net annual increment (annual growth minus natural decay). Conversely, if harvest rate stays below net annual increment, biomass will accumulate. Maximum carbon uptake (and maximum sustainable harvest) is thus achieved in the flex point of the curve, maximum carbon pool at the right extreme. To optimise economic output, forest management often aims to harvest trees at a size where the price is high, even where maximum annual sequestration has decreased, but well before the carbon storage capacity reaches saturation.

The long timeframes involved in regrowth after disturbances (natural or human-induced) imply that management options and their results have to be evaluated with location-specific scenarios and against appropriate time horizons.

Source: Modified after EEA, 2023.

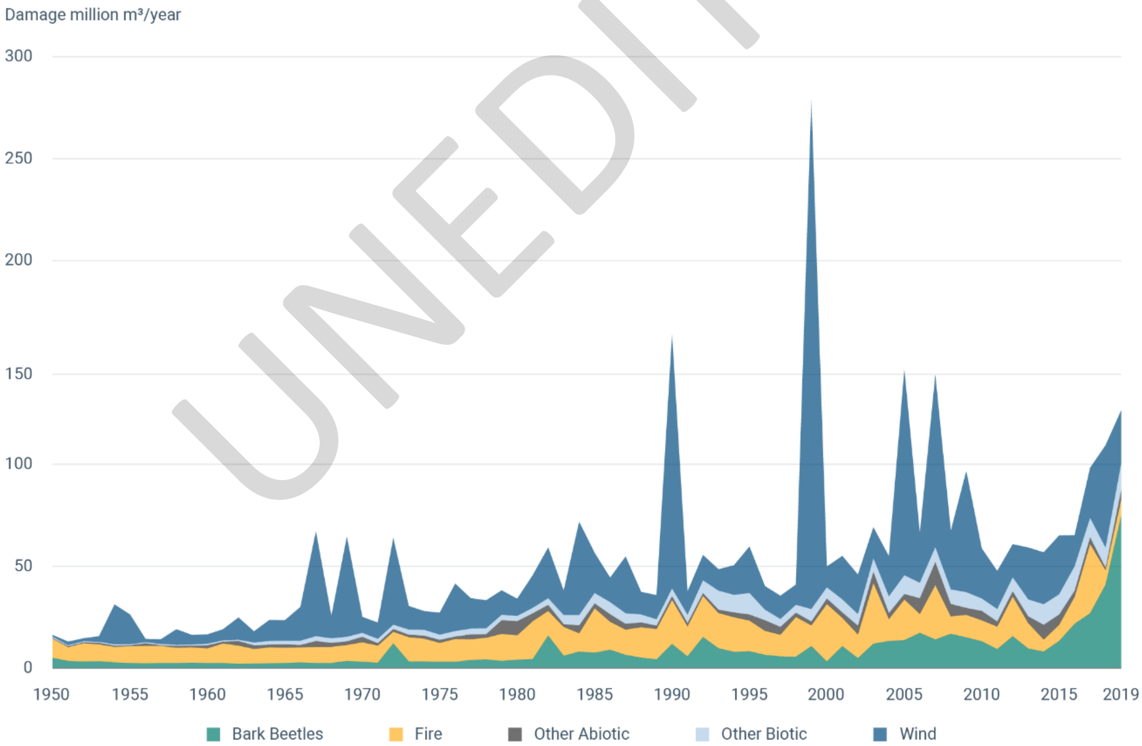
### *Forest disturbances*

As noted above, climatic and non-climatic risk drivers interact in complex ways, but the impacts of climate change are increasingly visible. Annual tree canopy losses in Europe are estimated to have increased by 18% between the periods 2001-2011 and 2012-2021 (Turubanova et al., 2023). An analysis of satellite-based canopy mortality maps from 1987 to 2016 found a significant correlation between excess mortality and drought across continental Europe, with an estimated 500,000 ha of forest loss associated with drought over those 20 years (Senf et al., 2020b).

Some forest disturbances are better documented than others. Long-term and spatially consistent data about forest fires across Europe, for example, based on reports from national fire services and satellite observations, are readily available through the European Forest Fire Information System (EFFIS). Data on windstorms and insects, however, are more uncertain, being based on reports with low granularity and coverage (Forzieri et al., 2020a, 2023; Patacca et al., 2023b) and modelling results that are not yet sufficiently robust (Forzieri et al., 2020b).

Using the available information, it has been estimated that across Europe windstorms cause the greatest share of forest biomass loss (38%), followed by fires (24%) and insect outbreaks (21%) (Forzieri et al., 2020b; Patacca et al., 2023). Figure 13.2 shows overall trends in the share of timber affected by different forest disturbances in recent decades.

**Figure 13.2 Estimated trends in timber volume affected by different forest disturbance agents across Europe**




Note: The time period displayed is 1950-2019. The values represent the sum of disturbed harvest stock for 34 European countries considered in the study. The bars represent a decadal average and the lines show the fitted long-term trends, but note that only biotic disturbances (including Bark beetles and Other biotic) show persistent decadal trends, while Fire, Wind and Other abiotic show decadal variations. It should further be noted that the data are based on inconsistent reports with different coverage and data-gaps across different countries. The time series are gap-filled based on modelling and expert judgement, but show general agreement with trends based on remote-sensing datasets.

Source: Reproduced from Patacca et al. (2023b).

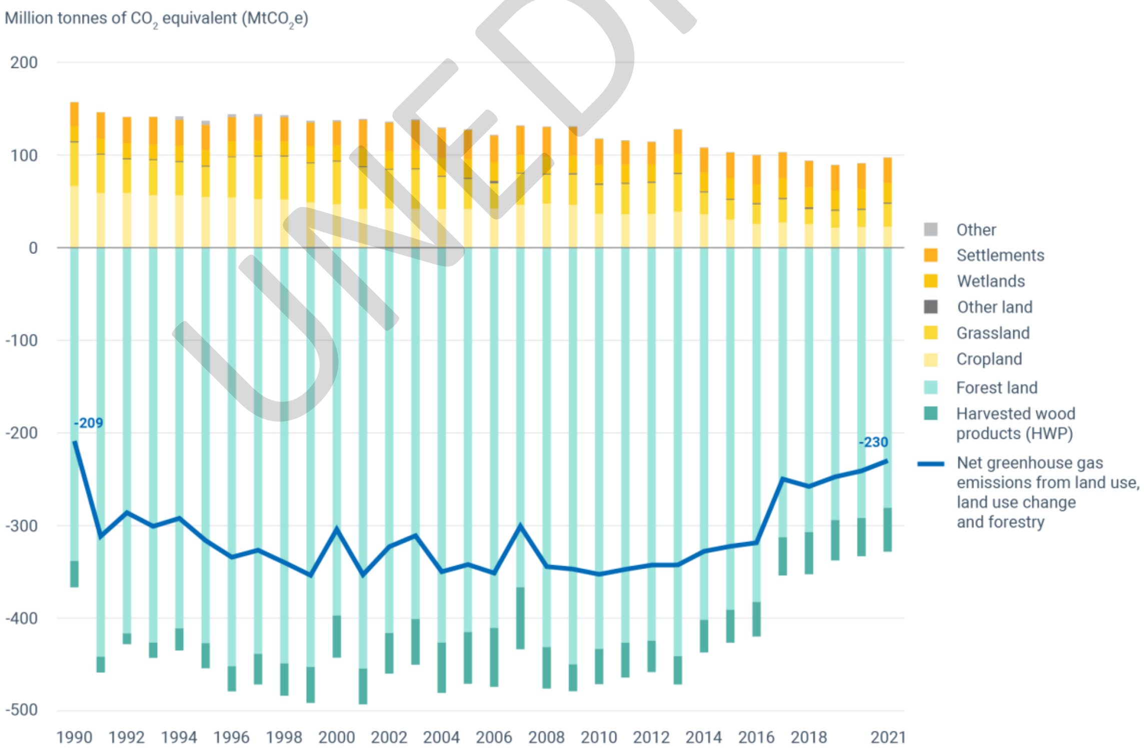
There are, however, large regional differences in the incidence of different climate-related forest disturbances and resulting tree mortality. Soil moisture droughts occur throughout Europe, for example, but are more intense and frequent in southern, central and eastern Europe (Seneviratne et al., 2021). Nevertheless, there is evidence that when droughts occur in wetter regions, forests may be just as vulnerable to drought-induced mortality (Choat et al., 2012).

Fire-related disturbances are the main drivers of forest dynamics in some regions, particularly in the Mediterranean region. While this is a fire-prone region, several unprecedented megafires have occurred in recent years, with major ecological, economic and human losses, as seen in the fire seasons of 2003, 2007, 2017, 2021, 2022 and 2023 (European Commission et al., 2018; J et al., 2022; Jesus et al., 2023). In 2023, wildfires burned more than 36,000 ha in Portugal, 88,000 ha in Spain, 97,000 ha in Italy and almost 175,000 ha in Greece (https://effis.jrc.ec.europa.eu/apps/effis.statistics/estimates) with a single fire burning more than 95,000 ha within days (DG ECHO, 2023). It is important to note, however, that while hot and dry conditions can facilitate the ignition and spread of wildfires, in Europe 96% of wildfires are reported to be started by human activity.

### *Carbon sink development*

Forest expansion and lower harvest rates, together with climate and other environmental changes, led the carbon sink in European forests to increase from about 100 Mt $CO_2$/year in the 1950s to over 400 Mt $CO_2$/year in the 1990s (Ciais et al., 2008; Nabuurs et al., 2003). Over the past two decades, however, the many pressures on Europe's forests have reversed some of those gains (see Figure 13.3).

**Figure 13.3 Annual GHG emissions and removals in the LULUCF sector, including projections**




Source: Reproduced from (EEA, 2023b).

The decline of Europe's forest sink in the past decade has been attributed to both climatic and non-climatic factors, including increased harvest rates, the saturation of the sink in ageing forests, a decline in afforestation sinks in southern Europe, and adverse weather and other climate-related forest disturbances (Nabuurs et al., 2013; Korosuo et al., 2023; Pilli et al., 2022).

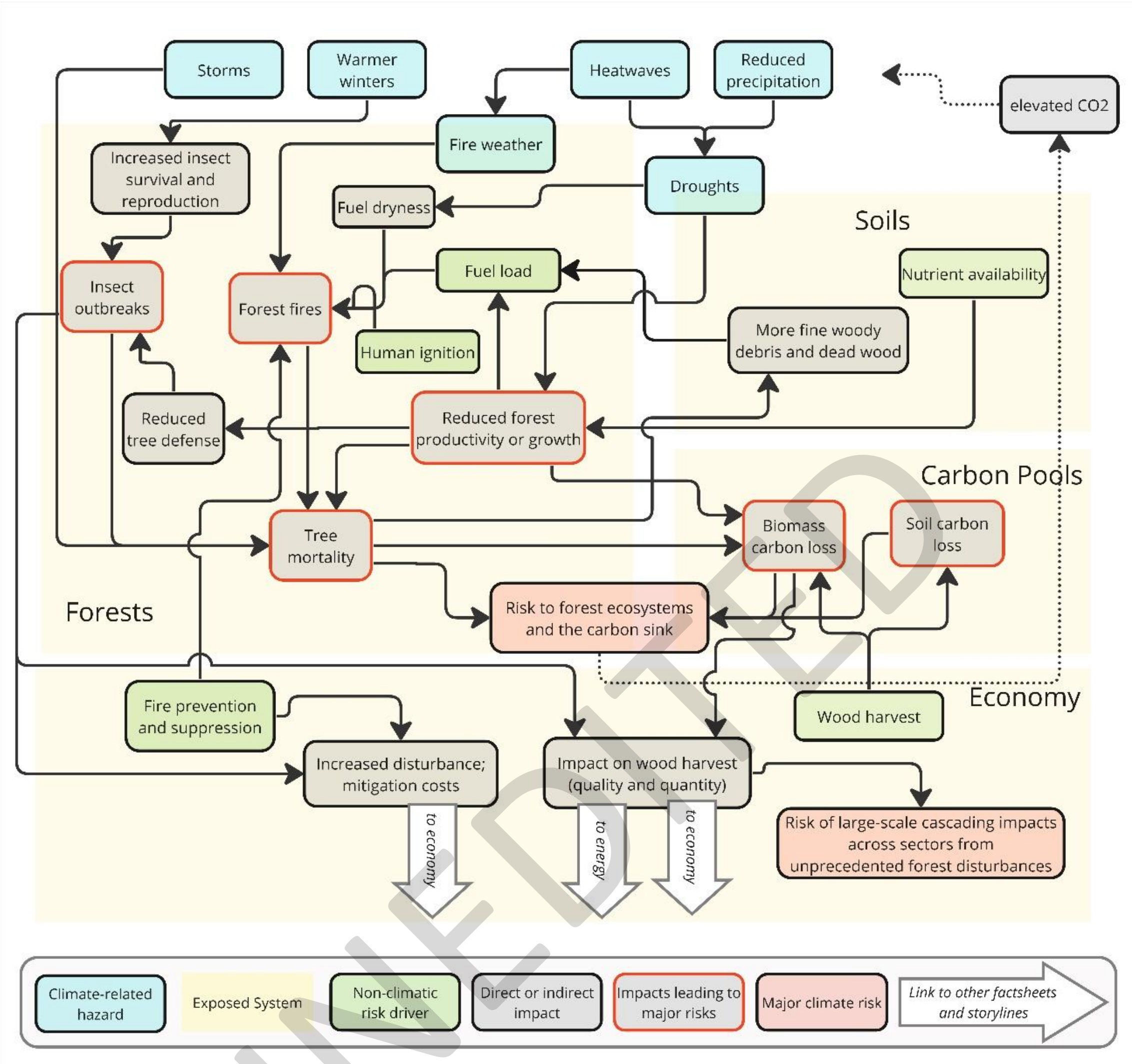
From 2016 to 2021, the sink in European forests declined by more than 25%, from 382 Mt $CO_2e$/year to 281 Mt $CO_2e$/year, while harvest removals increased by about 10 Mt $CO_2e$/year, associated with an increase in salvage logging (Korosuo et al., 2023b).

Some disturbances have larger impacts on carbon sinks than others. Windthrow events can cause very high biomass losses locally, for instance (Forzieri et al., 2020b), but even very destructive events tend to have moderate impacts on the carbon sink due to compensating transfers of carbon to deadwood pools and by salvage logging if transferred to long-lived wood products (Pilli et al., 2021, 2016). However, the remaining deadwood might, in some cases, contribute to promoting insect outbreaks in the subsequent years (Nardi et al., 2022), although contrasting evidence exists (Bellone et al., 2017).

Compound heat and drought events are of particular concern as, in addition to direct impacts, they further induce forest disturbances such as fires and insect outbreaks, leading to cascading impacts that amplify carbon losses. A few major wildfires associated with extreme fire danger conditions (hot, dry and windy) are responsible for the majority of burned area and fire emissions in Europe (Costa et al., 2020). Insect outbreaks promoted by summer heat and drought have turned some forests into temporary weak sources of carbon (Ciais et al., 2005; van der Woude et al., 2023a).

Heat and drought trends and extremes thus emerge as the most relevant climatic drivers of forest disturbances and their impacts on forest carbon sinks. Figure 13.4 illustrates how the different climatic and non-climatic factors can trigger a series of impacts on forests and their carbon sinks. To delve deeper into these issues in different European regions, two critical constellations are explored below.

**Figure 13.4 Impact chain for selected climatic and non-climatic impact drivers**






Note: Impact chain for selected climatic (heat, drought and storms) and non-climatic drivers (wood harvest, fuel management, nutrients), their influence on forest disturbances, forest carbon pools and feedback with climate. Fire ignitions are not represented as they can be both climatic and human-driven, but in Europe human ignitions account for over 95% of the fires. The most relevant and direct impacts on economic sectors are also shown. Note that some arrows continue underneath the boxes, so the corresponding link should be followed to the head of the arrow (e.g. fuel management and fire suppression influence forest fires, not tree defence).

Source: ETC.

### *Critical constellation 1: Heat, drought and biotic disturbances*

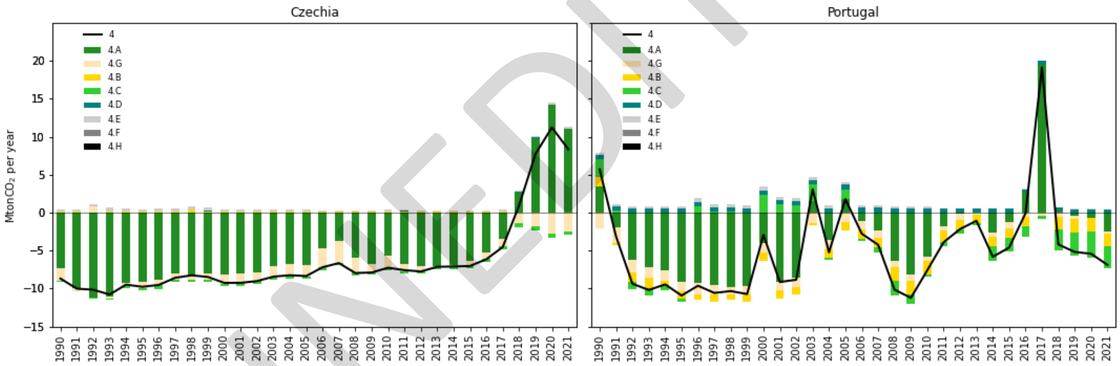
In 2018, central and northern Europe experienced a record-breaking summer heat and drought event. Central Europe was also struck by the destructive windstorms Friederike (previous winter) and Fabienne (subsequent autumn). The summer of 2019 was also extremely hot and dry in many regions, and the winter of 2019-2020 was unusually mild. As a result, soil moisture drought persisted over large areas for three consecutive years (Rakovec et al., 2022), exacerbated by warm, dry weather.

Already in 2018, major impacts on forest health were reported for ecologically and economically important tree species across central Europe (Schuldt et al., 2020). Also in 2018, Sweden experienced its worst wildfire year ever, with nearly 20,000 ha of forest and other wooded land burnt. Other widespread impacts included reduced forest productivity across most of central Europe, tree crown damage and defoliation and, in some extreme cases, fatal tree dehydration and hydraulic failure. Increased mortality was even noted for species typically considered as drought resilient, such as Scots pine, possibly due to the extreme heat (Schuldt et al., 2020; Hartmann et al., 2022). These impacts cascaded across sectors, with forestry losses from reduced wood products, accumulation of deadwood and economic losses reported, for example, in Germany (Schuldt et al., 2020; De Brito, 2021; BMEL, 2019).

Damage from the drought in 2018 left trees more vulnerable to insect or pathogen attacks in the subsequent growing season. Dead fallen trees from the destructive storms in winter and autumn 2018 might have provided further breeding material for bark beetles. The sustained hot conditions in 2019 and the warm winter in 2019-2020 further contributed to insect population expansion through increased reproduction and survival rates.

These effects compounded in time, and led to devastating effects on forests in 2018-2020, with unprecedented levels of forest disturbance rates in central and eastern Europe (Senf and Seidl, 2021b) and widespread insect outbreaks and high tree mortality rates (Hartmann et al., 2022; Hlásny et al., 2021c). In Germany, tree mortality rates increased seven-fold between 2018 and 2020, and remained extremely high in 2021 and 2022 (Hartmann et al., 2022; BMEL, 2023). The resulting costs to the German forestry sector in 2018 and 2019 amounted to EUR 17.8 billion (Trenczek et al., 2022), ca 10% of the sector turnover (FNR, 2022).

**Figure 13.5 Annual emissions in the LULUCF sector in Czechia and Portugal**




Note: The numbers are based on national GHG submissions to UNFCCC

Source: EEA.

These impacts contributed to the decline in the European carbon sink, and forests in many countries have shown sustained declines in biomass even in subsequent years. For example, in Czechia, bark beetle damage of Norway spruce increased 10-fold from 0.2-1.4% to 3.1-5.4% in 2017-2019 (Hlásny et al., 2021c) and the LULUCF sector switched from being a carbon sink to a net source of emissions (Figure 13.5) , which has persisted since 2018 (EEA, 2023b). This event illustrates how a series of climate-related disturbances can push forests beyond the limits of their resilience, potentially undoing years of climate change mitigation by land systems. The fact that forests in Czechia remain a carbon source even after four years indicates that recovery might be too slow to restore the forest sink in the near future, or that these impacts might be potentially irreversible when considered in the context of more frequent extreme events.

### *Critical constellation 2: Heat, drought and megafires*

2017 was the worst wildfire year recorded in Europe to date. Over 1 million ha were burnt across the EU, including more than 540,000 ha in Portugal alone, with Spain and Italy also severely affected (European Commission et al., 2018). Across Europe, the fires killed 136 people.

Europe's wildfire season historically runs from July through September, but already on 17 June that year, a large wildfire occurred near the village of Pedrógão Grande (Portugal), burning about

45,000 ha and killing 66 people. This was one of the first megafires in Europe. The fire started under critical drought and associated extreme fire danger conditions, including very severe drought and temperatures around 40°C, which facilitated its ignition and spread in an area with very high accumulation of fuels.

By the end of September 2017, the wildfire season was already considered one of the worst ever in Europe, but the damage was not over. The drought, combined with a large number of human ignitions associated with agricultural practices, and Cyclone Ophelia all contributed to the eruption of more than 500 fires in mid-October (Ramos et al., 2023). About 250,000 ha burned in just 2 days and 51 people died. The intense smoke plume generated by these fires affected air quality as far as northern Europe (Turco et al., 2019). As a result, the LULUCF sector also turned into a temporary, but very strong, carbon source (see Figure 13.5).

In addition to these immediate drivers, underlying socio-economic factors such as rural abandonment and expansion of the wildland-urban interface over the past decades have resulted in a large extent of poorly managed forests and fuel accumulation, which facilitate the occurrence of very large and uncontrollable fires (Fernandes et al., 2016; Benali et al., 2021).

## 13.4 Potential for future crisis

As noted in the introduction, the LULUCF Regulation aims to increase annual carbon removals from the LULUCF sector to 310 Mt $CO_2$e/year by 2030, which would require a forest sink of over 400 Mt $CO_2$e/year (Korosuo et al., 2023b). However, as discussed in Section 13.2, the LULUCF carbon balance is trending in the opposite direction. To meet the target, the carbon sink would have to increase even more than previously anticipated (by 80 Mt $CO_2$e/year rather than 42 Mt $CO_2$e/year). Forests are expected to contribute the most to this sink enhancement, but this seems highly unlikely under current management practices.

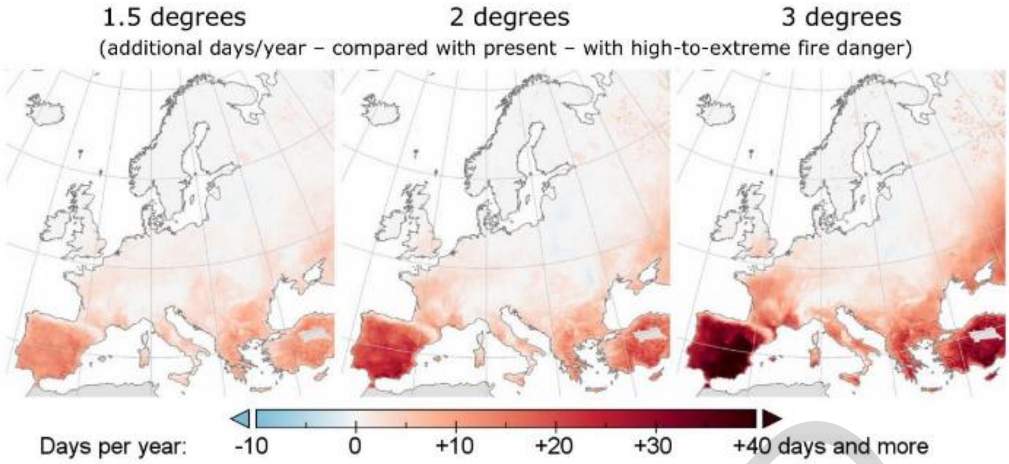
### *13.4.1 Future of climatic and non-climatic drivers*

Trends in heatwaves, droughts and compound hot-dry events are expected to be particularly important drivers of risks to forest carbon sinks, as they directly reduce forest productivity and growth but also indirectly increase forest disturbance hazards (fires, insects) and forest vulnerability to disturbances (e.g. reduced defence against insects and pathogens). Climate change is not expected to have major effects on wind speeds associated with storms in Europe (IPCC, 2021d).

Future climate projections for Europe indicate that rising temperatures, extreme heat, droughts and even insect outbreaks are all likely to worsen in the coming decades, particularly in high global warming scenarios (Bednar-Friedl et al., 2022d; see also Chapter 11). Across Europe, fire-prone areas are projected to expand and fire seasons are getting longer. Water stress is expected to exacerbate the incidence and effects of wildfires and other natural disturbances.

The Mediterranean region faces particularly significant wildfire risks, with an additional 10 days of high-to-extreme fire danger already at 1.5°C of local warming, and more than 30 additional days at 3°C of local warming, compared with average conditions in 1981-2010 (see Figure 13.). Across Europe, carbon emissions from fires are expected to increase until 2100 for medium to strong emission scenarios (SSP2-4.5 to SSP5-8.5) (Lasslop et al., 2020).

**Figure 13.6 Additional number of days with high-to-extreme fire danger compared to present**




Note: High-to-extreme fire danger defined as daily Fire Weather Index ≥ 30, for different levels of warming (local warming trends) compared to the present (1981-2010). These estimates are not strictly based on different emission scenarios but rather resulting warming levels. Nevertheless, they show that fire danger will increase with different levels of warming, which will lead to larger burnt areas and thus higher emission levels. It follows that emission reductions, e.g. avoiding 3-degree warming and aiming at 1.5-degree warming would considerably decrease these risks (compare right and left panel).

Source: Reproduced from (Costa et al., 2020).



Given the expected increase in climate-related and disturbance stressors in Europe in the future, it is widely recognised that management strategies for forest disturbance risk reduction and forest adaptation to climate change need to be put in place (Mauri et al., 2023; Vilà-Cabrera et al., 2018; Costa et al., 2020). Moderate rates of stand thinning, for example, effectively reduce fire risk and increase water availability as well as forest resistance to drought and insects (Gavinet et al., 2020; Anderegg et al., 2020).

Fuel management strategies such as prescribed burning, are efficient tools to reduce fire risk with minimal effects on carbon stocks, by avoiding large biomass carbon losses through fire and mortality and contributing to soil carbon accumulation through conversion of litter into stable pyrogenic carbon (Adams, 2013). Management of forest composition and age structure might further contribute to adaptation to climate change and disturbances. Proposed measures include promoting mixed stands in terms of composition and age structure, which are expected to increase resistance and resilience to disturbances, and landscape management to increase ecological connectivity (Isbell et al., 2015; Mauri et al., 2023).

Climate change is expected to contribute to biodiversity loss by reducing suitable habitat space, especially in southern Europe, or by bringing species closer to the fringes of their suitable climate envelope, e.g. spruce trees in central Europe (Mauri et al., 2023). This poses the risk that forests will not be able to withstand changes in disturbance regimes in the future, which are likely to happen at a much faster pace than natural seed dispersal and tree establishment dynamics.

### *13.4.2 Potential impacts, risk drivers and critical constellations*

In all EU regions except northern Europe, ecosystems are projected to become increasingly water-limited in summer, with resulting losses in productivity (Rossi et al., 2023b). Consistently, future projections of the European carbon sink indicate a slowdown in net carbon uptake, and even a decline after about 2040 (Jones et al., 2023, p. 2), as negative effects of climate change become increasingly more relevant and cancel out positive effects of elevated $CO_2$.

A key risk in this regard is the epistemic uncertainty associated with these feedbacks. Global models used in future climate projections represent fires poorly or not at all (Jones et al., 2022), and none include impacts of drought-induced tree mortality or effects of wind and insect disturbances on biomass and soil carbon stocks (Canadell et al., 2021; Pörtner et al., 2022a). Consequently, globally there is *medium confidence* that fire represents a positive carbon-climate feedback, but very *low confidence* in the magnitude of that feedback; there is *low confidence* on the magnitude of the feedback from other disturbances, with *medium agreement* on an increase in tree mortality globally and *medium confidence* on associated decrease in vegetation carbon. Even if the confidence on the magnitude of this feedback is low, the medium confidence that it is positive (i.e. reinforcing climate change) should be a reason for caution. Since feedbacks between more frequent/intense extreme events, forest disturbances and carbon stocks are only partially represented in future projections, current estimates of future land carbon sinks and of nature-based solutions for climate change mitigation may be overly optimistic.

Simulations by forest models (that do not consider feedbacks between forests and the atmosphere) estimated that climate change alone would increase European forest carbon stocks between 2021 and 2030 by 126.3 teragrams of carbon (TgC), if natural disturbances were not considered. However, if natural disturbances were considered, climate change would result in a net carbon loss of 7.4 TgC in the same period (Seidl et al., 2014). A more recent assessment has suggested that, considering the effects of disturbances, the biomass carbon that can potentially be stored by forests, if these were released from human management, would be much lower than previous estimates, amounting to about 44 petagrams of carbon (PgC) globally (Roebroek et al., 2023). According to the study, European countries with long-term human disturbance history like France, Italy and Spain would have higher carbon storage potential when released from forest management. But these values are still likely to be lower than the carbon storage potential assumed in previous assessments that did not consider the effect of natural disturbances. Critical aspects that might result in severe or unintended consequences are listed below.

*Rare compound events and worst case scenarios*

While natural disturbances are inherent components of forest dynamics, changes in disturbance regimes are pushing forests away from their past equilibrium. Importantly, rare combinations of climatic drivers, e.g. three consecutive dry summers, 'record-shattering' events or co-occurrence of heat-drought events and storms as exemplified in Section 13.2, lead to widespread disturbances that result in massive losses of biomass and soil carbon stocks (see Figure 13.5). Recovery of forests and peatlands from such rare and very severe disturbances is expected to take several decades to centuries. When additional pressures from non-climatic drivers are considered, the combination of more frequent rapid losses with reduced recovery ability might result in long-term, or even irreversible, changes to ecosystem composition, structure and carbon sequestration potential (Seidl and Turner, 2022; Anderegg et al., 2020).

Risk assessments need therefore to consider not just mean long-term changes in climate drivers, but especially the occurrence of rare weather extremes or compound events, to assess 'worst case' scenarios for low probability but high-risk events. This is typically not done in most risk assessments (including this one) as it requires propagating irreducible uncertainties from internal climate variability (Deser, 2020) and ecological dynamics (Bastos et al., 2023) to impact estimates. Since the probability of record-shattering events and/or compound events increases with warming (Fischer et al., 2021b; Bevacqua et al., 2022b), ambitious climate change mitigation and climate neutrality policies are an effective way to reduce potentially irreversible impacts on forests and their carbon sequestration potential from such low probability, high risk events.

*Management trade-offs*

Strategies for disturbance risk reduction and forest adaptation to climate change will need to be implemented, but these should consider potential trade-offs between mitigation and adaptation goals, as well as impacts on different sectors and at different timescales.

For example, management strategies to increase European forest carbon sinks, such as afforestation or reforestation, can have counteracting effects on local warming through changes in albedo and cloud cover. Conversely, management practices to reduce local temperatures have been projected to result in net $CO_2$ mitigation by 2100, but at a cost of a 25% reduction in wood harvest (Luyssaert et al., 2018). Short-term benefits for climate change mitigation/adaptation can be associated with negative long-term effects on soil carbon, water resources, nutrient cycling and biodiversity dynamics.

Measures that have co-benefits for biodiversity and various ecosystem services should be prioritised, although these may result in lower carbon sequestration than management strategies for carbon sink maximisation (Luyssaert et al., 2018). Sustainable forest management can promote carbon sequestration while boosting jobs and increasing forest resilience to disturbances. Among well-established strategies to promote carbon storage and other co-benefits are prescribed burning, salvage logging and sanitary felling for fire and insect outbreak prevention, stand thinning for increased drought resilience, and promotion of mixed stands and heterogeneous landscapes to increase resilience against droughts, insects and wind damage. Some measures, such as salvage logging, can counter biodiversity goals, requiring high rates of retention for biodiversity preservation (Thorn et al., 2020). Stand thinning has been shown to effectively reduce forest vulnerability to drought and facilitate recovery, but it requires reductions in stand density well below what is currently practiced (30-60%) (Navarro-Cerrillo et al., 2019; Schmitt et al., 2020; Gavinet et al., 2020). This results in more drought-resistant forests but may reduce long-term mean carbon storage compared to denser (and more productive) managed stands and could contribute to reduced biodiversity.

Measures to reduce vulnerability to ecosystem disturbances, preserve biodiversity and enhance natural carbon sinks take decades or even longer to take effect (Korosuo et al., 2023b; Thorn et al., 2020; Vilà-Cabrera et al., 2018). Available scientific evidence is predominantly focused on short-term and direct benefits, so that long-term effects of mitigation/adaptation strategies are still highly uncertain (Vilà-Cabrera et al., 2018).

*Twin climate-biodiversity crises*

Recent events have highlighted the high vulnerability of low-diversity forests to prolonged droughts and insect disturbances. Interacting effects between current trends in biodiversity loss and changing forest disturbance regimes might induce unforeseen feedbacks that could further accelerate carbon losses and reduce the climate change mitigation potential of European ecosystems. It is therefore crucial that strategies for increased forest resilience to disturbances address the twin crises of climate change and biodiversity loss through appropriate management practices. In Europe, there is evidence that to avert or mitigate losses in forest services, active changes in species composition (e.g. through assisted tree migration) might be required (Mauri et al., 2023).

## 13.5 Role of EU policies

EU policy action to reduce vulnerability to ecosystem disturbances and enhance natural carbon sinks is taken under the umbrella of the European Green Deal. The EU strategy on adaptation to climate change promotes nature-based solutions for adaptation, including sustainable management of forests, with financial incentives for carbon removals. This is supported by the EU biodiversity strategy to 2030 and the forest strategy for 2030, setting targets for ecosystem protection and restoration, including sustainable forest management, afforestation and rewetting of peatlands. Binding commitments for carbon removals until 2030 are included in the revised LULUCF Regulation, taking all land uses, including forests, into account. Finally, the Commission's Communication on Sustainable Carbon Cycles and proposal to establish a Union certification framework for carbon removals are relevant in this context.

Of the EU budget specified in the 2021-2027 Multiannual Financial Framework, 30% is earmarked for climate action, with special attention to biodiversity protection. Adaptation in the forestry sector is funded through the LIFE programme and rural development spending under the second pillar of the common agricultural policy. The European Regional Development Fund, including the INTERREG Europe programme, provides additional funding opportunities. Ample attention is also given to improving the knowledge base and capacity building, with the Forest Information System for Europe and the Biodiversity Information System for Europe as key information portals for practitioners and policymakers, although they rely mainly on data . New forest and carbon sink-related policies are in preparation, such as the forthcoming EU Nature Restoration Law (adoption expected for spring 2024), the Soil Monitoring Law and the Forest Monitoring Law. On the disturbance side, there are EU systems for early warning and monitoring of droughts (European Drought Observatory), wildfires (EFFIS) and floods (European Flood Alert System), under the Copernicus Emergency Management Service. The Union Civil Protection Mechanism contributes to strengthening wildfire risk management.

Risk assessments for ecological systems require a few additional considerations: (1) timescale dependence of different processes; (2) interactions between climatic and non-climatic drivers; both resulting in (3) inherent feedbacks and trade-offs; and (4) irreducible uncertainties. Upscaling of nature-based solutions for climate change mitigation requires knowledge sharing on the best forestry practices for biodiversity conservation and preservation of different ecosystem services, and assessment of trade-offs between mitigation and adaptation measures and between short and long timescales. This requires differentiated guidance according to local conditions, intensity of exploitation, propagation of uncertainties from climate variability and consideration of worst case low-probability scenarios that might lead to irreversible changes.

While policy awareness and incentives to reduce ecosystem vulnerability to disturbances driven by climate change and to mitigate climate change are in place, the effectiveness of concrete measures is characterised by high epistemic uncertainty and limited consideration of trade-offs and different timescales. Current EU climate targets focus on 2030 and 2050, and enhancing natural carbon sinks in forests is considered crucial to buy time to decarbonise the economy (Korosuo et al., 2023b). There are strong indications that meeting the targets for the LULUCF sector for 2030 would require substantial and rapid efforts in forest and overall land management (Korosuo et al., 2023b; Pilli et al., 2022b). Moreover, the modelling framework underlying LULUCF targets did not consider impacts on forest health, nor interactions between climate change and disturbances discussed in this storyline. The proposed Forest Monitoring Law does not consider soil carbon on monitored stands, thereby potentially overlooking long-term effects.

Developing a portfolio of mitigation and adaptation strategies for multiple physically plausible climate and management scenarios (including extremes) is crucial to improve preparedness to respond to forest disturbances and to promote long-term climate-resilient landscapes. In this context, measures that promote both short- and long-term goals as well as multiple ecosystem services are to be prioritised. For example, among the measures proposed in the new EU forest strategy for 2030, reduced harvest and promotion of long-lived wood products is more effective in climate change mitigation than increasing harvests to produce more wood-based materials and fuel (Korosuo et al., 2023b).

Additionally, better articulation of different actions proposed under the European Green Deal is crucially needed. For example, it has been reported that the pledge to plant at least 3 billion additional trees under the EU biodiversity strategy for 2030 could increase wildfire risk through increased fuel load and connectivity (Hermoso et al., 2021), reduce regional water availability (Hoek van Dijke et al., 2022) and in some cases result in biodiversity loss (Abeli and Di Giulio, 2023). The recently published voluntary guidelines on biodiversity friendly afforestation, reforestation and tree planting are expected to support decision-makers in avoiding these pitfalls.

Accurate monitoring of emissions and removals in the LULUCF sector and attribution of their causes (natural disturbances, different management practices, etc.), e.g. supported by Earth observation and higher order modelling, is needed for robust assessment of trajectories towards – and re-evaluation of – climate change mitigation targets for European ecosystems (Korosuo et al., 2023b; Bastos et al., 2022).

## 13.6 Aggregated risk assessment

This section presents the outcomes of the structured risk assessment for the major climate risks identified in this storyline. This assessment builds on information in this storyline, and possibly in other chapters of this report. The initial risk assessment was conducted by the authors of this storyline whereas the final assessment results reported here represent the consensus of the EUCRA risk review panel. Further methodological information is available in Annex 2.

The following key risks assessed in other chapters are relevant also for this storyline, but they are not presented here to avoid duplication:

- Risks to biodiversity and carbon sinks from increased frequency and intensity of wildfires (Chapter 3)
- Risks to food web dynamics and related ecosystem services due to phenological changes and species distribution shifts (Chapter 3).

**Table 13.1 Risk assessment for risk to forest ecosystems and the carbon sink from more severe and frequent hot-dry events and related insect pest outbreaks**

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)**<br>**- high warming**<br>**- low warming** |
|---|---|---|---|
| **Risk severity** | **Substantial**<br>Rising incidence of forest disturbances and disturbance-driven tree mortality. Increasing rates of drought, wildfires and insect outbreaks across Europe supported by multiple observational sources. | **Critical**<br>Increase in tree mortality induced by more severe and frequent droughts, compound hot-dry events, and insect and pest outbreaks. | **Catastrophic**<br>Further increase in tree mortality induced by compound hot-dry events, and insect and pest outbreaks.<br>**Critical**<br>See mid-term. |
| ***Confidence*** | **High**<br>Increasing incidence and severity of forest disturbances is well | **Medium**<br>Global model projections represent poorly (or not at all) incidental disturbances and related tree mortality, but the | **Medium**<br>See mid-term |

| | | | |
|---|---|---|---|
| | documented. This trend is likely to continue. | underlying drivers are well understood. Consequently, there is medium confidence that climate-driven disturbances represent a positive carbon-climate feedback, but very low confidence in the magnitude of that feedback. | |
| **Risk ownership** | **Co-owned**<br>The EU and its Member States both have legislative responsibilities relating to the safeguarding of forest ecosystems and the sustainable use of the ecosystem services they provide.<br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• EU biodiversity strategy for 2030 (2020/380)<br>• Forthcoming Nature Restoration Law (adoption expected in March 2024)<br>• EU forest strategy for 2030 (2021/572)<br>• Union Civil Protection Mechanism<br>• Proposed Forest Monitoring Law<br>• Habitats Directive (92/43)<br>At the national level, the main policies of relevance include those relating to:<br>• Forest management and forest disturbance prevention<br>• Wildfire suppression<br>• Restoration of disturbance-affected areas<br>• Civil protection and emergency preparedness | | |
| **Policy readiness** | **Medium**<br>• Policy awareness is high but policies are fragmented at EU and national level.<br>• EU policies are designed to support existing national policies, in most cases.<br>• Instruments appear to be in place but are potentially incoherent.<br>• Regionally differentiated guidelines and policy implementation are needed.<br>• Long turnover and lead time of forestry measures requires long-term planning.<br>• Forest adaptation requires high mobilisation of resources.<br>• Forestry was not included in the Treaty on the Functioning of the European Union and thus forest-related policies are the competence of national administrations. Views on forest management are very diverse among EU Member States. | | |
| **Policy horizon** | **Long term** | | |
| **Urgency to act** | **More action needed** | | |

Source: EEA.



### Table 13.2 Risk assessment for risk of large-scale cascading impacts across sectors from unprecedented forest disturbances

| | Current/near term (2021-2040) | Mid-term (2041-2060) | Long term (2081-2100) |
|---|---|---|---|
| **Risk severity** | **Substantial**<br>Unprecedented impacts reported across sectors due to disturbance cascades associated with compounding extreme events, but high uncertainty for insects and wind due to observational gaps. Few events result in long-term losses in forest carbon stocks and | **Critical**<br>Compounding impacts from low-likelihood high-impact events more likely under climate change due to increased frequency and intensity of extreme events, increased forest vulnerability, and increased disturbance interactions (limited evidence). | **Critical**<br>Compounding impacts from low-likelihood high-impact events more likely due to increased probability of 'record-shattering' heat-drought events (*medium confidence*), long-term increase in forest vulnerability and increased disturbance interactions (limited evidence). While potentially rare, they can lead to irreversible changes. |

| | | | |
|---|---|---|---|
| | climate change mitigation potential in some countries. | | |
| ***Confidence*** | **Low**<br>The incidence and impact of cascading events that themselves are difficult to model cannot be assessed with high confidence. | **Low**<br>See current/near term | **Low**<br>See current/near term |
| **Risk ownership** | **Co-owned**<br>The EU and its Member States both have legislative responsibilities relating to the safeguarding of forest ecosystems and the sustainable use of the ecosystem services they provide.<br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• EU biodiversity strategy for 2030 (2020/380)<br>• Forthcoming Nature Restoration Law (adoption expected in March 2024)<br>• EU forest strategy for 2030 (2021/572)<br>• Union Civil Protection Mechanism<br>• Proposed Forest Monitoring Law<br>At the national level, the main policies of relevance include those relating to:<br>• Forest management and forest disturbance prevention<br>• Wildfire suppression<br>• Restoration of disturbance-affected areas<br>• Civil protection and emergency preparedness | | |
| **Policy readiness** | **Medium**<br>See previous risk | | |
| **Policy horizon** | **Long term** | | |
| **Urgency to act** | **Further investigation** | | |

Source: EEA.

# 14 Infectious diseases

## 14.1 Key messages

- Warmer temperatures have already enabled some disease vectors to move northward and into higher elevations. Southern Europe is increasingly warm enough for mosquitoes to transmit tropical diseases such as dengue and chikungunya, with several small-scale outbreaks in recent years. Tick-borne diseases, which are most common in northern and central Europe, are on the rise as climate change favours tick survival and development.
- More frequent and severe floods and droughts are increasingly favouring the spread of water- and foodborne diseases such as *Campylobacter* and *Salmonella*.
- Extreme events can facilitate the spread of diseases by contaminating cropland and water sources, concentrating animals around water sources during droughts, or providing standing water where mosquitoes can reproduce. They can also disrupt water and sanitation systems and overwhelm health systems.
- These risks are expected to intensify, with especially severe impacts on vulnerable people. The convergence of infectious disease outbreaks and a surge in heat stress-related illnesses could place considerable strain on health systems.
- The EU is already taking steps to address the impacts of climate change on infectious diseases, but early warning and disease surveillance systems may need to be improved.
- Coordination between the EU and its Member States is needed to enable more systemic actions, such as new vector and infectious disease control programmes, health action plans, adaptation strategies and resilience measures.



## 14.2 Introduction

On a global scale, one of the biggest threats to human health from climate change is the increase in climate-sensitive infectious diseases, driven by rising temperatures, droughts and water scarcity, torrential rains, floods and warming oceans, among other factors (IPCC, 2023a). 58% of infectious diseases confronted by humanity worldwide have at some point been aggravated by climate hazards (Mora et al., 2022). The impacts on Europe to date have been limited, but there is growing evidence that vector-borne, foodborne and waterborne diseases will increase in the coming decades (Rocklöv et al., 2023). Changes in precipitation and temperature can also increase the risk of common respiratory infections, such as influenza and COVID-19 (Liu et al., 2020a; Mora et al., 2022). Warming causes certain disease fungi to spread into new areas that previously were too cold for them to survive. Through greater demand for patient care, these increases exert additional burdens on healthcare systems.

Warmer temperatures and changing rainfall patterns in Europe are creating more favourable conditions for mosquitoes, ticks and other disease-carrying insects (van Daalen et al., 2022). The geographic range of some vector-borne diseases is expanding, and so is the number of days per year when people are at risk. Highly seasonal water- and foodborne diseases such as *Salmonella* and *Campylobacter* are also becoming more prevalent (Semenza and Paz, 2021). More frequent and severe floods increase the risk of leptospirosis outbreaks (Suk et al., 2020) and warming oceans may accelerate the replication of pathogenic bacteria such as *Vibrio* species.

A surge in dengue cases in France in 2023, including the detection of the first autochthonous dengue cases in the Île-de-France region (Fournet et al., 2023), raised public awareness of the threat of mosquito-borne diseases in Europe. More than 1,400 cases were reported in France by 27 October. Most cases were linked to outbreaks in the Caribbean, with 36 cases the result of local transmission (i.e. in patients with no travel history) (Naddaf, 2023). With more than 5 million cases of dengue reported globally (WHO, 2023a), the EU's share is still minimal. Within a few years, however, dengue could be endemic in southern Europe (Rigby, 2023).

As this example illustrates, climate change is only one of several factors that may increase the prevalence of infectious diseases in Europe; travel and tourism, international trade and societal trends such as ageing populations are also at play. The European population's susceptibility to infectious diseases could also be exacerbated by ageing, chronic diseases, a rise in heat stress-related illnesses, underfunded health systems and inadequate disease surveillance. The quality of water supply systems and food safety regulation will also make a difference.

While Chapter 7 focuses on overall health impacts of climate change in Europe, this chapter examines the extent to which the population in Europe is already at heightened risk from infectious diseases due to climate change; the role of non-climatic factors; how future climate change is expected to increase infectious disease risks; and the role of EU policies in protecting public health.

## 14.3 Infectious disease risks in a warming Europe

Climate change can increase the prevalence of disease in numerous ways, and could aggravate more than half of known human pathogens – especially vector-borne and waterborne diseases (Mora et al., 2022). Climate change also affects human-to-human transmission of infectious diseases (He et al., 2023), and increases the likelihood of common infectious diseases such as influenza, which can overwhelm health systems. This section highlights some of the top concerns in Europe, as well as key drivers of risk.

### *14.3.1 Vector-borne diseases*

Vector-borne diseases cause large burdens of mortality and morbidity worldwide. Dengue has been on the rise in recent decades due to travel, trade, urbanisation and climate change, and dengue is estimated to lead to around 100 million symptomatic infections a year. Malaria continues to be a leading cause of death among children in Africa. Vectorial capacity (i.e. the ability of mosquitoes to transmit disease to humans) is highly influenced by ambient temperatures. Southern Europe is becoming increasingly warm enough for *Aedes albopictus* to transmit dengue virus. France has reported autochthonous (locally transmitted) dengue cases in 10 of the past 14 years, but with numbers only in the single digits until 2020, when 13 cases were reported; then in 2022, the number increased to 65 (Cochet et al., 2022), and to 43 in 2023 (ECDC, 2023a). Italy was dengue-free before registering 10 cases in 2020, then 76 from July to October 2023. While most cases have occurred in high summer, in some places local transmission occurred as late as October.

West Nile virus (WNV), which can be fatal to humans and horses, is also transmitted by mosquitoes, with most infections in Europe occurring in the summer and early autumn. An unusually warm spring in 2018 may have enabled WNV to start spreading earlier, contributing to a particularly large outbreak that year, with more than 2,000 symptomatic cases (Farooq et al., 2022). Rainfall can also affect WNV transmission by enabling mosquitoes to proliferate (Marini et al., 2021). Recent outbreaks, however, are likely to be related to drought conditions that led birds carrying WNV and mosquitoes to concentrate around water bodies, leading to more contacts. Infected birds may also have travelled farther during the drought searching for water and food (Watts et al., 2021). In 2023, there were 707 cases of WNV in EU/EEA countries and 67 reported deaths (ECDC, 2023f).

Europe has also experienced several outbreaks of chikungunya, another viral disease transmitted by *Aedes* mosquitoes: two outbreaks occurred in Italy, in 2007 and 2017, with hundreds of cases, and three smaller ones in France, in 2010, 2014 and 2017 (ECDC, 2019). *Aedes aegypti*, which transmits both dengue and chikungunya, used to be widespread along the coasts of the Adriatic and the Mediterranean, and was responsible for the largest dengue outbreak in Athens in 1927-1928. (Rosen, 1986). Large insecticide campaigns eradicated the mosquito after World War II, but it is now established on eastern coasts of the Black Sea and in north-eastern Turkey (ECDC, 2023b), and climatic conditions are still theoretically suitable for this species over much of Europe's southern coasts (Wint et al., 2022). The mosquito has also been found in Cyprus, raising concerns that it could spread and return to neighbouring Greece (ECDC, 2023a).

Tick-borne diseases are affected by climate change as well, as ticks may survive on their hosts during mild winters, and early spring can accelerate tick development (Jenkins et al., 2022). Two tick-borne pathogens are of concern in Europe: tick-borne encephalitis (TBE), which can cause life-threatening swelling of the brain and lingering neurological problems, and Lyme disease (neuroborreliosis), which can have lasting debilitating effects ([11]). A high incidence of both Lyme borreliosis and tick-borne encephalitis is correlated with mild winters and warm, humid summers (Rocklöv and Dubrow, 2020).

Rift Valley fever (RVF) is a zoonotic vector-borne disease transmitted by different *Culex* and *Aedes* mosquitoes. The largest RVF epidemics have occurred in sub-Saharan African and the Arabian Peninsula. Epidemics are characterised by a storm of abortions in livestock with large economic impacts. Humans can be infected by mosquito bites, but more often by contact with viraemic animal materials (blood, meat, foetus). In some cases, a severe and fatal haemorrhagic form of the disease can occur. Overall, the risk of RVF introduction into the EU through movement of infected animals is low, given strict veterinary and health safety policies on animal imports. Risk related to the movement of infected vectors is also considered to be very low (Nielsen et al., 2020).

A vaccine for TBE is available, but the disease is still common, with a total of 24,629 reported cases, 19,451 hospitalisations and at least 93 fatalities across 19 European countries from 2012 to 2020, mainly among unvaccinated people (Heuverswyn et al., 2023). Case counts vary annually, but they rose for 6 years in a row during that period, reaching 3,604 in 2020, and several countries reported outbreaks in 2023 (Satapathy et al., 2023). Unlike the mosquito-borne diseases, tick-borne diseases are most common in northern and central Europe.

Zoonotic diseases involve complex dynamics across ecological-animal and social systems, which are less well researched and understood today in relation to climate change. Climate affects viruses' ability to cross over from one animal species to another, eventually increasing the risk of spillover to humans. However, in the case of infectious diseases spreading primarily through contact between humans, the climate sensitivities and potential impacts from climate change are not well understood (Rupasinghe et al., 2022). Overall, human behaviour and contact patterns, such as indoor crowding, are thought to contribute to the aggregation of such diseases during the cold season in Europe, while for many recurrent infections this is also interacting with the immunity of the population (including the rate of vaccination) and the seasonal dynamics arising from gaining immunity.

### *14.3.2 Water- and foodborne diseases*

Climate change is affecting waterborne diseases by increasing the frequency and severity of conditions known to facilitate the spread of those pathogens: heavy rainfall, flooding and hot weather (Semenza, 2020). Floods can cause animal waste, chemicals and other pollutants from

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([11]) See ECDC factsheets: https://www.ecdc.europa.eu/en/tick-borne-encephalitis/facts/factsheet and https://www.ecdc.europa.eu/en/borreliosis/facts/factsheet.

fields, overflowing sewers, industrial sites, roads and other sources to flow into bodies of water, contaminating them, and potentially overwhelming water treatment systems (Semenza et al., 2022a). Waterborne infectious diseases are particularly likely to proliferate if procedures related to safe drinking water, sanitation and hygiene (WASH) are not adhered to. Within the World Health Organization (WHO) European Region, about seven people per day died in 2016 from diarrhoeal diseases linked to inadequate WASH facilities, such as viral gastroenteritis, hepatitis A and *E. coli* diarrhoea (WHO, 2022).

Contamination of floodwater with pathogens such as *Leptospira* can cause population exposure and then trigger an outbreak (Suk et al., 2020). In September 2023, following heavy rainfall and flash floods caused by Storm Daniel, several confirmed leptospirosis cases were detected in Greece (ECDC, 2023b). In coastal areas, meanwhile, marine bacteria like *Vibrio* thrive under elevated sea surface temperature and low salinity, conditions now found in the Baltic Sea (Trinanes and Martinez-Urtaza, 2021). Modelling suggests the largest changes in suitable coastline areas are occurring in north-eastern Europe, such as Germany, Poland and the Baltic and Nordic countries.

In several European countries, warm temperatures and, to a lesser degree, precipitation have been linked to a rise in campylobacteriosis (Lake et al., 2019b), a bacterial diarrhoeal disease that is transmitted to humans by eating contaminated food (mainly poultry) or by drinking or swimming in contaminated water ([12]). *Campylobacter* has been the most reported cause of human bacterial gastroenteritis in the EU since 2007, with 127,840 confirmed cases in 2021 and more than 10,000 hospitalisations (EFSA and ECDC, 2022).

Salmonellosis is the second most reported foodborne gastrointestinal infection in the EU, with 60,050 confirmed cases in 2021, and is the top cause of hospitalisations, 11,875 in 2021 (EFSA and ECDC, 2022). Like *Campylobacter, Salmonella* is climate-sensitive and grows in a narrow temperature envelope, with more frequent infections in Europe's summer months (Semenza and Paz, 2021).

Along with warm temperatures, foodborne diseases are affected by some other climatic drivers (Semenza et al., 2012a). For example, as noted above, extreme events such as floods can contaminate crops on fields; they can also disrupt food supply chains and the processing and preparation of food (Semenza et al., 2022a). Overall, within the WHO European Region, foodborne diseases continue to pose a significant public health challenge, contributing to more than 23 million illnesses annually, resulting in 5,000 fatalities, and causing over 400,000 disability-adjusted life years (World Health Organization, 2015). In 2022, 5,763 foodborne disease outbreaks, 48,605 cases of illness, 2,783 hospitalisations and 64 deaths were reported in the EU-27 and the UK (EFSA and ECDC, 2023). The consumption of tainted food not only jeopardises health, but also hinders socio-economic progress by disrupting international trade and market prospects.



### *14.3.3 How climatic risk drivers interact and compound*

As the discussion above shows, several climatic factors can affect the spread of infectious diseases, including temperature, precipitation, humidity, soil moisture, wind and light exposure. Some drivers may not be immediately obvious: for example, very dry weather may lead people to store more water, which can create favourable breeding conditions for mosquitoes. Overall, weather and climatic conditions may influence the reproduction and survival of animals, disease vectors and pathogens, as well as their geographic range, subsequent exposure and transmission potential.

([12]) See ECDC overview: https://www.ecdc.europa.eu/en/campylobacteriosis.

The population in Europe is also increasingly affected by indirect effects from climate-sensitive infectious diseases, which is of concern because of their epidemic potential. Extreme events can precipitate cascading impacts through a sequence of secondary events in natural and human systems that can result in physical, natural, social and economic disruption due to existing societal vulnerabilities. Even a relatively minor climate hazard can result in a cascade of downstream events when risks are causally connected, with one triggering the next. It can potentially generate an unforeseen sequence of system failures, with major public health consequences that need not be in proportion to the initial trigger. These impacts are a function of existing vulnerabilities in society, such as ageing infrastructure, suboptimal early warning and surveillance systems, and exposed structures that are susceptible to the effects of climate hazards. Critical infrastructure such as healthcare can then be disrupted by power cuts, flooding or physical damage.

Climate risks can also cascade, contributing to the transmission of disease in multiple ways. For instance, floods and heavy rainfall can result in standing water where mosquitoes can quickly reproduce and then transmit diseases like Zika, malaria and dengue. Floods can contaminate water sources and distribution systems, too, and lead to waterborne disease outbreaks (Suk et al., 2020; Semenza et al., 2022a).

Water shortages and drought can also give rise to cascading risks and cause diarrhoeal diseases (Suk et al., 2020; Semenza et al., 2022a). As noted earlier, limited water resources can prompt mosquitoes and birds to gather around water bodies, increasing the chances of disease transmission and spreading the prevalence of WNV.



### *14.3.4 Non-climatic risk drivers*

Infectious diseases that are becoming more prevalent with climate change do not affect all people equally. As highlighted by the EU One Health 2021 report, foodborne disease outbreaks led to the highest numbers of cases when they occurred in schools or kindergartens, and caused a disproportionate number of deaths when they occurred in healthcare and residential facilities (EFSA and ECDC, 2022, 2023). Social, economic, cultural and other factors affect people's exposure to pathogens as well as their vulnerability to disease. Those who are poor, elderly and/or already less healthy are likely to be more negatively affected. This, in turn, can exacerbate existing inequalities and could, in some contexts, lead to social unrest and political instability.

Improved public health systems (e.g. more hospital beds, vaccines, diagnostic tests) are essential for vector control, prevention and treatment. The COVID-19 pandemic is a prime example of the importance of public health services. They are also crucial for improving overall population health and thus reducing vulnerability due to pre-existing conditions, co-infections and auto-immune diseases.

Changes in land use and agricultural practices, meanwhile, can sometimes enable disease vectors to proliferate (Perring et al., 2016). For example, *An. labranchiae* is found in rice paddies, and this mosquito is competent to transmit malaria. Even measures that are generally positive and may support adaptation to climate change, such as creating more urban parks, may provide more standing water and nesting grounds for carriers of vector-borne diseases. The current decline of biodiversity, on the other hand, is closely associated with an escalation in the prevalence and elevated risk of zoonotic diseases (IPBES, 2020). This situation also undermines the dilution effect, which typically reduces the spread and infection rates of pathogens among people. Behavioural changes in response to warmer temperatures, such as wearing lighter clothing or spending more time outside, can increase exposure to ticks and tick bites.

## 14.4 Potential for future crises

### *14.4.1 Key risks*

An increase in multiple hazards, including prolonged heatwaves and droughts, is projected in Europe, leading to an increase in transmission of zoonotic diseases (which account for 75% of all emerging diseases), and in turn increasing risks to human and animal health. However, the increase in transmission will also be dependent on other drivers, such as changes in travel and trade, land use, deforestation, new control measures and the development of antimicrobial resistance.

The increasing suitability of the climate for various pathogens or their vectors may translate into a higher likelihood of geographic and temporal expansion of infectious and zoonotic diseases in large parts of Europe that are not yet set up to address these diseases. Furthermore, the pathogens and their vectors might be active for more months of the year. Combined with the growing number of travel-imported disease cases, and the lack of immunity to some of the emerging diseases among the population in Europe, this increases the likelihood of local outbreaks. Some populations groups like the elderly and children are more vulnerable, while others such as outdoor workers and low-income groups are more exposed due to living conditions, gaps in health coverage, public health responses and occupational settings.

Infrastructure and procedures are inadequate to address the increased disease risks in the context of climate change, and water treatment plants are not built to cope with the projected influx of pathogens. For example, an extreme precipitation episode could trigger a causal chain of events that could have a ripple effect and damage critical infrastructure (Semenza, 2020). Cascading risks depend on existing vulnerabilities in society that become exacerbated by climate change (Semenza, 2021). A heavy rain event could flush animal pathogens from pastures into waterways and overwhelm ageing water treatment and distributions systems, resulting in waterborne disease outbreaks (Semenza et al., 2012a; Guzman Herrador et al., 2016).

The blood supply must be safeguarded against contamination with infectious agents, such as HIV or Hepatitis B. Infected blood donors might inadvertently contaminate the blood supply when they give blood. However, blood banks are also at risk from donors returning from countries with endemic tropical diseases, which could find suitable climatic conditions in Europe. Thus, traditional blood supply screening methods face challenges in terms of cost-effectiveness and feasibility, necessitating a re-evaluation of current practices in the context of climate change (Semenza and Domanović, 2013). These challenges go beyond mere quantitative limitations and involve conceptual complexities. The introduction of new tropical pathogens, such as yellow fever, Japanese encephalitis, Zika and other vector-borne diseases not currently endemic in the EU, into a warming Europe could remain undetectable until sensitive tests are developed. Furthermore, the time between infection and seroconversion, when detectable antibodies against a pathogen emerge, creates a vulnerability in antibody screening tests for blood banks. Pathogen reduction technology operates before seroconversion, because it does not rely on the detection of antibodies or genomes. It can effectively eliminate bacteria and fungi in transfused blood or blood components. Detection, inactivation and elimination of blood-borne pathogens from blood and its components are essential for patient safety, with the aim of achieving a risk level of zero. The EU Blood Directive (EU, 2003) recommends considering scientific advancements in the field to reduce the risk of pathogen transmission through transfusion.

In a rapidly changing global landscape, climate change and international air travel will likely alter the dynamics of disease transmission for emerging infectious diseases. This presents a growing risk to current blood safety practices. Enhanced pathogen inactivation, coupled with donor and donation screening, may ultimately be the way forward to ensure the safety, sufficiency and affordability of the blood supply (Semenza and Domanović, 2013). Adapting to climate change and emerging infectious disease threats calls for the integration of new technologies, as described here, into the blood-testing paradigm to safeguard the blood supply from these pathogens.

### 14.4.2 Future of climatic and non-climatic drivers

Climate change is expected to increase the risk of pests and diseases in Europe. Rising temperatures, changing precipitation patterns and extreme weather events are likely to alter the geographic range and behaviour of many pests, resulting in new infestations and increased damage to crops, livestock, forests and natural ecosystems. In addition, changes in plant phenology and species composition could create new niches for pests and diseases, amplifying their impact. Globalisation and climate change are redrawing the landscape of plant pest distribution. This trend poses a threat to natural and managed environments, agricultural and forestry production, ecosystems and biodiversity in the EU territory. Warming in Europe will continue to rise faster than the global mean, widening risk disparities across Europe. Temperatures in Europe are expected to increase due to future climate change along with the frequency and intensity of heatwaves (see Chapter 2). Land temperatures in Europe are projected to rise by 1.2-3.4°C under the SSP1-RCP2.6 scenario and by 4.1-8.5°C under the SSP5-RCP8.5 scenario by 2071-2100, compared to 1981-2010 (EEA, 2021c, 2023g). Differential temperature increases are expected in north-western Europe and Scandinavia in the winter and in south-eastern and southern Europe in the summer. The highest level of warming is projected across north-eastern Europe, northern Scandinavia and inland areas of Mediterranean countries. Extreme temperatures and humid heatwaves are both expected to increase rapidly across Europe. The frequency and intensity of heatwaves are projected to increase across Europe, too, under future climate change, with the number of people exposed to extreme heat expected to rise substantially (see Chapter 2; Chapter 11; Chapter 7).

Variability in precipitation patterns and less precipitation during summer, together with increasing temperatures, are projected to increase the frequency and intensity of droughts. In addition, the frequency of flash floods, such as those of July 2021 in western Europe, is expected to rise. Projected changes in precipitation are expected to differ considerably across Europe and the seasons. In northern Europe, annual precipitation and heavy rainfall are likely to increase. Central Europe is expected to experience lower summer rainfall, but increases in heavy precipitation events, river floods and droughts. In southern Europe, annual precipitation and summer rainfall are projected to decrease, whereas the frequency of droughts is likely to increase (see Chapter 2) (EEA, 2021c).

### 14.4.3 Potential impacts, risk drivers and critical constellations

Europe is experiencing a warming trend with more frequent warm spells, longer and warmer summers, milder winters, and an increase in the frequency, duration and severity of heatwaves. Weather conditions contribute in a non-linear way to infectious disease transmission and are one of the key drivers of the emergence, re-emergence and spread of infectious diseases. Moreover, climate conditions contribute to the survival, reproduction and distribution of disease pathogens and vectors, as well as to their transmission and geographical patterns; in fact, nearly two thirds of human and domestic animal pathogens in Europe are climate sensitive. Higher temperatures, along with increasing frequency and intensity of extreme events due to future climate change, are projected to exacerbate the spread of infectious diseases in Europe, particularly in vulnerable populations such as children, the elderly, immuno-compromised individuals and those with pre-existing medical conditions. This is particularly problematic in Europe given the overall ageing population. These impacts could lead to socio-economic public health challenges and long-term impacts on communities. Given that many of the climate-related infectious disease risks are not yet known and can be difficult to predict, integrated early warning and disease surveillance systems to detect new outbreaks are a key priority for Europe.

Water availability has also changed with reduced precipitation in southern and eastern Europe and more frequent and severe rainstorms and floods in northern Europe (Kreienkamp et al., 2021). The risk from waterborne diseases is compounded by cascading climate events that could trigger a sequence of secondary events which may cause disruption of natural or human systems (Semenza, 2020). For example, extended periods of excessive precipitation can saturate soils and mobilise pathogens from fields and pastures, and flush them into water treatment and distribution systems, possibly resulting in waterborne disease outbreaks (Semenza and Paz, 2021).

Temperature-related range expansion of certain vector-borne diseases such as Lyme disease already occurs and is projected to continue, along with higher incidence rates of certain food and waterborne diseases (Kendrovski et al., 2017; Semenza and Suk, 2018). The frequency, duration and/or severity of extreme events in Europe are also expected to increase, including storms, heavy rainfall, floods, droughts, wildfires and sea level rise, which may result in a sequence of events that leads to a succession of system failures (Semenza, 2020). Extreme weather episodes can precipitate cascading impacts, through a sequence of secondary events in natural and human systems, that can result in physical, natural, social or economic disruption due to existing societal vulnerabilities. Even a relatively minor climate hazard can result in a cascade of downstream events when risks are causally connected and cascading in nature, with one triggering the next. Such a hazard can potentially generate an unforeseen sequence of system failures with major public health consequences that need not be in proportion to the initial trigger (Semenza and Paz, 2021; Semenza et al., 2022a; EEA, 2022).

Future warming and variable precipitation patterns will affect the spatial and temporal transmission of several vector-, water- and foodborne diseases in Europe, and these changes are likely to be spatially heterogeneous (Ebi et al., 2018). While changes in the magnitude and pattern of climate-sensitive health outcomes are likely, if thresholds are crossed, some of these impacts could be significant (Tong and Ebi, 2019). Weather and climate events, population movement, land use changes, urbanisation, global trade and other drivers can catalyse a succession of secondary events, which can lead to a range of health impacts, including infectious disease outbreaks. These cascading risk pathways of causally connected events can result in large-scale outbreaks and affect European society at large (Semenza et al., 2022a).

Climate change exposes existing vulnerabilities in society and acts as a threat multiplier (IPCC, 2022). Heatwaves disproportionally affect the elderly, the poor and marginalised individuals with pre-existing medical conditions. Mosquito-borne disease outbreaks affect vulnerable communities living in close proximity to mosquito breeding grounds, that lack screens on windows or access to repellents. Cascading risks depend on existing social vulnerabilities that become exacerbated by climate change. While climate change is not the main driver of social inequality in Europe, poor households and marginalised groups are more severely affected than other social groups by flooding, heat and drought, and consequently experience more health risks due to spreading diseases. Land use change causes habitat fragmentation, which enhances human contact with natural areas and wildlife. Habitat degradation results in the proliferation of generalist and sympatric species that are adapted to humans and live in closer contact with them; they are thus more likely to spread diseases to humans. Increased environmental stress impairs wildlife immunity, causing shedding of pathogens to the environment and infection of other individuals. The effect of habitat degradation is even more pronounced for animal health, for example bovine tuberculosis and natural reservoirs such as badgers, or interaction between domestic pigs and wild boars, which favours swine flu epidemics.

Individually, climate change and antimicrobial resistance (AMR) pose significant challenges to public health, with far-reaching consequences for health and wellbeing globally. AMR, which refers to the innate or acquired ability of microorganisms to resist the effects of antimicrobial treatments, stands as a major contributor to global mortality, with over 6 million attributed deaths in 2019 alone (Murray et al., 2022). Both empirical and synthesised evidence underscore the connection between rising temperatures and the proliferation of antimicrobial-resistant pathogens.

The intricate relationship between climate change and AMR encompasses shared risks and impact pathways that affect health on a global scale (Blair, 2018). Under the influence of climate change, the environmental pressures influencing the development, transmission and spread of AMR may be altered (MacFadden et al., 2018). Moreover, there exist detrimental synergies between climate change and AMR that have the potential to fuel the emergence, transmission and spread of antimicrobial-resistant bacteria (McGough et al., 2020). Nevertheless, there is a need for a more comprehensive understanding of the intersections between AMR and climate change to inform the development and implementation of policies across various government remits (EC, 2017a). The effective management of ecosystems and natural resources, coupled with advancements in agricultural innovation and ensuring food security, will be crucial components in addressing these challenges.

### 14.4.4 Transmission pathways

*Vector-borne diseases*

Climatic conditions indirectly affect vector-borne diseases such as mosquito- and tick-borne diseases. Alterations in environmental conditions can have secondary effects on vector populations, replication rates of pathogens and vector-host interactions. In addition, climatic events can result in cascading secondary effects that can alter the transmission pathway for vector-borne diseases. These cascading risk pathways are complex and interconnected, and draw on the nexus of hazard, exposure and vulnerability (Semenza et al., 2022a). For example, extreme weather events associated with climate change can disrupt successful vector control programmes designed to manage and reduce the populations of disease vectors, such as mosquitoes, ticks, flies and fleas (Lamy et al., 2023). Extreme weather events can disrupt vector surveillance intended to collect data on vector species, their abundance, distribution and infection rates. It can also disrupt habitat management aimed at eliminating vector breeding sites through draining stagnant water, removing debris and controlling vegetation. It can wash out insecticides or larvicides targeted at vector populations and interrupt biological control efforts (Organisation of vector surveillance and control in Europe, 2021). Suspending such comprehensive strategies and interventions for vector control can then result in a resurgence of vector-borne diseases. Stagnant water left behind by floods (due to heavy precipitation, storm surge, etc.) provides ideal conditions for vector reproduction and can lead to localised outbreaks of diseases. Conversely, drought can draw birds to scarce water sources where the transmission cycle of WNV is accelerated by mosquitoes that also bite humans. The potential trade-off between vector control measures and wetland restoration needs to be acknowledged, given the importance of both these adaptation measures (Weiß et al., 2023).

These cascading risks highlight the interconnectedness of climate change, vector biology, disease transmission and human vulnerability. To effectively address climate change impacts on vector-borne diseases, comprehensive strategies integrating these cascading risks and complex interactions need to be maintained. Public health and vector control measures must also adapt accordingly (Semenza and Paz, 2021). Useful tools may include early warning systems, improved surveillance and targeted interventions to mitigate the effects of climatic events on disease transmission.

*Waterborne diseases*

Climate change alters the continuous circulation of water on Earth in unpredictable ways. Severe weather events, flooding, storm surges and droughts are all early manifestations of the hydrological cycle gone awry (Semenza, 2021). As opposed to gradual changes in climate, abrupt and sudden changes are even more challenging for public health practice. Waterborne diseases are associated with changes in climate such as heavy precipitation events (Semenza, 2020). Warming has been linked with elevated incidence of campylobacteriosis outbreaks in various European countries (Yun et al., 2016; Lake et al., 2019a). Marine bacteria, like *Vibrio*, thrive under elevated sea surface temperature and low salinity, such as is found in the Baltic Sea (Trinanes and Martinez-Urtaza, 2021) (ECDC Vibrio map viewer — European Climate and Health Observatory, 2020). The largest changes in suitable coastline areas are simulated in north-eastern Europe, e.g. Germany, Sweden, Denmark, the Baltic states, Finland (Trinanes and Martinez-Urtaza, 2021) (ECDC Vibrio map viewer — European Climate and Health Observatory, 2020). Interactions between climate hazard, exposure and vulnerability can amplify cascading risks. Contamination of floodwater with pathogens such as leptospirosis can cause population exposure to pathogens and then trigger a leptospirosis outbreak (Suk et al., 2020) (Suk et al., 2019). The resulting impacts of a sequential chain reaction within natural and human systems can be significantly larger than the initial hazard, and can cause additional physical, natural, social or economic disruption in Europe. The occurrence of extreme rainfall events can also exacerbate industrial chemical disasters. For example, the dioxin accident that occurred in Seveso, Milan, in 1976 and affected the local population: the spread of toxins was exacerbated by heavy rainfall during the autumn that year (Cerlesi et al., 1989; Semenza et al., 2022b; Poglayen et al., 2023).

***Foodborne diseases***

The transmission pathway of foodborne diseases through the food chain is complex and susceptible to several climatic drivers (Semenza et al., 2012a). Extreme events can also disrupt food supply chains and the processing and preparation of food (Semenza et al., 2022a). *Campylobacter* is the most reported cause of human bacterial gastroenteritis throughout the EU. *Salmonella* is climate sensitive, too, and grows in a narrow temperature envelope, with more frequent infections in the summer months in Europe (Semenza et al., 2012b; EFSA and ECDC, 2022). The incidence of human *Salmonella* infections is higher in summer than in winter and is thus highly seasonal.

***Projected changes in infectious diseases and pests in Europe under future climate change***

- Chikungunya: temperature projections under climate change scenarios for Europe indicate a moderate increase in the climatic suitability, particularly in central Europe, especially over France and Italy and areas surrounding the Rhine and Rhone rivers, but a decline in northern Italy near the Adriatic coast (Tjaden et al., 2017).
- Dengue: the potential length of the dengue transmission season could increase by about 1-2 months by 2080 over south-eastern Europe, leading to an additional population at risk of about 150-250 million, depending on the emission scenario (Colón-González et al., 2021). Such future changes mostly occur at low altitudes (<500m).
- West Nile fever: climate change projections predict an expansion of areas affected by WNV, particularly in western Europe (Farooq et al., 2022). In the medium term (2050s), the risk of WNV transmission is simulated to increase mostly over south-eastern Europe, north-eastern Italy and south-eastern France (Semenza et al., 2016).
- Malaria: moderate increase in the length of malaria transmission season (1-2 months) is simulated over south-eastern Europe by the 2080s over low population density areas. Such changes could lead to an additional population at risk of 200-250 million (Colón-González et al., 2021). However, there are large uncertainties depending on the selected malaria model, the emission-population scenario and the climate model considered. A systematic review estimates that the malaria transmission season could be extended by 6 months over southern Europe in future (Fischer et al., 2011).

- Tick-borne diseases: Lyme disease risk in future shows a nonlinear response to the emission-population scenario. Under SSP1-RCP2.6, a reduced risk in Lyme disease is estimated, while the largest risk increase is simulated over northern Europe under a 2.4°C global warming level. Future droughts and conversion of forests to agriculture might limit the risk over southern Europe (Li et al., forthcoming).
- The development of *Leishmania* parasites into the infectious form in the sandfly vector is accelerated by ambient temperature. It extends the infectious period in the vector's life cycle. Sandfly vectors can occupy new ecological niches if the long-term temperature and precipitation constraints become more suitable. Projecting the climatic conditions, from where the vectors are at present, forward in time under climate change scenarios and taking landscape features into account can delineate the vector's expansion (Fischer et al., 2011; Koch et al., 2017; Chalghaf et al., 2018; Erguler et al., 2019). For example, *P. ariasi* is currently restricted to south-western Europe but is projected to expand eastwards towards western Germany and western Switzerland by 2040. By 2100, *P. ariasi* is projected to reach south-eastern Germany and eastern and north-eastern Austria (Farooq et al., 2022).
- Microbial foodborne illness is typically a seasonal phenomenon. Therefore, if summers are longer and hotter, anticipate an increase in illnesses from bacteria such as *Salmonella* is anticipated.

## 14.5 Role of EU policies

Prevention of cascading risks of climate change-induced spread and emergence of infectious, waterborne and foodborne diseases requires both EU and national-level policies and local-level actions. To support public health, the EU provides funding and legislation on tackling cross-border health threats, medicines, patients' rights in cross-border healthcare, disease prevention and promotion of good health, while Member States are responsible for organising and delivering health services and medical care. Examples of areas where EU policy is relevant include prevention, preparedness and response, risk assessment, early warning systems, control strategies for pathogens and vectors, coordinated investments focused on new diagnostic tools or drugs (Bett et al., 2017; Vercruysse et al., 2018), and regulations to ensure safe trade and reduce the risk of introducing or spreading pests (European Commission, 2016), along with coordinated funding for climate change adaptation. Europe has implemented indicator surveillance systems that can identify emerging infectious diseases, but integrated surveillance that incorporates environmental, animal and climate indicators is usually siloed and should be merged in the near future.

Chapter 7 provides additional information on European health policies, including public health preparedness and emergency response, which are critical to managing infectious disease and disease outbreaks. These include the Health Emergency Preparedness and Response Authority (HERA), the Emergency Framework Regulation, the Regulation on Serious cross-border threats to health ((EU) 2022/2371), and the EU Civil Protection Mechanism. In the case of an infectious disease outbreak, HERA will ensure the availability of vaccines, antibiotics, medical equipment, chemical antidotes, therapeutics, diagnostic tests and personal protective equipment such as gloves or masks (see Chapter 16).

A priority area for EU policy is addressing increasingly serious cross-border health threats linked to pathogens with high epidemic and pandemic potential. Improved risk assessment and management plans for cross-border health threats include looking into specific viral families of concern, also considering the zoonotic nature of most high-consequence emerging infectious diseases. The Regulation on Serious cross-border threats to health (see Chapter 7) provides rules for epidemiological surveillance, monitoring, early warning and combating serious cross-border threats to health, including planning related to those activities, to coordinate and complement national policies.

To prevent cascading risk pathways affecting the blood supply, a number of steps need to be taken, such as screening, deferral and pathogen reduction strategies. The EU Blood Directive (2002/98/ECEN) covers all steps in the transfusion process from donation, collection, testing, processing and storage to distribution. This directive lays down standards of quality and safety for human blood and blood components, in order to ensure a high level of human health protection. This policy, and others, may need to be modified to reduce inherent vulnerabilities and enhance infectious disease control programmes.

The Eighth Environment Action Programme, the EU's legally agreed common agenda for environment policy up to 2030, acknowledges the importance of a healthy environment for the wellbeing of EU citizens, and includes measures to address environmental factors that have a direct or indirect impact on human health. Furthermore, the EU is taking steps to address the impacts of climate change on infectious diseases, such as through the adaptation strategy. This strategy contributes to more effective adaptation, including interventions to contain cascading risk pathways, which also entail forecasting meteorological conditions that predict the emergence of climate-sensitive infectious disease. The adaptation strategy established the European Climate and Health Observatory; climate-sensitive infectious disease was a focus of the observatory's 2021-2022 workplan, which produced a report investigating the topic as an emerging threat in Europe (EEA, 2022).

A sufficiently detailed evidence base is needed for continued effective EU policymaking. For example, regional risk factors and population health needs in Europe are a prerequisite for effective systematic policies of vector and infectious disease control programmes, health action plans, adaptation strategies and resilience measures. The impacts of upstream climate policies on zoonotic disease outcomes need to be monitored for cross-border implications and unintended consequences of these policies. While acknowledging that public health is under the jurisdiction of the Member States, improved coordination between Member States and the EU is needed for more systemic actions to improve health linked to infectious diseases across the region.

## 14.6 Aggregated risk assessment

This storyline does not include risk assessment tables. The following key risk assessed in another chapter is also relevant for this storyline, but it is not presented here to avoid duplication: Risk from geographic expansion and increased transmission of infectious diseases (Chapter 7).

# 15 Major disruptions of critical infrastructure

## 15.1 Key messages

- Europe's critical infrastructure, such as transport (land, sea and air), energy, communication and water infrastructure, is increasingly exposed to extreme weather events. Heat, floods, droughts, landslides and other climate-related hazards threaten the services infrastructure provides.
- Infrastructure assets are often part of an interconnected network, so a failure at one point in the network can cascade across the system. Understanding and managing the performance of the system as a whole is a prerequisite for climate resilience.
- Infrastructure operates over long time frames. Due to the age and condition of much of Europe's infrastructure, there is a significant adaptation deficit even before considering increasing climate risks in the future. Proactive action is needed to adapt rather than wait until systems fail.
- Incremental adaptation may be sufficient in some cases. Yet in some sectors and locations, transformational change will be needed to ensure the resilience of critical infrastructure in the long term.
- Better data and analytics are required to understand the condition of existing assets, the risks they face and how to best adapt. This is likely to include regulatory 'stress tests' to explore weaknesses and prioritise infrastructure investments.
- It is important that policies to increase the resilience of critical infrastructure are implemented with proper consideration of climatic hazards, now and in the future. There must be clear responsibilities for infrastructure owners and managers.



## 15.2 Introduction

Europe relies on the services provided by built and natural infrastructure every day. This infrastructure protects us from disasters and meets our basic needs for energy and water. It enables us to communicate, travel and transport goods; supports commerce and industry, and underpins the well-being of people and nature. Despite this central and pervasive role, recent years have revealed the fragilities of these services, with rail lines forced to close; collapsed roads and bridges (Koks et al., 2022); and water and energy supplies threatened by drought and extreme heat (Horowitz, 2022). Already stressed, climate change will increasingly test the resilience of critical infrastructure and its ability to service Europe's needs. This chapter examines these threats and how they might evolve in the coming decades. The Critical Entities Resilience Directive (EU, 2022a) identifies energy, transport, health, drinking water, wastewater and digital infrastructure as critical, and these are reflected here. Please refer to Chapter 16 for the production, processing and distribution of food, and Chapter 17 for the banking and financial market infrastructure.

Section 15.3 begins by reviewing recent experience and the vulnerabilities it reveals: from the weaknesses of ageing infrastructure to interconnections and interdependencies that can amplify the impact of a localised failure, as well as non-climatic risk drivers. Section 15.4 of this chapter considers the potential for future crises as the impacts of climate change intensify, highlighting existing deficiencies as well as trends that could exacerbate risks. Although the analysis focuses on the loss of services provided by built infrastructure, it reinforces the need to recognise the services provided by natural infrastructure as 'critical' for both people and biodiversity, and that they are also under threat. In contrast to other storylines, the emphasis is not on specific hazards, but rather on the systems under threat. Indeed, one of the greatest challenges in making Europe's infrastructure more climate-resilient is that systems face multiple threats at once. Section 15.5 concludes with a discussion of relevant public policies, the extent to which they are already promoting enhanced resilience, and key gaps that require urgent action.

## 15.3 How climate change is testing Europe's critical infrastructure

The European Parliament and Council define critical infrastructure as 'an asset, a facility, equipment, a network or a system, or a part of an asset, a facility, equipment, a network or a system, which is necessary for the provision of an essential service'. It is a service 'which is crucial for the maintenance of vital societal functions, economic activities, public health and safety, or the environment' (EU, 2022a).

Critical infrastructure failure is a key concern in the Europe chapter of the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report, which notes a 'substantial increase' in climate change impacts, particularly from extreme events (Bednar-Friedl et al., 2022e). The IPCC cites multiple examples, including 'significant reductions and interruptions' of power supply in several countries during exceptionally hot and dry years, and heat-related disruptions to road and rail transport (Vogel et al., 2019b; Ferranti et al., 2018).

This section delves deeper into some of those impacts, highlighting the increasing severity of climate hazards, their often long-lasting effects, and the many ways in which a shock in one place can cascade and escalate across systems and locations.

### *15.3.1 Major events affecting multiple infrastructure systems*

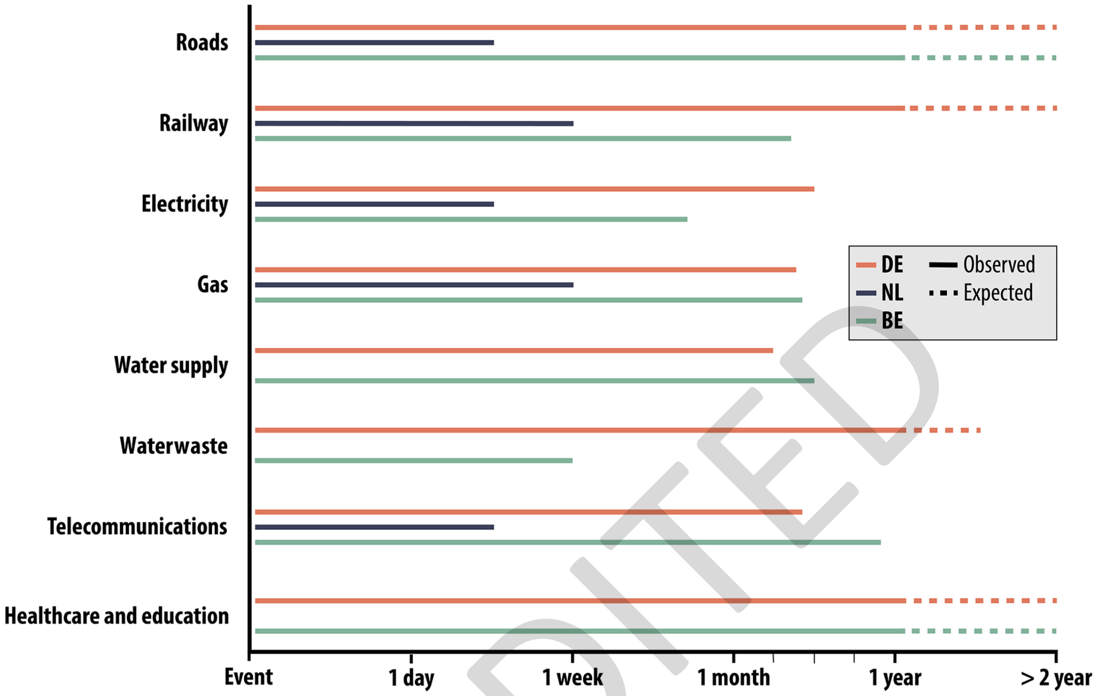
Several extreme weather events over the past two decades have damaged critical infrastructure and disrupted essential services. Droughts and heatwaves have strained drinking water supplies, farm irrigation systems, the power sector and transport on inland waterways. The prolonged drought across large parts of Italy, France, Spain and Portugal since 2018 has disrupted water supply and food production, with its impacts exacerbated by summer heatwaves (Blade, 2022; Bhargava and Granados, 2022).

In 2007, Storm Kyrill damaged and destroyed infrastructure through a combination of strong winds, lightning, torrential rains and coastal floods (Kettle, 2023). In 2010, Storm Xynthia breached seawalls and embankments and caused an estimated EUR 1.5 billion in damage (Koks et al., 2022). In October-November 2023, Storm Babet and Storm Ciarán arrived two weeks apart, leading to widespread flooding and damage (MetOffice, 2023a, 2023b; Olsen and Pylas, 2023).

One of the most destructive events in recent years in terms of critical infrastructure damage was the flooding in Germany, Belgium and the Netherlands in July 2021. A prolonged low-pressure system caused extraordinary rainfall in the catchments of the Meuse and Rhine rivers, resulting in devastating floods (Koks et al., 2022). Residential and commercial structures suffered major destruction, alongside critical infrastructure assets. Moreover, more than 240 people died in the floods. In Germany, road and railway networks sustained severe damage. For example, a 50km stretch of motorway remained closed for two months and rail lines are expected to take over four years to fully rebuild (Dailey, 2023a). Power outages affected about 200,000 people in Germany. Most of the power infrastructure was restored within eight weeks, but in some areas it took six months (see Figure 15.1). In Belgium, fully restoring the gas supply took five months.

The drinking water supply was also affected and sewage treatment plants in Rhineland-Palatinate (Germany) were largely destroyed, so emergency facilities had to be built. The floods wrought havoc on healthcare and education as well, with hospitals, daycare centres and schools sustaining significant damage in Germany and Belgium.

**Figure 15.1 Recovery times of several critical infrastructure systems**




**Note:** Recovery times after the flooding in Belgium, the Netherlands and Germany in 2021.

**Source:** Reproduced from Koks et al., 2022.

### *15.3.2 Three hard-hit sectors: transport, energy and water*

In August 2023, damage from Storm Hans caused a critical railway bridge on the line from Oslo to Trondheim, Norway, to collapse (Bryant, 2023). Passenger and freight traffic was diverted to another line, but just days later, heavy rainfall caused landslides which shut down that line as well (Geerts, 2023). Weeks later, torrential rains, floods and mudslides in Austria shut down several rail lines, including cross-border routes (Dailey, 2023b). In September 2023, a landslide damaged the motorway between Sweden's second-biggest city, Gothenburg, and Norway's capital, Oslo (Reuters, 2023).

Often, the extreme events that disrupt railways also shut down other transport infrastructure. Storm Babet's impact on the UK in October 2023 is a recent example: not only was rail service along the flood-affected east coast severely disrupted, but so were other rail services in Scotland and northern England, and Leeds Bradford airport closed after an aircraft skidded off the runway (MetOffice, 2023a). A North Sea oil drilling platform lost anchors during the storm, and the port of Sunderland's pier was damaged.

Transport infrastructure is also being affected by extreme heat. During the severe summer heatwave of 2022, for instance, rail traffic in France was disrupted by power outages, fires and heat impacts on catenary lines (Slavicek, 2022), Fires, technical problems with trains, and tracks expanding and buckling on hot days similarly disrupted railways in Belgium, Spain, the Netherlands and the UK in 2022 (Geerts, 2022). Roads and airport runways were also affected as the heat softened and deformed the asphalt (Dhanesha and Jones, 2022; Topham, 2022). Major waterways that are critical for freight transport have been affected as well, with extremely low water levels in the Rhine and Danube hindering navigation for extended periods several times in recent years (Henley, 2022).

The water and energy sectors have been strained even more by heat and droughts, with several countries forced to impose restrictions on household and agricultural water use, hydropower plants operating well below their usual capacity, and nuclear and thermal power plants unable to secure all the water needed for cooling (Horowitz, 2022; Bhargava and Granados, 2022).

Table 15.1 provides an indicative overview of the sensitivity of different types of critical infrastructure assets in Europe to an array of climate hazards, based on the combination of an extensive literature review and an expert survey (Forzieri et al., 2018c). Once again, transport, energy and water infrastructure stand out for their sensitivity to multiple hazards. It should be noted that this table focuses on the sensitivity of the infrastructure itself rather than the services provided by it. For example, the social sector shows considerable vulnerability to heatwaves even though sensitivity of the relevant infrastructure to heatwaves may be low.

**Table 15.1 Sensitivity of different critical infrastructure types in Europe to climate hazards**

| Sector | Infrastructure type | Heatwaves | Cold waves | Droughts | Wildfires | River and coastal floods | Windstorms |
|---|---|---|---|---|---|---|---|
| Energy | Fossil and nuclear power plants | Medium | Low | Medium | Low | Medium | Medium |
| | Biomass and geothermal power plants | Medium | Medium | High | High | Medium | Low |
| | Hydro power plants | Low | Medium | High | Low | Medium | Low |
| | Solar power plants | No | Medium | No | Low | Low | Low |
| | Wind power plants | No | Low | No | Low | Low | High |
| | Electricity distribution/ transmission | Low | Medium | No | High | Medium | High |
| | Gas pipelines | No | Low | No | High | Low | No |
| Transport | Roads | Medium | Medium | No | Medium | Medium | Low |
| | Railways | Medium | Medium | No | Medium | High | Low |
| | Inland waterways | Low | Medium | High | Low | High | Medium |
| | Ports | Low | Medium | Low | Low | High | Medium |
| | Airports | Low | Medium | No | Low | Medium | Medium |
| Industry | Metal industry | Low | Low | Low | Low | Medium | Medium |
| | Mineral industry | Low | Low | Low | Low | Medium | Medium |
| | Chemical industry | Low | Low | Low | Low | Medium | Medium |
| | Refineries | Low | Low | Low | Low | Medium | Medium |
| | Water and waste treatment | Medium | Medium | Medium | Medium | High | Medium |
| Social | Education & health | Low | Low | Medium | Medium | High | Medium |



**Note:** This table reproduces the content of Forzieri et al., 2018b, Table 1 in a simplified way. Individual entries in this table may not fully agree with the analysis performed in this report, which considers additional and more recent information.

**Source:** Adapted from Forzieri et al., 2018b.

### *15.3.3 Compound events*

A full array of climate hazards influence Europe's critical infrastructure. Understanding of the subtle complexities of these events (beyond single design storms) and how events can act to compound impacts is increasing (Sayers et al., 2015; Zscheischler et al., 2018). The combined influence of multivariate events — when two or more hazards impact a single infrastructure component at once — can increase the chance of failure. These combinations include droughts and extreme heat, for example, and wildfires exacerbated by high winds; coastal storm surges combined with extreme waves; or coastal storm and intense rainfall increasing local flooding. A recent multivariate event is storm Triplet Dudley-Eunice-Franklin, occurring consecutively in February 2022, which caused large-scale power outages in the UK and disruptions along public transport services in the UK and the Netherlands. In August 2023, Slovenia was severely affected by floods, which also triggered over 170 landslides, posing a further threat to infrastructure and electricity provision (IFRC, 2023).

When multiple locations are affected, multiple failures across the infrastructure network can occur simultaneously, exacerbating the impacts as disruptions cascade and escalate through interdependent infrastructure networks. The August 2023 events that damaged Norwegian railway lines are an example. Not only was rail traffic disrupted but major roads were also shut, so they were not a viable alternative (Nikel, 2023). Providing multiple alternatives can help give built-in redundancy to infrastructure, reducing the impact of a single failure; but it cannot eliminate the impact of widespread, large-scale or compound events that may overwhelm multiple infrastructure components at once.

Climate events that occur in sequence can also push infrastructure to its limits. The collapse of the seawall in Dawlish, UK, is a prime example. During the winter of 2013-2014, the UK experienced a series of extreme events, resulting in some of the most significant coastal flooding in 60 years (Haigh et al., 2016). Very high seas in December were followed by storms in January and February that caused widespread damage to defences, property and infrastructure on the south-western coastlines of England and Wales. On 5 February 2014, the seawall that protected the main railway line collapsed at Dawlish in Devon (Dawson et al., 2016).

Capturing the temporally-compounding influence of a series of storms on infrastructure failure at a single location is difficult due to the complexity of the analysis. However, it is important to study this issue further, as infrastructure is now typically designed to withstand a single design event, not multiple ones in sequence (Sayers et al., 2015). The long repair and recovery times post-failure are also important considerations. Future events — perhaps months or even years after the first but occurring before a repair is complete — can impact an already-weakened infrastructure system.

Extremes of freeze thaw, temperature and humidity, and other climate variables can increase stress to infrastructure components. They can accelerate deterioration, particularly for those that may already be in poor condition. Maintenance is the Achilles' heel of infrastructure performance; ensuring proactive and appropriate maintenance is often difficult but will be increasingly important as our infrastructure systems age and the climate changes (Pathirana et al., 2021).

### *15.3.4 Network effects, interdependencies and cascading impacts*

The functioning of critical infrastructure can be disrupted by direct physical damage, reduced transmission capacity leading to congestion, or failures stemming from contagion and cascading effects. Risk transmission pathways vary greatly across infrastructure systems, even within the same sector.

Direct asset-level impacts, the subject of the analysis in Table 15.1 above, are the most straightforward to understand and prepare for. Resilience to specific hazards can be built into the design of each asset, though there are still significant challenges (Tang, 2022). As illustrated by the Dawlish seawall failure, it is also crucial to prepare not only for a single severe shock, but also for compounding impacts, including over several months and years.

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 systems. When one or more assets within these networks fails, the effects may cascade, as such infrastructure systems are generally strongly interconnected. This could either be at a geographical level (from one area to another) or between systems (from one system to another). Power system failures that originated in Italy in 2003 and Germany in 2006, for example, led to large-scale blackouts, respectively affecting about 57 million and 45 million people across several European countries (Guo et al., 2017). The events prompted significant policy improvements governing the security of electricity transmission throughout Europe (van der Vleuten and Lagendijk, 2010).

Different infrastructure networks also rely on one another and these interdependencies can lead disruptions in one system to cascade into others. A prime example is power outages which can quickly affect telecommunications, transport, and even water supply and treatment. Conversely, as power generation, transmission and distribution are controlled by digital systems, a disruption in digital infrastructure can also lead to power outages. Indeed, in a technologically-advanced world, infrastructure systems are increasingly interdependent (Rinaldi et al., 2001).

There is empirical evidence that cascading infrastructure failure events are common in Europe, with approximately 60% of power failures and 24% of telecoms failures causing outages in other sectors (Luiijf et al., 2009). Such instances underscore the critical importance of safeguarding and enhancing the resilience of critical infrastructure to mitigate the far-reaching impacts of potential cascading failures.

### *15.3.5 Non-climatic risk drivers*

Climate change impacts do not occur in a vacuum; the ability of infrastructure to withstand any given hazard will depend to a great extent on non-climatic drivers. In Europe in particular, a key concern is that much of the infrastructure base is ageing and already experiences failures, and much is not designed to withstand a future climate. In other words, there is already an adaptation deficit and without significant investment, this is set to increase (Bednar-Friedl et al., 2022e; Warren et al., 2016). Climate change interacts with non-climate influences. Climate change can, for example, increase the rate of deterioration of infrastructure or limit the window of opportunity for maintaining moveable structures. For instance, the increased frequency of using tidal surge barriers as sea levels rise can critically restrict the opportunity for routine maintenance. Such aspects can increase the chance of failure (Sayers et al., 2015).

Moreover, the essential nature of critical infrastructure to the functioning of society makes it vulnerable to other threats, such as cybersecurity attacks and terrorism. Such threats can further stress the performance of critical infrastructure (Cassotta and Pettersson, 2019).

A lack of redundancy within infrastructure systems, or insufficient redundancy, can heighten the criticality of a component: individual infrastructure components become more critical, as their failure would be more disruptive to essential services.

Proactive action to upgrade existing infrastructure and develop new connections that respond not only to climate change but also to evolving socio-economic demands will be important for maintaining resilience. For example, energy systems that can meet today's needs, even with some disruptions, may not be fit for purpose as Europe transitions to a net-zero society. Given the long lead time associated with upgrading infrastructure networks (making the investment case, planning approvals, design and implementation can take many years, if not decades), exploring how these non-climate drivers may interact with climate drivers needs to be a central influence on today's choices. This includes developing plans that anticipate future spending (and that allocate budgets accordingly) and setting out agreed-upon actions for when a future event occurs. The latter entails taking the opportunity to reconfigure the system (where necessary) and not simply building back as before.

As infrastructure sectors grow more interdependent, fostering knowledge-sharing and coordinated actions becomes crucial for overall resilience. This involves improving information exchange among sectors, including operators and regulators. Enhanced awareness of individual assets and connections exposes vulnerabilities that compromise resilience both within and between sectors. Achieving greater clarity on acceptable resilience at both asset and system scales across critical infrastructure sectors can drive necessary investments and targeted actions. In various sectors, like the nuclear and dam industries, the ALARP principle (As Low as Reasonably Practicable) is already applied to individual components (Health and Safety Executive, 2001). In many sectors, the focus remains on the performance of individual components; extending risk management and enhancing resilience at the scale of the infrastructure system is imperative for maintaining critical infrastructure services amidst changing demands and the climate. Stress testing current and future scenarios is crucial for this process, and the lack of defined infrastructure stress tests and performance criteria poses significant barriers to progress (Joint Committee on the National Security Strategy, 2022).

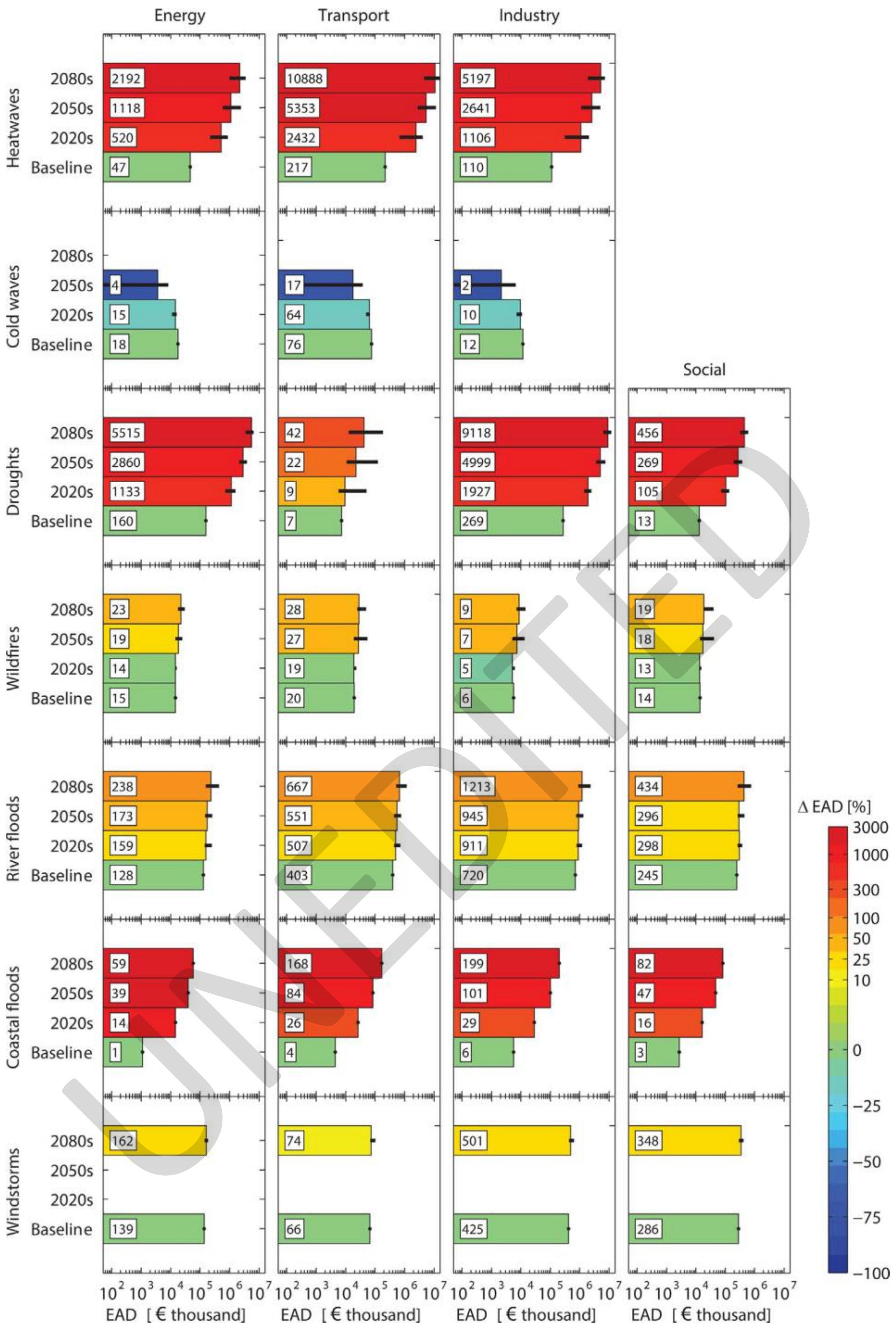
Setting out adaptation planning is now becoming an established part of many major infrastructure planning processes. This process can be guided by the technical guidance on the climate proofing of infrastructure in the period 2021-2027 (EC, 2021a). These plans recognise future uncertainty but also the need for investment today — to embed adaptive capacity within our infrastructure systems which enables a flexible response as the future unfolds (Sayers et al., 2012; Haasnoot et al., 2013). Academic methods, practical examples (such as 2021/C 373/01 and the Thames 2100 programme) and guidance (e.g. ISO, 2021) are emerging, but more is needed to support infrastructure providers in case of investment in resilience and how to develop appropriate designs and plans.

## 15.4 Europe’s critical infrastructure in a heating climate

Projections of future climate change vary greatly by location and scenario, and Europe’s critical infrastructure systems, as discussed, vary greatly as well. This makes it impossible to paint a clear picture of what the future may hold. However, several analyses have been conducted that provide some indications.

Forzieri et al. (2018), for instance, whose analysis of current risks to European infrastructure was presented in Table 15.1 above, estimated future financial risks for different infrastructure systems to 2080 (see Figure 15.2). They found that while the economic annual damage (EAD) to European infrastructure in the 2000s was EUR 3.4 billion, it could rise to EUR 9.3 billion by the 2020s, EUR 19.6 billion by the 2050s, and EUR 37.0 billion by the 2080s. Large increases in transport risk are also underlined by, for example, the JRC PESETA IV project (Bubeck et al. (2019), Alfieri et al. (2017) and Christodoulou et al. (2019)). It should be noted that these model results refer to annual averaged damage. Damage in individual years, and even from individual events, can be higher than the values indicated above. Furthermore, the model results likely underestimate actual damage as this study was unable to consider more recent evidence on the increase in downpours and pluvial floods as a result of climate change.

**Figure 15.2 Expected annual damage to critical infrastructure assets**




**Note:** Expected annual damage (EAD) to critical infrastructure assets aggregated at European level (EU+) for each hazard, time period and sector. Bar length indicates the ensemble median — also reported in numerical labels in millions. Whiskers reflect the inter-model climate variability. Colours reflect the relative change in EAD with respect to the baseline.

**Source**: Adapted from Forzieri et al., 2018.

The energy sector is projected to experience the strongest rise in damage, followed by the transport sector, industry and the social sector. River floods and windstorms currently account for the majority of multi-sector damage. Yet by the end of the century damage from drought and heatwaves could represent almost 90% of climate hazard damage, the analysis showed. Please refer to Chapters 8 and 9 for a more in-depth analysis of future risk to transport and energy systems.

### 15.4.1 Making progress - Pitfalls to avoid

It is not inevitable that Europe's critical infrastructure will fail as the climate and social demands change. Future resilience will fundamentally reflect the effort devoted to adaptation. In a dynamic and changing context, recent history may provide only limited guidance for future events; nevertheless, there are valuable lessons to be learnt. These pitfalls are set out below; not as future projections, but to contribute to the assurance that forthcoming design guidance, planning processes and infrastructure policies are aptly tailored. This aims to ensure appropriateness in approaches to risk allocation, identification of the underlying drivers of those risks, and the implementation of well-directed actions to enhance the resilience of infrastructure systems.

*Lack of foresight leads to lack of preparedness and unnecessary impacts*

Before 2021, much of Central and Northern Europe felt well-protected from flooding. Longstanding safety standards reinforced a sense of safety. The widespread floods and disruption in 2021 came as a surprise. Many infrastructure providers did not anticipate the risks they faced and were thus insufficiently prepared. To avoid this going forward, it is crucial that infrastructure providers better understand future risks and act proactively. Policymakers, regulators, infrastructure owners, engineers and scientists all have a role in providing and acting upon insights into future risks.

*A false perception of preparedness undermines progress towards climate resilience*

Low awareness of the potential severity of climate impacts results in inadequate preparation (Select Committee on Risk Assessment and Risk Planning, 2021). The COVID-19 pandemic was a clear example (Booth, 2023). Many European national authorities recognised the risk of a pandemic, but they were not prepared for one so serious (Renda and Castro, 2020). Climate change risks are also known, but frequently underestimated. The absence of meaningful stress tests for critical infrastructure resilience within and across infrastructure sectors enables a false narrative of preparedness to persist, creating a false sense of security and complacency. This includes stress tests that provide insights to asset-level and systems-scale resilience to motivate and target action. Adaptation is not for the future, but for today. A greater sense of urgency is needed across Europe and across all infrastructure sectors to drive timely action. This need for action is supported by the Critical Entities Resilience Directive (see Section 15.5) which requires Member States to adopt national legislation focused on infrastructure resilience by 17 October 2024.

*Infrastructure planning does not look far enough ahead*

European ports, for example, already recognise climate change impacts and are implementing *incremental adaptation* (improving power supplies and operational rules) to reduce near-term risks. Making the case for *transformational adaptation* — elevating facilities or even relocating them — remains difficult for ports, as it does for many infrastructure sectors and planners in general (Sayers et al., 2022). Coastal storms and sea level rise are already affecting European marine supply chains and international marine trade, as well as land and air transport (Economist Impact, 2023a; Yesudian and Dawson, 2021). Unless well-managed, these impacts will erode Europe's economic advantage as the climate continues to change. A more long-term perspective (aided by the next generation of climate services, such as the Horizon 2020 CoCliCo project (EU H2020, 2021)) can help infrastructure operators (ports, rail, airports, etc.) focus on investing in long-term climate resilience (e.g. León-Mateos et al., 2021). Access to long-term climate projections (looking beyond 2150 — the typical limit of the CMIP6 projections — to 200 or even 300 years into the future), together with the use of storyline approaches to help plan for an uncertain and long-term future, will be important (see Box 15.1).

***Box 15.1 Applying storylines to develop adaptation strategies for critical infrastructure along the European coastline***

Planning new critical infrastructure is generally a long process, and when new critical infrastructure components are built, their anticipated operational lifetime is likely to be many decades (e.g. a power plant), and potentially even centuries (e.g. a bridge). Given their long operational lifetimes and the crucial services they provide, it becomes imperative to incorporate future climate change considerations into infrastructure investment and design decisions.

Koks et al. (2023) present a storyline framework for an event-based assessment of coastal flood risks to critical infrastructure. Each storyline represents a ‘physically self-consistent unfolding of past events, or of plausible future events or pathways’ that connects the drivers of sea level rise and local adaptation choices with socio-economic impacts.

With evidence-guided expert judgement, planners can use the framework to imagine futures informed by specific historical events, such as storms Xynthia, Xaver and the storms that hit Emilia-Romagna. For instance, when considering Storm Xynthia, focusing solely on strengthening existing flood defences results in only minor reductions in damage should the storm recur. However, directing efforts towards local resilience through dry-proofing individual infrastructure assets can lead to a significant 30% decrease in total damage.

This connected narrative offers a level of clarity that surpasses what traditional probability risk assessments can achieve alone, empowering decision-makers to make more informed choices regarding coastal infrastructure and flood risk management. By incorporating future climate change projections into our infrastructure planning, we can better safeguard critical assets and services for generations to come.



### *A lack of whole-system thinking places a false emphasis on recovery*

In June 2018, major floods and landslides occurred across Japan. Alongside the devastating human and economic impacts, many households were left without electricity, clean water supplies were disrupted, and many trains were cancelled. Before the energy system could be restored, two other extreme events followed: a heatwave in July and typhoons in August. In the absence of electricity to support access to cooling, concerns over heatstroke and lack of safe drinking water prevented recovery and exacerbated the impacts. Moreover, the country experienced two major earthquakes in 2018. Because of Japan’s strict building standards, however, damage was limited (Fujimura, 2019). Japan’s experience through 2018 demonstrates how damage may accumulate in time and in response to multiple hazards; an accumulation that seriously undermines resilience. In an increasingly connected world, cascading impacts are difficult to identify, but they will continue to occur without an appropriate ‘whole system’ understanding (of all the sources, pathways and receptors of risk; see e.g. Sayers et al., 2002).

### *A failure to recognise the critical services provided by natural infrastructure threatens biodiversity and social well-being*

Natural infrastructure (e.g. large-scale wetlands, coastal dunes, rivers, urban parks, green roofs) is legitimate critical infrastructure and increasingly recognised as essential for addressing climate risks (as ‘nature-based solutions’). This is a positive trend, but too little attention is paid to ensuring the resilience of services that natural infrastructure provides to people and nature. Without this awareness, natural infrastructure networks, which for instance support fish and bird migration, keep soils healthy, improve water quality and moderate flood risks, may fail to attract the necessary priority for action (see also Chapters 3, 7 and 14) , Monteiro and Ferreira (2020) and Opperman et al., 2017)). Repeated stress from wildfires, a lack of space to evolve as sea levels rise and squeeze inter-tidal areas (e.g. impacting the natural protection they provide), and poor development choices (e.g. roads, pipelines and dams) degrade and fragment natural infrastructure, further undermining the critical services they provide.

*Everyone assumes that someone else will take the lead in enhancing climate resilience*

There remains a lack of clear leadership and accountability for risk planning across government departments, agencies and private sector infrastructure providers, resulting in gaps and inconsistencies in risk management (Raju et al., 2022). Fragmented planning and investment hinder cooperation between sectors and reduce potential synergies. Cross-sectoral and public-private infrastructure planning offers opportunities for effective and efficient investment in climate resilience, but it is difficult to achieve without supportive governance structures and strategic leadership. Without this, addressing long-term climate change is often not considered part of an infrastructure provider's (public or private) responsibilities. Instead, resilience to flooding, for example, is left to government planners and agencies, and the climate resilience emerges from the energy mix and distribution networks determined by a free market. As a result, no one takes the lead, and climate risks escalate.

*Reactive or overly narrow approaches result in maladaptation*

Adaptation measures are not inherently good. Actions may be taken that protect some while neglecting others, or even exacerbating the risks they face. Choices taken today may 'lock in' future generations to increased risk or costly action (e.g. failing to consider coastal change when selecting the location of a new power plant or rail line). More details on maladaptation are given in the Chapters 19, 20 and 21.

## 15.5 Role of European policies

Ensuring resilience is primarily the responsibility of Member States but EU policies provide the framing. Managing climate-related risk within infrastructure systems (and more broadly) relies on appropriate use of a range of instruments, including guidance on assessment approaches, design guidance, spatial planning, regulations and policies at national and European levels. The European Programme for Critical Infrastructure Protection, for example, was launched in the 2000s with Directive 2008/114 as its central pillar. This directive identified and designated European critical infrastructures (ECIs) in the transport and energy sectors that would have significant cross-border impacts on at least two Member States if they were to experience disruptions. Meanwhile, Regulation 2019/941 in Risk Preparedness requires an assessment of the impact of extreme events on the security of energy supply. However, a review of the ECI Directive found the framework insufficient due to increasing interdependencies between critical infrastructure sectors and evolving risks, including those from climate change and terrorism. Furthermore, incoherences in the management of critical infrastructures could be found at the national scale, where 'similar types of entities are considered as critical in some Member States but not in others, and those which are identified as critical are subject to divergent requirements in different Member States' (EU, 2022a).

The Critical Entities Resilience (CER) Directive (2022/2557) on the resilience of critical entities will, upon entering into force in October 2024, replace the current directive. It broadens the understanding of what is considered vital. Critical entities are now understood as those providing essential services that are vital for the well-being of EU citizens and the proper functioning of the internal market. These entities need to be capable of preparing for, coping with, protecting against, responding to and recovering from natural hazards, terrorist threats, health emergencies or hybrid attacks.

The new directive sets out two new main measures. The first is the obligation for Member States, which are required to implement the directive and to adopt a 'strategy for enhancing the resilience of critical entities' by January 2026. This strategy must include a governance framework containing a description of the roles and responsibilities of the different authorities, critical entities and other parties involved in its implementation (Article 4). The second main measure is the need to carry out a risk assessment, including cross-border risks (accidents, disasters, public health emergencies such as pandemics, hybrid threats and other antagonistic threats, including terrorist offences, criminal infiltration and sabotage). This risk assessment must also be carried out by January 2026 and revised at least every four years. Its aim is to identify and provide a list of essential services and critical entities for each relevant sector highlighted in the directive's annex — namely energy, transport, banking, financial market infrastructure, health, drinking water, wastewater, digital infrastructure, public administration, space and production, processes, and food distribution. Attention must also be given to supply chains and foreign ownership of critical infrastructure. The CER Directive also requires that these critical entities carry out risk assessments of their own, take appropriate and proportionate technical, security and organisational measures to enhance their resilience, and notify about incidents. Member States must support the critical entities; the European Commission (EC) will also provide support, for example by providing an EU-level overview of cross-border and cross-sectoral risks to the provision of essential services.

In 2021, the EC released technical guidelines for ensuring that infrastructure funded from the EU funds is resilient to climate change (EC, 2021a). The guidelines have a wider coverage and encompass buildings (e.g. private homes, schools and industrial facilities); nature-based solutions (such as green roofs, walls, spaces and drainage systems); network infrastructure; waste management systems (e.g. incinerators and landfills); and other physical components. These guidelines provide a minimum framing, with national authorities responsible for interpretation and project preparation.

Progress is also being made in the regulation of individual infrastructure systems. For example, the updated guidelines for trans-European energy infrastructure specify that climate-related disruptions and climate adaptation measures need to be explicitly accounted for in the evaluation and implementation of projects. Similarly, revisions in the trans-European transport corridors TEN-T Regulation will strengthen focus on climate resilience and climate-proofing transport infrastructure (EC, 2021m). Specifically for inland waterway transport, the Naiades III action plan promotes climate resilience (EC, 2021f).

Thus, EU policies to deal with risks to critical infrastructures have improved recently and become more coherent following the COVID-19 pandemic and the Russian war of aggression against Ukraine. It seems that non-climatic drivers can sometimes help in advancing resilience or adaptation to climate change. Another non-climatic driver considered very important by the EU is cybersecurity threats, which are addressed in Directive (EU) 2022/2555, released at the same time as the CER Directive. These two directives have many elements in common, and need to be considered coherently and implemented together by Member States.



## 15.6 Aggregated risk assessment

This section presents the outcomes of the structured risk assessment for the major climate risks identified in this storyline. This assessment builds on information in this storyline, and possibly in other chapters of this report. The initial risk assessment was conducted by the authors of this storyline whereas the final assessment results reported here represent the consensus of the EUCRA risk review panel. Further methodological information is available in Annex 2.

The tables in this section present high-level assessments of the risks and associated policy readiness. They should be considered as indicative and will need to be advanced with more structured and complete analysis in further risk assessments. The risks set out in the tables do not attempt to be, and are not, comprehensive. For example, this first EUCRA does not include a systematic risk assessment for climate risks to transport on inland waterways.

The following major risks assessed in other chapters are also relevant for this storyline, but they are not presented here to avoid duplication:

- Risk of large cascading impacts across sectors originating from unprecedented forest disturbances (Chapter 13);
- Risk of energy disruption due to damage to energy transportation or storage infrastructure following coastal or inland flooding (Chapter 8);
- Risk of electricity disruption due to heat and drought impacts on energy production and peak demand (Chapter 8);
- Risks of water scarcity to population and economic sectors (Chapter 5);
- Risk of damage to infrastructure and buildings due to slow-onset climate change and extreme climate events (Chapter 9).

### Table 15.2 Risk assessment for threats of widespread disruption of coastal and marine transport

| **Illustrative risk pathway:** poorly adapted ports across the North Sea simultaneously experience an extreme North Sea surge combined with sea level rise, causing widespread disruption. The storm is prolonged with repeat events occurring over the following months. Transport infrastructure along the coast is disrupted. Repair times are long, exacerbating the impact of the climate event. | | | |
|---|---|---|---|
| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long-term (2081-2100)**<br>• high warming<br>• low warming |
| **Risk severity** | Limited | Substantial | Critical<br>Substantial |
| **Confidence** | **Medium** | **Medium** | **Medium** |
| **Risk ownership** | **Co-owned**<br>The EU and Member States both have legislative responsibilities relating to critical infrastructure and the services they provide.<br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Critical Entities Resilience Directive (2022/2557);<br>• Integrated maritime policy (2007/0575): EU sea basin strategies;<br>• Revised EU maritime security strategy and action plan;<br>• TEN-T Regulation (2013/1315);<br>• EC technical guidance on infrastructure resilience.<br>At the national level, the main relevant policies include those relating to:<br>• Transportation;<br>• Maritime affairs;<br>• Civil protection and emergency preparedness;<br>• National adaptation funding. | | |
| **Policy readiness** | **Medium** | | |
| **Policy horizon** | **Medium-term** | | |
| **Urgency to act** | Further investigation | | |

**Source**: EEA.

### Table 15.3 Risk assessment for threats of widespread disruption of land-based transport

| **Illustrative risk pathway:** intense heat buckles rail lines, causing widespread disruption as components fail. This may be aggravated by co-occurrence of prolonged drought periods leading to low water levels on inland waterways, which inhibits the transport of bulk goods for industry or agricultural products, resulting in a reduction of redundancy.<br>Floods and landslides continue to impact all modes of transport and other land-based infrastructures. Recovery is slow. | | | |
|---|---|---|---|
| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long-term (2081-2100)** |
| **Risk severity** | Limited | Substantial | Substantial |
| **Confidence** | **Medium** | **Medium** | **Medium** |
| **Risk ownership** | **Co-owned** | | |

| | |
|---|---|
| | The EU and Member States both have legislative responsibilities relating to critical infrastructure and the services they provide.<br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Critical Entities Resilience Directive (2022/2557);<br>• Proposed revision of the Energy Performance of Buildings and Energy Efficiency Directive (2021/0426);<br>• EU renovation wave (2020/662);<br>• TEN-T Regulation (2013/1315);<br>• EC technical guidance on infrastructure resilience;<br>• Union Civil Protection Mechanism;<br>• Energy Efficiency Directive (2023/1791).<br>At the national level, the main relevant policies include those relating to:<br>• Transportation;<br>• Spatial planning and infrastructure;<br>• Civil protection and emergency preparedness;<br>• National adaptation funding. |
| **Policy readiness** | **Medium** |
| **Policy horizon** | **Medium-term** |
| **Urgency to act** | **Further investigation** |

**Source**: EEA.

Key evidence underlying both risk assessments is described here:

**Risk severity:** a JRC study estimates that EAD for critical infrastructure across Europe was around EUR 3.4 billion in the 2000s and could have risen to EUR 9.3 billion by the 2020s, and could rise to EUR 19.6 billion by the 2050s, and EUR 37.0 billion per year by the 2080s (Forzieri et al., 2018). These are likely to be significant underestimates, with the true figures perhaps an order of magnitude higher. Transport infrastructure and services (land, air and sea) are among those affected.

**Confidence:** there is a growing (but partial) evidence base that relates climate and non-climate drivers to infrastructure failure (e.g. ports, transport, energy, water). Although an incomplete picture, it highlights issues, and that the pace of adaptation is too slow and long-term transformation too limited. Thus, confidence is assessed as medium, as future risks depend strongly on adaptation choices. Adaptation progress within the infrastructure sector at a European scale remains rather opaque.

**Policy readiness:** guidance on resilient design is available but this often remains focused at the component level rather than the system level (EC, 2021a). To make progress at a European scale, a better understanding of system-scale risks (including 'systems-of-systems' approaches) and the ability to adapt systems while require policy support are needed. This support is not currently fully in place (although various policies do exist to encourage system thinking), and hence policy readiness is assessed as medium-low.

# 16 Disruption of international supply chains

## 16.1 Key messages

- The EU's high level of engagement in global supply chains exposes it to significant risks from climate change impacts outside Europe. These include water stress and droughts affecting agriculture and water-intensive industries, and extreme weather events that can shut down factories and transport infrastructure.
- Climate-induced disruptions to key supply chains can create shortages of essential goods including food and medicines, drive up prices, slow or stop production within the EU and harm consumers. Moreover, they can have cascading effects across sectors and borders.
- Disruptions to the supply of critical raw materials and components could negatively affect EU business operations, export-driven growth and the energy transition.
- EU policies to strengthen supply chain resilience do not pay sufficient attention to climatic risks. The systemic, regional nature of these risks may make localised measures relatively ineffective.
- Some adaptation measures within the EU related to international supply chains can have spillover effects on those societal groups outside Europe particularly exposed or vulnerable to climate hazards.
- EU policies need to incentivise adaptation measures in the private sector, providing guidance to ensure they align with EU priorities at home and abroad, and creating appropriate monitoring and accountability mechanisms.



## 16.2 Introduction

The EU is not only the world's largest single market, but also one of the most engaged in global value chains (Szczepański, 2021). International trade has been central to the success of European economies, providing everything from animal feed, fuels, key pharmaceutical ingredients and raw materials to parts and components for goods manufactured within the EU.

As the COVID-19 pandemic and the Russian war of aggression against Ukraine have starkly shown, however, the EU's heavy import dependency also creates major vulnerabilities. Disruptions to key supply chains can create shortages, drive up prices, slow or stop production within the EU, and harm consumers.

Climate change is already making such disruptions more common. In recent years, droughts, heatwaves, wildfires, floods and major storms around the world have led to spikes in coffee prices; delayed deliveries of cars, electronics and other goods; and resulted in shortages of semiconductors, among other impacts. As the effects of climate change intensify, multiple supply chains may be affected at any given time, with serious economic, social and political implications.

This chapter examines major risks to the EU from global supply chain disruptions, including factors such as the vulnerability of trade partners, the geographic concentration of key sectors, the exposure of crucial transportation infrastructure, and prevailing business practices, as well as the potential for crises within the EU, geopolitical issues and policy choices to compound risks.

Starting from recent experience and drawing on research and data about the EU's and individual Member States' reliance on global supply chains, this chapter considers the potential for future shocks due to major crop failures and losses; disruptions in the supply of key pharmaceuticals or drug ingredients; damage to manufacturing operations and/or transportation infrastructure abroad; and compound risks. It concludes by assessing how well EU policies address these risks, and promote effective adaptation by the private sector, and identifying priorities for action.

## 16.3 Climate change and global supply chain risks today

Europe has sourced food and raw materials from other countries and regions for centuries. As complex global value chains have emerged in virtually every sector, most European countries have found their competitive edge close to the end of these chains, buying agricultural commodities, materials, parts and components, and transforming them into high-value-added goods and services.

After the COVID-19 pandemic shut down entire markets and severely disrupted trade, the European Council called for an analysis of strategic dependencies, particularly in sensitive value chains such as health, and proposed adaptive measures to reduce vulnerability to future disruptions. European Commission (EC) staff analysed more than 5,000 products and found 137 for which the EU is highly dependent on imports, mainly involving energy-intensive industries, health, and inputs and products needed to support the green and digital transformation (European Commission, 2021).

The impacts of climate change to date may seem modest compared with the COVID-19 pandemic or the energy crisis triggered by the Russian war of aggression against Ukraine, but, within the affected value chains, they have been significant – particularly in combination with non-climatic factors.



### *16.3.1 Agricultural commodities markets*

Europe produces a majority of its cereals and vegetables, but still imports large volumes of agricultural commodities, particularly for animal feed. A study for the EC found the EU's agri-food imports increased by 82% between 2005 and 2018, spanning a wide range of products (European Commission, 2022). Most notably, in 2018 the EU imported 82% of its soybeans and 77% of its soy meal.

The EU also depends on imports for widely consumed products grown in tropical regions, such as cocoa, coffee and bananas, and commodities like palm oil, beet and cane sugar (EEA, 2021d). Some of these imports come from just a few countries: 78% of the EU's palm oil comes from Malaysia and Indonesia, for instance, and the vast majority of its soy (beans and cake) comes from Brazil, the United States and Argentina. If one or more of these producers experiences a climate shock, the effects could reverberate across Europe.

In 2021, for example, Brazil's coffee plantations experienced a drought, then a devastating hard frost (Kurmelovs, 2021). Global wholesale coffee prices spiked, affecting consumers as well as commercial buyers. From May to November 2021 alone, the International Coffee Organization's composite indicator price rose by 45% amid record-high volatility in the market (ICO, 2021). Brazil's crop has since recovered, leading to more stable prices for Arabica beans, but the price of Robusta beans was expected to be 28% higher in 2023 than in 2022 due to unusually dry conditions in Indonesia ([13]) (Hunt, 2023).

When extreme weather affects multiple producers of a key commodity at once, the effects can be particularly severe. In 2023, the worst drought in 60 years cut Argentina's soy harvest by

([13]) In this case the culprit is El Niño, but climate change is also making droughts more frequent and more severe around the world.

more than half and also sharply reduced maize output (Sigal and Raszewski, 2023). US producers were in no position to fill the gap, as they faced their own historic drought (Plume, 2023) ([14]).

Simultaneous droughts and extreme heat also caused upheaval in global rice production, with Italy – which grows about half the EU's rice (Boffa, 2023) – sowing its smallest crop in a quarter-century in 2023, even as Thailand's crop was reduced by dry weather, California's by drought, and India's by damage from monsoon rains (Edmond, 2023). To protect domestic supplies, India imposed a ban on non-basmati white rice exports (Jadhav et al., 2023) ([15]). The country, which accounts for about 40% of global rice exports, had already banned exports of broken rice in 2022. Following the new ban, global rice prices went up by 15-25%, with particularly dire effects on poor people in South Asian and African countries (Sharma, 2023).

For Europe, the growing number and severity of crop failures and losses abroad translate into higher and more volatile food prices and costs for EU livestock producers and food industries. They also pose challenges in compensating for climate change impacts on European agriculture. As the rice example illustrates, droughts can occur on multiple continents at once, severely constraining supplies. The EU may be able to outbid other buyers – but at a moral (and geopolitical) cost.

### *16.3.2 Pharmaceutical supply chains*

Climate change also poses growing risks to Europe's supply of medications, which was already under strain even before the COVID-19 pandemic. Official EU data show a 20-fold increase in recorded medication drug shortages over the period 2000-2018 (European Parliament, 2020a), and an independent analysis found more than 22,000 recorded shortages in nine EU countries from 2018 to early 2023 (Zafeiropoulos et al., 2023).

Almost a third of European pharmacists responding to a survey in late 2022 reported shortages of at least 500 different medications in their respective countries in the previous year (PGEU, 2023). Cardiovascular drugs, nervous system medications and antibiotics were among the worst affected (Zafeiropoulos, et al., 2023), but a surge in respiratory infections in the winter that year also contributed to a shortage of antibiotics (European Medicines Agency, 2023).

There are a wide range of reasons behind these drug shortages, including disruptions of manufacturing processes, factory closures and supply chain bottlenecks (EU Member States, 2023). Europe has a bustling pharmaceutical industry, but it has specialised in drug discovery and in the production of high-value products, while increasingly importing active pharmaceutical ingredients (APIs), chemical raw materials and off-patent medicines from non-EU countries, particularly China and India (Raza et al., 2021; European Parliament, 2020a).

The European Parliament's 2020 Medicines Shortage Report shows 40% of medicinal end-products marketed in the EU originate in third countries, and 60-80% of active pharmaceutical ingredients are manufactured outside Europe, with 40% of supplies from China alone (European Parliament, 2020b). For example, all of Europe's simvastatin (a cardiovascular drug) comes from China and India; so does 90% of the prednisolone (a steroid) and 70% of amoxicillin (an antibiotic) (Raza et al., 2021).

With industry consolidation and increased outsourcing have come more frequent shortages, as the COVID-19 pandemic highlighted. The United States faces many of the same challenges as the EU, for similar reasons (Jewett, 2023). Geopolitical concerns are also significant, particularly

([14]) Farmers and ranchers in the western, south-western and central United States also struggled with severe droughts in 2021, with 74% of respondents to a survey by the American Farm Bureau Federation reporting yield losses, averaging 38%; see Munch (2022).

([15]) Just weeks later, to cope with reduced sugar production due to drought, India banned sugar exports (Jadhav and Bhardwaj, 2023).

around China (Martuscelli, 2023). Natural hazards, including climate change impacts, are affecting these supply chains, too.

A case in point is Hurricane Maria in 2017. Puerto Rico is home to 49 pharmaceutical and medical device manufacturing plants, supplying about 10% of all medications used in the United States (Lawrence et al., 2020). An in-depth analysis found multiple factors coalesced to create a crisis, including the severity of the storm and the inadequacy of buildings and infrastructure, but also the concentration of the supply and an influenza outbreak on the mainland. About half of US hospitals suffered shortages of saline solution – an essential item. The storm also affected other countries, as Puerto Rico produced a quarter of US pharmaceutical exports at the time (Bomey, 2017). In 2021 the share was 19%, but Puerto Rico is still the country's top drug manufacturing hub (BLS, 2021).

A similar disaster affecting a major supplier to the EU could be just as disruptive – particularly if it coincides with other supply problems or with a disease outbreak. However, the ongoing EU policy discourse on addressing medical shortages ignores climate change (for example, see European Commission, 2023, which does not mention it even once).

### *16.3.3 Critical raw materials and components*

Europe's manufacturing sector employs over 29 million people (Eurostat, 2023a), many of them in industries that depend on critical raw materials and technological components made outside the EU (EC, 2023l). As with medications, production is highly concentrated, and climate change is a growing concern, since many suppliers are situated in high-risk areas (XDI, 2023).

The Taiwan Semiconductor Manufacturing Co. (TSMC), for example, holds more than half the global market for contract chip production (Ryan, 2022). Other Taiwanese companies hold a further 10%. It is a water-intensive industry, with TSMC's facilities alone using 99,000 tonnes of water per day (Li, 2023).

So when Taiwan was beset by a severe drought in 2021 – amid a global shortage due to pandemic-related lockdowns and volatile demand – the impact was felt around the world (Mohammad et al., 2022). Manufacturing and agriculture across the island were disrupted; TSMC had to rent water tanks and drill wells to cope (Li, 2023). Worst of all, the drought has persisted and typhoons have been absent. With reservoirs depleted, Taiwan has struggled to balance demands for scarce water.

For strategic reasons, Taiwan has prioritised chipmakers (Feng, 2023), but the ongoing water shortage highlights the growing risks to the technology sector from climate change. Water stress can affect manufacturers directly, as in this case, or indirectly, by decreasing water availability for hydropower production or for cooling in thermal-electric power plants. Extreme heat can also disrupt manufacturing operations, and spikes in electricity demand for cooling can strain power grids. All these factors can affect facilities producing critical raw materials and components used by businesses in Europe and across the globe.

In 2022, large parts of China suffered the worst heatwave in 60 years, as well as a severe drought that reduced hydropower production. As a result, the authorities in the province of Sichuan, a key manufacturing hub for the electronic and other tech industries, were compelled to ration industrial electricity consumption. Factories were ordered to close for 6 days, which caused disruptions to the operations of many multinational corporations, including Toyota, Apple supplier Foxconn and Intel (He, 2022). Sichuan is also a lithium and battery production hub, and lithium output was reduced by an estimated 1,200 tonnes during the closure (Agence France-Presse, 2022).

Increasingly hot and dry conditions in East Asia matter greatly to European industries and jobs because the EU imports some critical raw materials from just a few countries. For instance, the EU depends on China alone for around 98% of its rare earth minerals, which are mainly sourced from a few concentrated mining regions **(EC, 2023s)**. A study of nine metals and minerals that are important to Germany's economy found that mining operations in all the source countries were exposed to climate hazards, highlighting droughts and destructive floods in particular (Rüttinger et al., 2020).

Typhoons, floods and other disasters can also severely disrupt the production of key components. The 2011 floods in Thailand have been widely studied as an example of climate vulnerabilities. Seven industrial parks hosting 804 companies were inundated, and it took 33-62 days to discharge all the water (Haraguchi and Lall, 2015). Thailand was a top producer of hard disk drives and, in Europe, the electronics sector saw the cost of drives rise by 80-190%. Japanese automakers were also hard hit. Factories were slow to return to full production, and global industrial output was reduced by an estimated 2.5%.

### *16.3.4 Global transport infrastructure*

Extreme weather exacerbated by climate change not only disrupts manufacturing and the sourcing of critical raw materials; it can also destroy transport infrastructure or render it inaccessible or unusable. A 2019 study found that about 27% of global road and railway assets are exposed to at least one natural hazard and estimated direct damage to those assets – mainly from floods – at USD 3.1-22 billion (Koks et al., 2019c). A 2023 study of 1,340 ports worldwide found 86% were exposed to more than three natural hazards, and USD 63.1 billion of trade is at risk every year.

Such disruptions are increasingly common. In July 2021, for instance, record rainfall in central China caused severe floods. Zhengzhou, the capital of Henan province, is a major transportation, logistics and industry hub, and the floods stalled the delivery of goods and materials by rail (Patton, 2021) ([16]).

In December 2021, a typhoon caused the worst floods on record in Malaysia, severely affecting Port Klang, one of the world's largest shipping container ports (Bernama, 2021). Operations at the port's terminals and at nearby warehouses and container depots were disrupted, and many employees could not get to work. Vessel berthing was also delayed due to inclement weather, and the port authority warned that deliveries would be delayed by several days (Lim, 2021) ([17]).

Droughts can have severe impacts on transport as well, as seen on the Panama Canal, through which 40% of US shipping container traffic travels every year, carrying about USD 270 billion in cargo (LaRocco, 2023; Sengupta, 2023). Moving ships through the canal's locks uses hundreds of millions of litres of freshwater per ship, sourced from nearby lakes. When a drought in 2023 greatly limited water availability, ship traffic had to be reduced, and individual ships had to reduce their loads by as much as 40% to avoid hitting the bottom.

While the traffic congestion at the Panama Canal has not significantly affected the EU (Kaufmann, 2023), it has increased the relative appeal of the Suez Canal to global shipping companies (LaRocco, 2023), which could ultimately affect traffic there. Yet the Suez Canal, which was blocked for 6 days in 2021 by a large ship that ran aground in an incident that was not climate-related, has been found to have climate vulnerabilities of its own (Barnes et al., 2022). A 2022 analysis found growing coastal inundation risk, particularly in the northern port infrastructure, and increasing risk of extreme heat events.

Climate change is also making inland waterways less reliable, as highlighted by the shutdown of goods transport for 132 days on the Rhine in 2018 due to low water levels (Kaufmann, 2019). Fuel prices rose, steel giant ThyssenKrupp produced 200,000 fewer tonnes of steel and Germany's GDP was reduced by an estimated 0.2%. Companies in the region saw their transport

([16]) The floods also curtailed production of important raw materials, such as aluminium and lead (Zhou, 2021).

([17]) As in China, the floods also directly affected manufacturers, particularly semiconductor producers.

costs rise by as much as 50%, and a majority struggled to keep up their supply chains (Wrede, 2022).

Just 4 years later, in the summer of 2022, another drought forced barges on the Rhine to load only 30-40% of their capacity to avoid running aground (Wagner and Sterling, 2022). Water levels in Kaub, the shallowest part of the river, dropped to just 48cm, a third of the level required for fully loaded ships. Freight charges for a liquid tanker barge rose to about EUR 110 per tonne in August, from around EUR 20 per tonne in June. Economists estimated the potential impact on GDP at 0.25% or more.

## 16.4 International supply chain risks in a heating climate

The Intergovernmental Panel on Climate Change's Sixth Assessment Report makes it clear there is strong evidence that extreme weather events are already increasing around the world due to climate change – and those effects will worsen as global temperatures continue to rise (IPCC, 2023b). In particular, it warns that heat extremes will keep rising; heavy precipitation and floods will intensify and become more frequent; droughts may become more frequent and severe; tropical cyclones may intensify; and compound heatwaves and droughts will likely become more frequent.

Europe is considered far less vulnerable than less developed regions, but it still faces both the direct risks discussed throughout this report and the indirect impacts transmitted through global supply chains. Business operations and commodity flows around the world will be increasingly disrupted, and that will affect the delivery of materials, components and goods to Europe from climate-vulnerable countries and regions. In fact, climate risk assessments in the UK, Germany, Switzerland and Sweden have found the cross-border impacts of climate change to be at least as large as domestic impacts (DEFRA, 2023; Lager and Benzie, 2022; Peter et al., 2021; INFRAS et al., 2007).

The EEA published an assessment in 2016, which concluded that Europe is particularly vulnerable to the economic effects of cross-border climate impacts through its trade linkages and dependency on global value chains, and that these impacts are expected to increase in the coming decades (European Environment Agency, 2017). European countries in the Mediterranean region were found to be particularly vulnerable to disruptions to agriculture supply chains, because of their relatively high dependency on food imports from outside Europe and the prominence of the food sector in their domestic economies. Small, open and highly developed European economies, meanwhile, were identified as being particularly susceptible to disruptions in access to critical raw materials caused by the effects of climatic hazards on manufacturing industries and transport infrastructure.

The EU's Joint Research Centre (JRC) recently projected the economic fallout for the EU from the cross-border impacts of climate change via trade at EUR 10.32 billion per year in a 2°C warming scenario and EUR 27.38 billion in a 3°C scenario. However, these projections are likely to underestimate the cumulative impacts of supply chain disruptions, as models tend to be conservative and do not sufficiently account for the interplay between multiple climatic and non-climatic drivers, nor the cascading effects of such disruptions. Moreover, climate change impacts have come sooner and been more severe in recent years than anticipated by most climate models.

### *16.4.1 Agricultural commodities markets*

On a global scale, a recent analysis found that between 1980 and 2019 average crop yield potentials for maize declined by 5.6%, and for soybeans, by 4.8% (Watts et al., 2021b) ([18]). Droughts and heatwaves have also caused major yield reductions and crop losses – and by 2050 nearly 40%, and potentially as much as half, of the world's cropland could experience 3 months or more per year of severe drought (Arnell et al., 2019) ([19]).

The probability of a 10% or greater maize crop yield loss in the top four producing countries (United States, China, Brazil, Argentina) at some point during the 2040s was recently estimated at just under 50% (Tigchelaar et al., 2018). Multiple studies looking at different crops and timescales offer similar warnings, even for the coming decade (Chatzopoulos et al., 2021). One stressed the risk that record-breaking heat, combined with drought, could hit wheat crops in US and Chinese breadbasket regions at once (Coughlan de Perez et al., 2023). This could send bread prices soaring, particularly if it coincides with non-climatic factors affecting other suppliers – such as the Russian war of aggression against Ukraine.

The 2007-2008 global food crisis, triggered by a mix of climatic and non-climatic factors, offered a preview of what the future might hold, if supplies of staple foods are constrained and prices rise sharply: food insecurity and hunger, social unrest and emergency measures such as export bans (Quiggin et al., 2021; Wright, 2011).

As noted in Section 17.3 the EU's relative wealth and buying power provide significant protection when agricultural commodity prices spike. Even if climate change impacts sharply reduced yields of a staple crop in Europe and abroad, as happened with rice in 2023, Europeans are recognised to be at far less risk of hunger than people in lower-income regions, such as Asia and Africa (Bezner Kerr et al., 2022d).

Still, with only the current tools in place, a catastrophic crop failure in two or three countries that produce wheat or another food staple could create a severe enough crisis, and drive prices up enough, that lower-income Europeans might struggle to feed their families. Meanwhile, if a key animal fodder crop such as soy became scarce, the EU's livestock sector could be severely affected. International humanitarian crises might also ensue, as countries in Africa, for instance, where food insecurity is already rampant, could be pushed into famine.

Importantly, non-climatic drivers could play significant roles in the unfolding of food crises, as several countries have shifted towards nationalism in their politics, and great power relations, such as between China and the United States and between Europe and Russia, have deteriorated. If these trends continue, they could increase the EU's vulnerability to global food supply chain risks.

Even in the absence of acute crises, the EU is likely to see food prices rise and supplies of individual commodities become less reliable. For example, a recent analysis projected a global yield reduction of 58.5% by 2071-2099 relative to 1980-2010 for sugarcane, 45.2% for Arabica coffee, 27% for maize, 8.1% for rice, and 7.2% for soy (Adams et al., 2021b). A key factor in those projections was that the crops were mainly sourced from a small number of countries, such as Brazil, China, the United States and Thailand.

Another recent European study, which looked specifically at climate risks for the EU's reliance on third countries' agri-food supply chains, concluded that more than 44% of the EU's agricultural imports will become highly vulnerable to droughts already in the next 20-30 years, and drought severity in production locations of the EU's agricultural imports will rise by 35% in 2050 (Ercin et al., 2021).



([18]) This measure is tied to crop growth duration and declines with rising temperatures. The analysis also found the global crop yield potential for winter wheat declined by 2.1%, and for rice, by 1.8%.

([19]) For this and the following projection, see also the discussion in Quiggin et al. (2021).

A recent assessment of the Nordic countries' transboundary climate risks showed that although they largely trade with relatively climate-resilient countries, they are still exposed to global supply chain disruptions (Berninger et al., 2022). These might affect inputs to the region's agricultural system (maize and soy for animal feed) and food industries and consumption (rice, sugarcane and coffee). If left unaddressed, the effects could lead to increased costs and reduced availability of some products. Unfortunately, similar regional assessments have not been conducted for other European regions thus far.

### *16.4.2 Pharmaceutical supply chains*

Food is a necessity, but no single food item is essential to Europeans' survival. Medications, by contrast, are less interchangeable: specific drugs or classes of drugs are needed to treat acute conditions, prevent infections and keep people with chronic illnesses healthy – or even alive (WHO, 2023c). As noted earlier, EU policymakers are already aware of the severity of drug shortage risks, though further action is still needed (EU Member States, 2023). What is less understood is how climate change could exacerbate those risks.

As a 2021 report to the European Parliament noted, 'where a particular country or region is an important production hub for certain products sourced by companies from many other countries, as is the case for APIs in China, the economic effects of this single country being hit by an external shock may be felt internationally' (Raza et al., 2021).

Without strategic efforts to not only diversify the EU's pharmaceutical supply chains, but also make them more climate-resilient, it is highly likely that as climate shocks become more severe, one or more will shut down production of an essential drug or API, or hinder its delivery to Europe. China, for instance, which accounts for 40% of global API production (Payne, 2023) and 42% of global antibiotic exports (Armstrong, 2022), is already experiencing water stress (Collins and Reddy, 2022), which climate change is expected to worsen. Sea level rise and coastal storms also pose serious threats to China's coastal economic centres and ports (Gan, 2023) ([20]).

The impacts of droughts and other weather extremes in China could also affect India – the next-largest antibiotic exporter – as the country relies heavily on China's APIs for its own antibiotic production, for instance (Bjerke, 2022). India faces rapidly escalating climate hazards as well, so the same concerns that arise with China also apply there. Moreover, India is the world's top vaccine manufacturer, accounting for about three fifths of global production (Invest India, 2023). A climate-related disruption to India's vaccine industry, or another pandemic that affected India at the same time as the EU, could result in a critical vaccine shortage.

Overall, global pharmaceutical supply chains are particularly vulnerable to climatic hazards. A recent assessment by the WWF and AstraZeneca of 5,273 pharmaceutical manufacturing sites worldwide found that 89% are already exposed to medium to very high flood risks, and a quarter are exposed to high or very high water scarcity risks (Dobson, 2021). The analysis also showed that 55% of sites are currently exposed to very high water quality risks, which could increase to 75% by 2050 in a business-as-usual climate scenario.

The risk of antibiotic and vaccine shortages is of particular concern given that, as discussed in Chapter 14, climate change is expected to drive the proliferation of both new and existing infectious diseases. At the same time, chronic diseases, which affected 35% of Europeans as of 2021 (EUROSTAT, 2023c), are becoming more prevalent as Europe's population grows older, more people live to an advanced age, and obesity rises (EFPIA, 2022). For example, 33 million people in the EU were diabetics as of 2010, and the number is rising (EC, 2023o) ([21]).

([20]) For a comprehensive overview of climate risks to China and other Asian countries, see Shaw et al. (2022).

([21]) For the broader European region, including Russia and other non-EU countries, the International Diabetes Federation projects a 13% rise in the number of diagnosed diabetics from 2021 to 2045 (IDF, 2021).

The likelihood and severity of drug supply shortage crises because of climate-induced disruption to pharmaceutical supply chains could also be exacerbated by geopolitical conflict, such as tensions between the West and China over Taiwan's sovereignty. In such circumstances, China could perhaps be more inclined to resort to export controls of drugs and APIs, which would increase prices of these vital drugs and reduce their availability, to a catastrophic end for European healthcare services.

### 16.4.3 Critical raw materials and components

The EU leadership is keenly aware of the need to secure Europe's supplies of critical raw materials and components. A JRC analysis that underpins the Critical Raw Materials Act assessed supply chain dependencies for 15 key technologies and found an overwhelming reliance on imports, particularly for raw materials (Carrara et al., 2023). It also projected dramatic increases in EU demand for those materials, with lithium demand for electric vehicle batteries projected to rise 11-fold by 2030 and 21-fold by 2050 in a high-demand scenario. EU demand for neodymium and dysprosium (two key rare earths), nickel and graphite was projected to grow by factors of 6, 7, 16 and 26, respectively.

The JRC analysis raised several major concerns, including geopolitical risks, growing global competition for critical materials and components, as well as cross-sector competition, as rare earths, for instance, are used for wind turbine generators, electric vehicles and digital technologies alike. One of the biggest issues raised with most of the technologies, however, was the concentration of supplies in just a few countries, particularly China, which dominates some supply chains entirely.

For example, the JRC report shows that in 2020 China had 60% of global production capacity for refined cobalt, 93% for graphite active materials, 69% for refined lithium, 79% for battery-grade manganese and 63% for nickel sulphate – key materials for lithium ion batteries. Supply chains for processed materials, components and assemblies are also concentrated in Asia, dominated by Chinese firms. Other materials and technologies were found to be more geographically distributed, but many of the countries of origin have serious social, environmental and sometimes political challenges of their own – including the Democratic Republic of the Congo, South Africa, Russia, Bolivia and Chile.

What the JRC study did not delve into is that the concentration of these supply chains also exposes the EU to the climate risks faced by the exporting countries, and many face acute and escalating risks. For instance, the mining regions of southern China already experience some of the strongest rainfall in the world, with pluvial flooding almost every year, and extreme precipitation events could double by 2030, according to some private sector analyses (Woetzel et al., 2020). This means that it is very likely, particularly as climate change impacts intensify, that storm and flood damage could severely disrupt the flow of critical minerals from China, and the EU might have no alternative source to turn to.

Bottlenecks elsewhere in the supply chains, due to both climatic and non-climatic drivers, exacerbate the risks. As noted earlier, the persistent droughts in Taiwan have put severe water stress on global supply chains for semiconductors in recent years – and semiconductors also require rare earths. The compound effects of climate-related disruptions on both rare earth metal mining and semiconductor production within a short period of time could seriously harm the EU economy.

The EU's high-tech sector, which exported a record EUR 446.1 billion in products in 2022 (EUROSTAT, 2023a), is deeply vulnerable to these disruptions, as the 2011 floods in Thailand showed. As Europe's green transition accelerates and global demand for relevant materials and components increases, crucial green technologies could also be adversely affected, hindering the transition and undermining the EU's competitiveness.

Another factor to consider, along with the potential for extreme weather events to disrupt production, is the risk that the mines and industries that are supplying the EU could exacerbate the climate vulnerabilities of local communities. For example, lithium production is concentrated in water-scarce areas and is also associated with extensive pollution (Maxwell et al., 2022). Failing to address local impacts could result in future supplies being disrupted by social unrest and humanitarian crises. However, ensuring the social and environmental sustainability of the EU's imports is a complex challenge in itself (see e.g. Melin et al., 2021).

### 16.4.4 Global transport infrastructure

The discussion of future climate risks from global supply chains has up to now focused mainly on climate shocks affecting the production of commodities, goods and materials. Yet, as also highlighted by Chapter 15, climate change impacts are likely to increasingly hinder the delivery of all those things to their destinations in Europe, with impacts across all sectors.

Ships deliver more than 80% of global trade, so disruptions to port operations and shipping routes can significantly affect supply chains (UNCTAD, 2023). Already, sea level rise and increasingly severe coastal storms are putting stress on the maritime industry, and those impacts are expected to intensify with future climate change, particularly in high-emission scenarios. Extreme weather events (and, as the Panama Canal crisis showed, even droughts) can shut down ports and other shipping facilities, creating choke points that delay delivery and increase costs. With ageing fleets navigating ever-rougher seas, and coastal disasters becoming more common, a recent industry report also warned that some vessels and goods will become uninsurable, making shipping riskier and more expensive (Economist Impact, 2023b).

Even in Europe, port infrastructure is at heightened risk due to sea level rise and worsening storms, and ports in key exporting countries are even more imperilled. A recent multi-hazard risk assessment of 1,340 large ports around the world found 86% were exposed to more than three climate and other natural hazards, and 40% were exposed to extreme maritime conditions that could disrupt their operational capabilities (Verschuur et al., 2023). Some of the places with particularly exposed ports included Japan, Taiwan, mainland China and the United States. Several countries have created special economic zones and industrial hubs near major ports, so climate shocks in those coastal areas affect both production and freight.

Land-based transport infrastructure is also at significant risk from climate change, especially from floods and landslides, but also increasingly from extreme heat, wildfires and other impacts (Dodman et al., 2022c). An analysis by researchers at the World Bank, the JRC and other institutions found that about 27% of the world's road and railway assets were exposed to one or more natural hazards, including from climate change (Koks et al., 2019c). Assets in Japan and China had the greatest multi-hazard exposure. Surface and river floods were identified as the costliest hazards. In some countries, annual economic damage was projected to be as high as 0.5-1% of GDP, on the order of national transport budgets.

### 16.4.5 Risks from business practices and policy interventions

Businesses, particularly major corporations, are increasingly assessing and disclosing climate risks to their operations, though there is extensive evidence of an adaptation deficit, particularly when it comes to supply chains. For instance, PricewaterhouseCoopers' August 2023 survey of business leaders found just 23% were contingency planning for climate-related disruptions within the next 12-18 months, and only 18% perceived climate change as a serious threat (PwC, 2023). Some of the main barriers to business-led adaptation that have been identified include lack of access to, and limitations of, risk data, lack of human resources and expertise, relatively short timeframes for risk management, and the lack of incentives for actions in the current policy landscape (Cote & Mikaelsson, 2023; World Economic Forum, 2023).

Most corporate reporting on climate has focused on emissions, but the recommendations of the Task Force on Climate-Related Financial Disclosures (TCFD, 2023), which have also been adopted by CDP, are leading more companies to report on climate risks and their management, including in supply chains. This is a crucial first step towards adaptation. The challenge now is to ensure that the strategies pursued by businesses do not simply shift risks and exacerbate others' vulnerabilities. For example, companies may just stop buying from suppliers that are highly exposed to climate risks (Pankratz and Schiller, 2022), adversely affecting local economies and leaving people poorer and less resilient to shocks. Some companies may impose a risk premium on suppliers, or require them to shoulder the cost of adaptation, as has happened with sustainability measures (Ponte, 2020). Either of those actions could deepen the suppliers' own vulnerability. If those suppliers are themselves buying from smaller, even more vulnerable actors – as is common in some agricultural supply chains – the very poorest people may end up bearing the greatest burden (Vigil and Kim, 2023).

Another common form of maladaptation is hoarding resources, such as purchasing water rights in a water-stressed region (Stanley-Becker et al., 2023) or building a dam that leaves people downstream without enough water. Protective infrastructure like seawalls may shift climate risks as well, exposing nearby coastal areas to even greater hazards. By collaborating with their suppliers and, as relevant, also with policymakers and civil society, companies can instead develop mutually beneficial solutions, and thus contribute to more socially just and sustainable results overall – just resilience (Dzebo et al., 2022).

Lastly, it is important to note that governments can also engage in maladaptation, through export bans that prevent other countries from accessing resources they need, through infrastructure investments and through various policy interventions. International cooperation and diplomacy will play a crucial role in addressing these risks as climate change puts more pressure on governments.

## 16.5 Role of EU policies

Trade policy and relationships with countries outside the EU is an exclusive competence of the EU and thus under the legislative remit of the European Commission and other EU institutions. The EC is therefore both responsible for, and well positioned to take actions to, manage the risks from climate change on global supply chains that are channelled both through internal commodity flows and international trade linkages.

The EU has recognised its strategic dependence on some foreign inputs for quite some time, taking action to increase its autonomy through the EC's raw materials initiative, for instance (EC, 2008). The supply chain disruptions caused by the COVID-19 pandemic added momentum to these efforts. The EU's 2020 Trade Policy Review highlights supply chain resilience as a key pillar of strategic autonomy (Cagnin et al., 2021). The Critical Raw Materials Act is a major step in that direction, with ambitious targets up to 2030 (EC, 2023h).

The EU has begun to introduce policy measures aimed at improving transparency and broader risk management of supply chains (Eggert and Hartmann, 2022). The Corporate Sustainability Reporting Directive (2022/2464/EU), introduced alongside the revised European Sustainability Reporting Standards (2023/2772/EU), which will enter into force from 2024, will require companies, among others, to disclose the physical climate risks in their own operations and value chain, an estimation of the monetary amount of assets and business activities at risk, as well as their adaptation policies and actions.

Yet EU policies have largely focused on sustainability at the expense of adaptation. For instance, the proposed Corporate Sustainability Due Diligence Directive, if adopted, would make important progress on addressing environmental impacts and human rights violations, but it does not require that companies assess and manage physical climate risks (European Parliament, 2023).

The European Commission has recently established the publicly accessible SCAN monitoring mechanism, which assesses supply chain distress and systemic risks stemming from foreign dependencies for raw materials. However, while Supply Chain Alert Notification (SCAN) enables the monitoring of geographic concentration of supplies by country, it does not take into account climate risks that could affect multiple bottlenecks at the same time (Arjona et al., 2023).

The EU has also introduced policy measures to improve the resilience of supply chains in key sectors. For example, the EC recently launched the European Food Security Crisis preparedness and response mechanism (EFSCM) as a key pillar of the EU's food contingency plan, under the farm to fork strategy (EC, 2021c). Established in response to the supply chain shocks from the COVID-19 pandemic and the Russian war of aggression against Ukraine, the EFSCM aims to strengthen public-private sector cooperation to improve food market and supply chain monitoring and better manage food price and supply volatility. The revised EU pharmaceutical strategy and proposed revision of the EU's pharmaceutical legislation also includes provisions regarding evaluation of vulnerabilities of pharmaceutical supply chains and on the establishment of shortage prevention plans (EC, 2020b). Health Emergency Preparedness Response Authority (HERA) has launched the EU FAB network, with the aim to reserve sufficient and agile manufacturing capacities for different vaccine types that can be swiftly mobilised in case of a public health emergency.

Taken together, these no- and low-regret measures are likely to enhance supply chain resilience. However, the EU has yet not produced any economy-wide stress test to assess the exposure of the EU's supply chains to climate-related risks. Moreover, the policy levers being used are mainly based on traditional risk management principles: monitoring systems, emergency reserves, supply chain diversification, and more local production (onshoring). These measures may be effective in addressing non-climatic risks, but they will not suffice in a world where climate shocks affect multiple locations at once, including Europe's own production centres and logistics hubs.

Moreover, none of the EU policies to date explicitly address the underinvestment of businesses in climate adaptation in their supply chains, or the need to ensure that social risks are incorporated into the design of adaptation measures adopted by businesses. That is an important gap to close; in fact, multinational corporations have been calling on governments to more proactively create an enabling environment to promote business-led adaptation, through legislation and market incentives (Dzebo et al., 2022).

The EU should consider embedding additional requirements for large businesses and other relevant organisations to adapt to physical climate risks into the existing Corporate Sustainability Due Diligence Directive framework, aligned with Corporate Sustainability Reporting Directive (CSRD)no and European Sustainability Reporting Standards (ESRS) reporting requirements. It can also establish initiatives to help smaller businesses and other organisations compile and access relevant climate risk and scenario data, to support operational risk management and adaptation planning among smaller businesses and other key organisations.

The EU should also leverage international trade policy, international collaboration and overseas programmes to increase investment and implementation of adaptation to minimise the exposure of global supply chains to physical climate impacts, as well as to avoid maladaptation by governments and businesses. Such efforts and investments should not be viewed as philanthropic endeavours, but rather strategic investment in the EU's own interest.

On the public sector side, the EU should also embed physical climate risks into public procurement systems at both the EU and Member State levels, through the creation of criteria and standards for adaptation, alongside appropriate metrics and targets. With public procurement accounting for 15% of the EU's GDP, such measures could be effective tools to create market incentives for business adaptation. The EU should also bolster efforts to support capacity building and access to finance for small and medium-sized enterprises.

## 16.6 Aggregated risk assessment

This section presents the outcomes of the structured risk assessment for the major climate risks identified in this storyline. This assessment builds on information in this storyline, and possibly in other chapters of this report. The initial risk assessment was conducted by the authors of this storyline whereas the final assessment results reported here represent the consensus of the EUCRA risk review panel. Note that the risk assessment for all major risks in this storyline showed considerable heterogeneity across evaluators. Further methodological information is available in Annex 2.

**Table 16.1 Risk assessment for the risk to food security in Europe from climate impacts on agricultural production and supply chains outside Europe**

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)**<br>• **high warming**<br>• **low warming** |
|---|---|---|---|
| **Risk severity** | **Substantial**<br>European food prices can increase due to climate change impacts on non-European food production and/or trade disruptions. Higher food prices may reduce food affordability for low-income households. As long as climate impacts are mixed globally, the risk for such price signals is moderate when markets are functioning. | **Critical**<br>International demand will increase with rising and wealthier populations, while (sub)tropical food production is projected to increasingly experience climate-induced damage to crops. Global food markets are affected more regularly and strongly, trickling down to European markets and consumer prices. | **Catastrophic**<br>Risk severity will depend on the transformation of food systems, trade and societal developments in response to climatic and non-climatic drivers, which are difficult to quantify.<br>**Critical**<br>See mid-term |
| **Confidence** | **Medium**<br>Trade disruptions are difficult to predict, average crop production may be outside the historical variability in many regions, while increasing demand for food items and more animal-based food has a high likelihood. | **Medium**<br>Global population is very likely to increase, associated with higher food demand. Climate impacts intensify but are region-specific and it is difficult to project future farming systems outside Europe. Moderate-to-severe food insecurity is increasing substantially for socio-economic pathways with higher societal challenges and increasing inequality. | **Low**<br>Population development is SSP-specific, so is overall food demand. Climate impacts differ strongly between greenhouse gas trajectories (i.e. climate mitigation efforts), and future farming systems and trade patterns are very difficult to project. |
| **Risk ownership** | **EU**<br>The EU should play the leading role in managing the risk of climate-related disruptions of supply chains, including for food and feed products, as trade policy falls under its exclusive competence. In addition, some national policies could play an important supplementary role.<br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Corporate Sustainability Reporting Directive (2022/2464)<br>• Corporate Sustainability Due Diligence Directive (2019/1937)<br>• Farm to fork strategy (2020/381) | | |

| | |
|---|---|
| | • SCAN monitoring tool<br>• Fund for European Aid to the Most Deprived<br>• European Food Security Crisis preparedness and response Mechanism<br>At the national level, the main policies of relevance include those relating to:<br>• Agriculture<br>• Public procurement<br>• Industry<br>• National adaptation funding |
| **Policy readiness** | **Medium**<br>Although the EU has put in place policies and measures to better monitor and respond to potential shocks and disruptions to agricultural supply chains, there have not been any policies implemented to proactively improve supply chains' resilience via adaptation, to minimise the likelihood and severity of such disruptions. |
| **Policy horizon** | **Short term** |
| **Urgency to act** | **Further investigation**<br>The urgency classification results from the risk assessment for the near-term future, because this risk can be managed with a short policy horizon. |

**Source**: EEA.

### Table 16.2 Risk assessment for risk of public health crises due to interrupted pharmaceutical supply chains caused by extreme weather events outside Europe.

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)**<br>• **high warming**<br>• **low warming** |
|---|---|---|---|
| **Risk severity** | **Substantial**<br>Key pharmaceutical manufacturing hubs, from where the EU imports many essential medicines, are already climate vulnerable, with large portions of production sites exposed to risks of flooding and water stress. | **Critical**<br>The limited evidence available suggests that a growing and substantial share of pharmaceutical manufacturing sites worldwide will face high risk exposure to climate impacts by 2050 under the business-as-usual scenario. | **Catastrophic**<br>Risk severity will depend on the transformation of medicine production, trade and societal developments in response to climatic and non-climatic drivers, which are difficult to quantify.<br>**Critical**<br>See mid-term |
| **Confidence** | **Medium**<br>Aside from evidence of the risk to public health underpinned by the current frailty of global pharmaceutical supply chains, there are consistent forecasts of increased impacts of weather extremes in main export countries, and on key transport infrastructure, as well as limited systematic assessment of climate-related water risks for a significant share of manufacturing hubs globally. | **Low**<br>Numerous analyses forecast growing frequency and severity of climate impacts in key manufacturing hubs for this period, while population growth and climate change will drive heightened demand for many drugs, including antibiotics and vaccines. | **Low**<br>Population development is SSP-specific, which will equally influence the pressures on the healthcare system. Climate impacts also differ strongly between greenhouse gas trajectories, which will bring about starkly different scenarios relating to the health impacts of climate change and the ability of the pharmaceutical industry to help manage some of these effects. |
| **Risk ownership** | **EU**<br>The EU should play the leading role in managing the risk of climate-related disruptions of supply chains, including for pharmaceuticals, as trade policy falls under its exclusive competence. In addition, some national policies could play an important supplementary role.<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Corporate Sustainability Reporting Directive (2022/2464)<br>• Corporate Sustainability Due Diligence Directive (2019/1937) | | |

| | |
|---|---|
| | • EU pharmaceutical strategy (2020/761)<br>• Proposed revisions of the EU pharmaceutical legislation (2023/0131)<br>• EU FAB network<br>• Supply Chain Directive<br>At the national level, the main policies of relevance include those relating to:<br>• Healthcare<br>• Public procurement<br>• Industry<br>• National adaptation funding |
| **Policy readiness** | **Medium**<br>The EU's pharmaceutical strategy recognises the generic risk of supply chain disruptions and medicine shortages, but the EU has failed to implement any policies to strengthen resilience of pharmaceutical supply chains, via supply diversification or adaptation. |
| **Policy horizon** | **Short term** |
| **Urgency to act** | **Further investigation**<br>The urgency classification results from the risk assessment for the near-term future, because this risk can be managed with a short policy horizon. |

**Source**: EEA.



### Table 16.3 Risk assessment for risk of business disruptions in key industrial sectors in Europe due to supply chain disruptions for critical raw materials or components from outside Europe.

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)** |
|---|---|---|---|
| **Risk severity** | **Substantial**<br>Growing weather extremes are already prevalent in key sourcing and production countries, on which the EU has strong dependency for critical raw materials and components. | **Critical**<br>The limited evidence available indicates a substantial increase in risk from extreme weather events in the coming decades in key mineral depositories and manufacturing hubs. | **Critical**<br>See mid-term |
| **Confidence** | **Medium**<br>The surge in demand for critical raw materials in the coming decades underscores a small margin for error with regard to disruptions. At the same time, growing climate impacts in key sourcing countries and limited private sector analysis corroborate a trajectory of a growing risk. | **Medium**<br>Demand is certain to increase, alongside intensified climate impacts in key sourcing countries for critical raw materials. Geographical constraints limit options to diversify or alter sources of supplies, although a strong shift towards circularity could somewhat ameliorate demand-side pressures. | **Medium**<br>Technological development is SSP-specific, and so is overall demand for critical raw materials. Different greenhouse gas trajectories will correlate with differences in demand for critical raw materials. These in turn will affect climate impacts, which are difficult to predict. |
| **Risk ownership** | **EU**<br>The EU should play the leading role in managing the risk of climate-related disruptions of supply chains as trade policy falls under its exclusive competence. In addition, some national policies could play an important supplementary role.<br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Corporate Sustainability Reporting Directive (2022/2464)<br>• Corporate Sustainability Due Diligence Directive (2019/1937)<br>• Critical Raw Materials Act (2023/0079)<br>• Critical raw materials action plan<br>• Supply Chain Directive<br>At the national level, the main policies of relevance include those relating to:<br>• Industry<br>• Public procurement<br>• National adaptation funding | | |

| | |
|---|---|
| **Policy readiness** | **Medium**<br>Several different policy measures have been announced and/or implemented to reduce the EU's dependencies on critical raw material imports and strengthen risk analysis, but the evidence of progress is not clear and there are no requirements for adaptation to strengthen the resilience of existing supply chains from climate-vulnerable regions. |
| **Policy horizon** | **Short term** |
| **Urgency to act** | **Further investigation**<br>Since the EU is currently well aware of high-severity climate risk, and has implemented some policy measures to reduce the EU's import dependencies on third countries and improve risk monitoring, the risk has been assigned with 'further investigation' classification. |

**Source**: EEA.

# 17 Stability of financial markets and public finances

## 17.1 Key messages

- As high-cost events have occurred recently, such as the July 2021 floods in Germany, Belgium and the Netherlands (EUR 44 billion) or the August 2023 floods in Slovenia (equivalent to up to around 16% of national GDP), climate change is now recognised as a major macroeconomic, fiscal and financial risk. Economic losses from weather- and climate-related extreme events affect public finances, insurers, investors and financial markets, as well as the wider economy.
- To date, climate-related extreme events have not led to a major sovereign financial crisis or financial instability in Europe, though some Member States have experienced large shocks, and the EU's Solidarity and Emergency Aid Reserve was exhausted in 2021, 2022 and 2023.
- Major shocks in a single country can have wide-ranging financial and political implications for the whole EU, while the costs from climate-related events may be underestimated by existing models and studies. However, it is difficult to fully identify and analyse all the transmission pathways for these financial risks.
- Financial markets and companies will start to price in climate risks, but could also divest or exit from high-risk investments or products, resulting in some financial instability or crises. These responses could transfer more risk to households and the public sector. Financial markets may anticipate climate impacts and act early, bringing forward these impacts.
- Climate risks to public finances, European financial markets, and European property and insurance markets are currently substantial, while risks to the viability of the European solidarity mechanisms are already critical. Major increases in these risks are projected for the future.
- The social implications of financial risk management and adaptation actions must be considered. For example, withdrawing flood insurance coverage in high-risk regions may limit risks to insurers but will increase the protection gap for vulnerable households as well as the risk for public finances.



## 17.2 Introduction

Climate change is now recognised as a major macroeconomic, fiscal ([22]) and financial risk. Extreme weather events are already causing large losses in Europe. For example, the 2021 floods in Germany, Belgium and the Netherlands cost an estimated EUR 44 billion (EEA, 2023d). These impacts affect public finances, insurers, investors and financial markets, as well as the wider economy. The economic costs of climate change are projected to increase significantly in the coming decades in Europe (Feyen et al., 2020d; COACCH, 2020). These risks may arise from the

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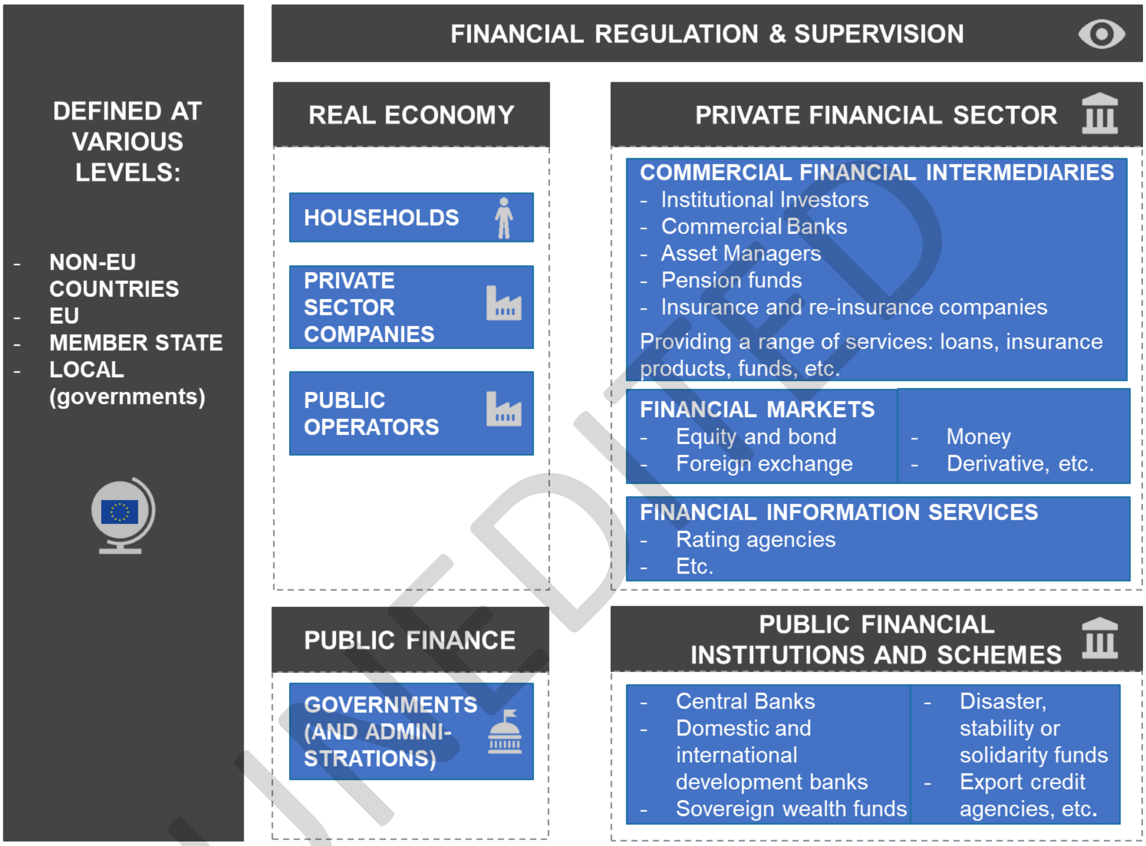
([22]) This chapter uses the term 'fiscal' broadly, including for those aspects where the EU adaptation strategy uses the term 'macro-fiscal'.

economic and financial impacts in Europe, or from the impacts internationally cascading back to Europe (Mandel et al., 2020), and can arise directly or from complex interdependencies and contagion.

This chapter investigates the risks of climate change to the public finances of Member States and the EU budget, as well as the risks to the financial sector (public financial institutions, financial markets, private financial institutions, financial intermediaries, financial market infrastructure), and thus the risk to the financial system (see Figure 17.1), including the interconnections to the real economy (FSB, 2021).

**Figure 17.1 Illustration of the financial system considered in this storyline**






**Source:** Authors of the chapter.

## 17.3 How Europe's fiscal and financial system is already being affected

Europe's economy is large, with an EU-27 gross domestic product (GDP) of EUR 15.9 trillion in 2022 (Eurostat, 2023c). This provides some protection, but Europe has still experienced several shocks and periods of financial instability in recent years.

A first example is the 2007-2009 global financial crisis, which began in the United States, propagated through the global financial markets, and ultimately led to a recession in Europe (European Parliament, 2019). The EU's debt-to-GDP ratio grew from about 60% in the period 2000-2008 to over 80%. Governments, regulators, financial markets and (most) economists failed to predict this event.

A second example is the Greek debt crisis, where a rising budget deficit led to fears of default and a credit rating downgrade. The increased borrowing costs, and concerns over the ability to repay, triggered a debt crisis (Amadeo, 2020), which spilled over to the Eurozone. Financial assistance was provided to prevent default (EUR 110 billion in 2010, EUR 130 billion in 2012, and EUR 86 billion in 2014 (CFR, 2023)), along with required measures and reforms. Real GDP declined and unemployment grew. It is noted that the subprime crisis (the financial crisis) had linkages to the Greek crisis (Kchaou et al., 2022).

The COVID-19 pandemic was another major shock, which affected the entire economy and led to a 4% drop in EU-27 GDP. Government deficits increased substantially, and the aggregate fiscal deficit of the EU-27 grew from 0.5% to 6.7%, along with an increase in debt-to-GDP ratios (Eurostat, 2023d).

This evidence demonstrates that events in one country or market can lead to volatility and risks to financial stability with sizeable contagion or spillover effects. They highlight the importance of sound fiscal management to anticipate potential shocks and ensure that public finances are sufficiently resilient, as well as the importance of effective financial market regulation to maintain stability ([23]) and protect the economy. The rest of this section examines the potential for climate change to lead to similar shocks and stresses. It focuses on physical climate risks only (both acute and chronic climate risks), but it is important to note that the shift to a low-carbon economy entails additional transition risks (TCFD, 2017; NGFS, 2019) that could affect the financial sector (Battiston et al., 2017; Alessi et al., 2022; TNFD, 2023; Gourdel and Monasterolo, 2022), including reputational risks, and policy and legal risks (TCFD, 2017). They are beyond the scope of this report but warrant further investigation as well.

### *17.3.1 Risks to public finances*

Climate change is a macroeconomic and fiscal risk to EU Member States and, by aggregation, to the EU. Climate change can affect economic performance and public finances (Feyen et al., 2020a), potentially reducing tax revenues while increasing government expenditure (e.g. for disaster recovery or social costs), and potentially affecting fiscal space, as well as affecting external performance (e.g. reduced exports affecting the trade balance), increasing contingent liabilities and increasing risks of financial uncertainty. Climate impacts can impact on the economy, including from capital stock damage, lower productivity, reduced labour supply and trade flow disruption, and they can even lower economic growth (Gagliardi et al., 2022).

Climate change may also affect debt sustainability, through price and interest rate channels (Avgousti et al., 2023). These various factors could affect sovereign creditworthiness (Dunz and Power, 2021) as climate change will affect the key criteria (e.g. economic performance and economic growth, fiscal and institutional strength) used for ratings. This can, in turn, lead to credit rating downgrades (Moody's Investors Service, 2016), affecting the sovereign bond yield and increasing the cost of borrowing and of capital for a country. It is also possible that climate change could increase inflation. A recent study on the impact of weather shocks on the euro area reports some seasonal responses of inflation to temperature shocks, mainly via food, energy and services prices (Ciccarelli et al., 2023). Figure 17.2 illustrates how physical climate risks can affect public finances.

Most of the focus to date has been on extreme weather events. A study by DG ECFIN found that over the period 1980-2020 the annual average economic losses from extreme events were less than 0.1% of the EU's GDP, though individual events had larger impacts at the national level (Gagliardi et al., 2022). Uninsured losses were found to be the main driver of adverse macroeconomic shocks.

A 2023 study by the European Central Bank (ECB) found that – compared with the 2008 financial crisis, the 2012 debt crisis and the COVID-19 pandemic – extreme weather events to date had relatively low impacts on Member States' fiscal balances (Avgousti et al., 2023). However,

([23]) The ECB defines financial stability as a condition in which the financial system – which comprises financial intermediaries, markets and market infrastructures – is capable of withstanding shocks and the unravelling of financial imbalances. This mitigates the prospect of disruptions in the financial intermediation process that are severe enough to adversely impact real economic activity.

particularly large disasters were found to have disproportionately large impacts, affecting the fiscal balance by an average of 0.74% of GDP (for these large disasters) and higher than this at 1.4% in new Member States.

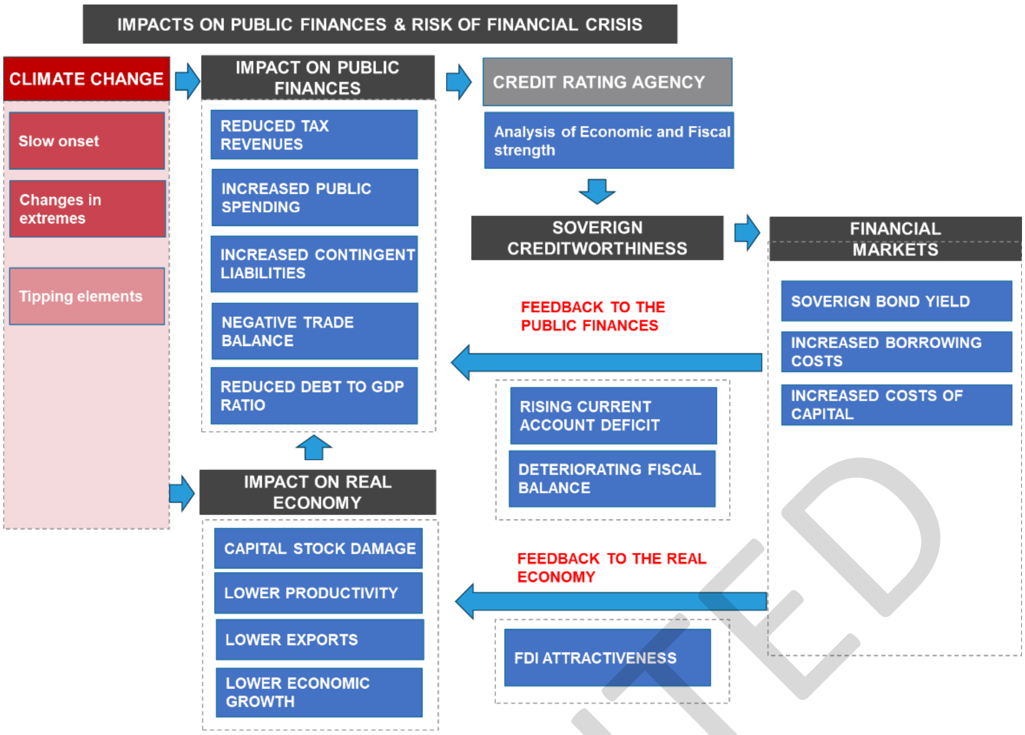
Year-by-year data tallied by the EEA provide additional perspective. They show that between 1980 and 2022, weather- and climate-related extremes caused EUR 650 billion in economic losses in the EU Member States (in 2022 euros), of which only 19.5% were insured (EEA, 2023d). Notably, more than 17% of the cumulative losses occurred in just 2021 – EUR 59.4 billion (0.4% of GDP) – and 2022 – EUR 52.3 billion (0.3% of GDP) (Eurostat, 2023c).

The floods in Germany, the Netherlands and Belgium in 2021, which cost an estimated EUR 44 billion (EEA, 2023d), multi-billion euro flood losses in Italy and Slovenia in 2023 (Albanese, 2023; Maček, 2023), and the 2022 compound heat and drought event, with an estimated cost of EUR 40 billion (EEA, 2023d), are much greater in scale compared to historic events. These larger events can have a disproportionate fiscal impact on public finances, and potentially on borrowing. They may also affect the fiscal space of governments and limit other planned investment. There is, too, a possibility of repeated extreme events in a country, where impacts accumulate and there is not sufficient time for recovery for government budgets.

One way of managing these climate extremes is through solidarity funding, i.e. by risk pooling at the European level. While this is a form of adaptation, the effects of climate change to these mechanisms are considered as a standalone risk. Recent years' extreme events have put pressure on the EU's Solidarity and Emergency Aid Reserve (SEAR), as Member States increasingly seek support after major climate-related losses. After the 2021 floods, for example, the EU Solidarity Fund (EUSF) paid out EUR 707.6 million, mainly to Germany (EUR 612.6 million) and Belgium (EUR 87.7 million) (European Parliament, 2022). The SEAR has a maximum annual budget of EUR 1.2 billion, which was exhausted in both 2021 and 2022, leading the European Commission to propose (in the context of the mid-term review of the 2021-2027 Multiannual Financial Framework) another EUR 2.5 billion for the period 2024-2027 (Abnett, 2023). The EUSF Regulation (EC, 2020f) defines the level of financial support for a disaster at EUR 3 billion in 2011 prices or 0.6% of the affected Member State's gross national income: this is being exceeded with growing frequency. Moreover, the scale of recent unprecedented extremes – and the potential for larger or increased accumulation of large events – indicates a current different scale of risk.

These same transmission pathways can affect public finances in countries outside the EU, and this could cascade back to the financial markets in Europe (for example, via sovereign bonds).

**Figure 17.2 Illustration of transmission pathways for physical climate risk for public finances**




**Source:** Authors of this chapter.



### *17.3.2 Risks to financial market stability*

The Task Force on Climate-Related Financial Disclosures and the Network for Greening the Financial System, as well as the European Central Bank, have identified climate change as posing serious risks to financial market stability including also broader banking activities (TCFD, 2017).

Financial markets are very complex, including a range of markets (bond, capital, money, derivatives, foreign exchange, etc.) that provide financial services and assets to actors in the real economy (corporates, governments, etc.). This makes it extremely difficult to assess the potential effects of climate change, as risks can be generated and cascade through the financial system, as well as through impacts on the real economy that are difficult to identify.

Limited reporting in Europe and abroad makes the assessment challenging, but available insights suggest the costs are likely very large. For instance, two thirds of 400 Standard &Poor's companies disclosed the climate risk on their value chain through Carbon Disclosure Project in 2021, estimating them at a combined USD 237 billion for acute risks and USD 141 billion for chronic risks (CDP, 2022). Another example is the 2021 floods in Germany, which shut down several major manufacturing plants, power plants, railways, etc. (Holtschneider and Reimann, 2021) ([24]).

Observations at global level as well as modelling exercises by researchers provide a basis to clarify how climate impacts in the real economy could affect EU financial stability.

Figure 17.3 illustrates some of the main climate risk transmission pathways to financial markets. Portfolios of corporate equity and bonds, for example, can be exposed to climate impacts through value chains and the macro environment ([25]). Physical climate impacts can affect

([24]) See Chapter 16 for further information.

([25]) For example, according to Ranger et al. (2022), 'the impact of physical climate risks on the banking sector is highly dependent on the level of resilience of the financial sector overall (to any shock) and the vulnerability of their borrowers. For example, countries with weaker supervision and regulation and with more concentrated and less companies' cash flows, increase insurance premiums, and affect balance sheets and profits (Zhou et al., 2023). This can influence expected rates of return for investors, reduce the market price of securities and increase their volatility. This affects investors and savers and may also increase the cost of capital for companies, disrupting some of their investment plans. Climatic and non-climatic impacts can also compound, as was seen with the COVID-19 pandemic at a global level. For example, Dunz et al. (2023) have modelled that after a climate event, such as a hurricane, firms tend to rebuild their production capacity, but the pandemic reduced demand, with macro consequences on the economy.

Banks can also be exposed to climate risks through their loan portfolios and, if not insured, there could be a greater likelihood of default after a climate shock. This was already seen with small and medium-sized enterprises (SMEs) following floods in Europe (Barbaglia et al., 2023c). Not only may banks incur losses, but they may tighten credit conditions, reducing access to finance to the counterparties. This, in turn, can lead to uncertainty within the economy as a whole, which leaves the financial system with fewer business opportunities to recover from the shocks as well. Depositors, on the other hand, may need to withdraw savings after a climate shock to offset a reduction in income/revenue or to cover the cost of damage. If many depositors do this at once, it can increase liquidity risks for the bank (Ranger et al., 2022).

As also discussed in Chapter 16, climate shocks outside the EU-27 can cascade into EU financial markets through corporate value chains, as well as through trade (Anisimov and Magnan, 2023). EU investors may also be involved with foreign economic actors through portfolio investments, non-EU sovereign bonds, etc. Another channel of exposure is the emerging markets for securities transferring climate risk to financial markets, such as insurance-linked securities and catastrophe bonds.

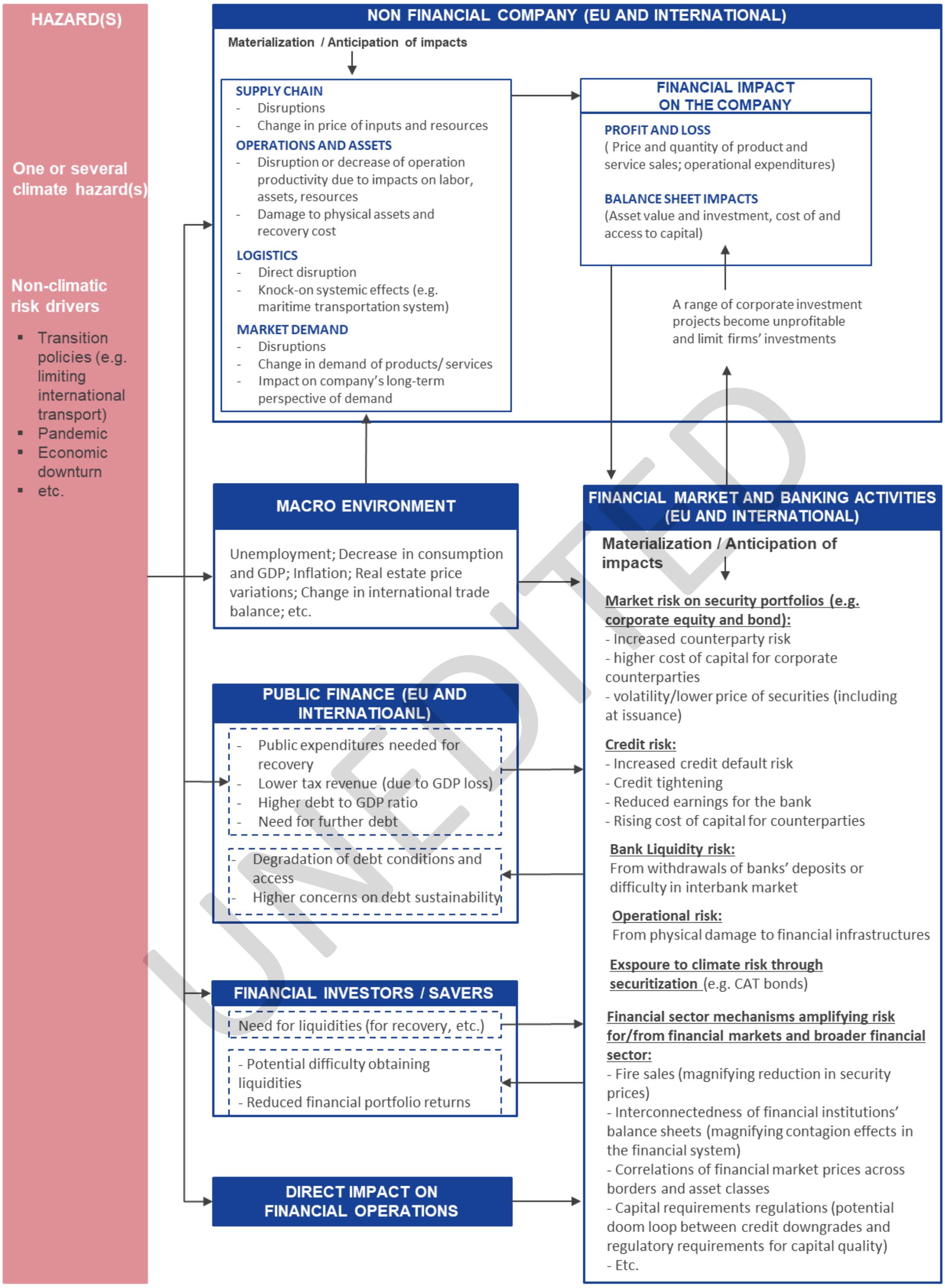
An important dynamic to consider as well is how markets can amplify climate-related financial risks. Investors' expectations on the realisation of climate scenarios affect the cost of capital and thus firms' investment decisions (Battiston et al., 2021). Some mutual fund portfolio managers may also sell financial assets they deem as risky. Fire sales can be particularly harmful for investors' returns (Mirza et al., 2020; Bellia et al., 2023a). As many companies are still not disclosing climate risks, when they finally disclose this information – or when they experience a shock – the effect on their share value and, by extension, on the market could be more pronounced. The financial market structure can also amplify financial risk. For example, at EU level, banks, funds and insurance companies hold each other's securities (Mirza et al., 2020). This can increase the potential for contagion.

Overall, the takeaway is that financial markets, while they could stimulate adaptation and thus reduce climate risks, can also transfer or amplify the difficulties for the real economy (OECD, 2022).



interconnected banking sectors will see greater risks, while more advanced and resilient financial sectors will be less affected. Smaller economies will be more vulnerable, particularly small island states where economic losses can constitute a significant proportion of their gross domestic product'.

## Figure 17.3 Illustration of transmission pathways for the financial markets






**Source:** Authors of this chapter.

### *17.3.3 Risks to insurance markets and property portfolios*

Insurance plays a crucial role in mitigating the economic and financial consequences of climate change-related events, particularly around disasters, providing funds for reconstruction and to help cover revenue losses and costs during recovery. However, as noted earlier, only 19.5% of losses from extreme weather events in Europe in the period 1980-2022 were insured, with large disparities across countries (EEA, 2023d). There is also a significant protection gap at the global level (Banerjee et al., 2023). Tackling Europe's climate insurance gap is a widely recognised priority, and the European Central Bank and European Insurance and Occupational Pensions Authority's (EIOPA) staff have published a discussion paper with policy options to reduce this gap (ECB and EIOPA, 2023).

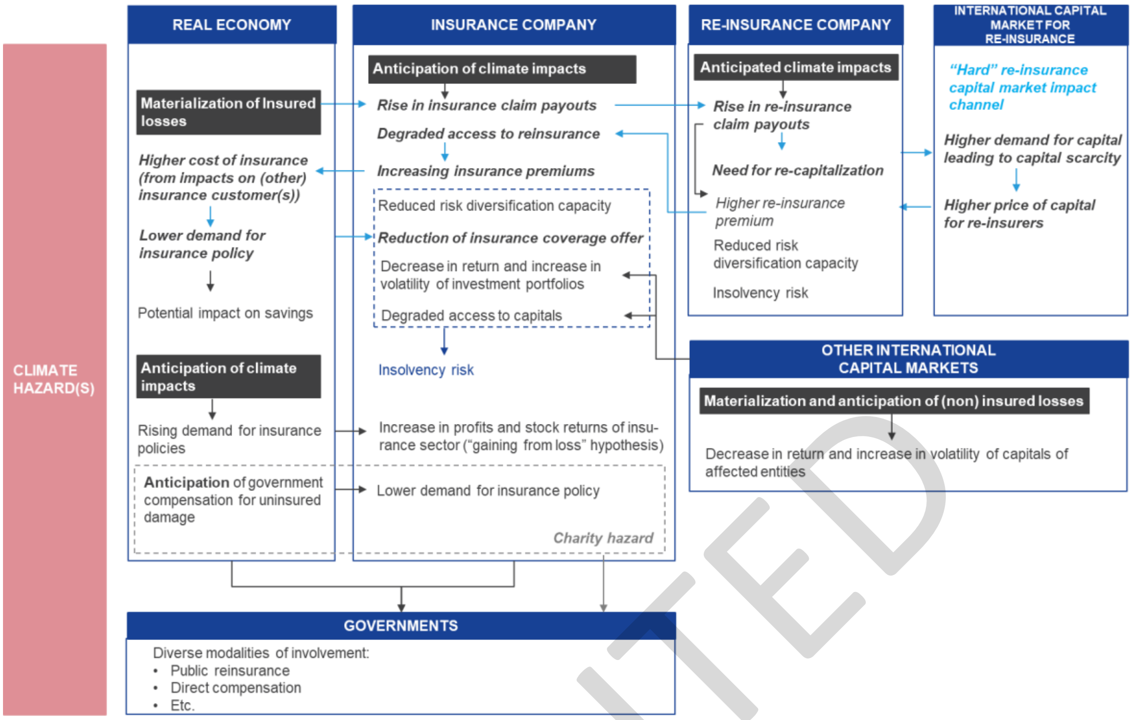
A key challenge for reducing this protection gap is that increases in the frequency and severity of natural disasters could generate higher claims over time, thereby raising insurance premiums; shock-induced price rises in premiums may also appear following events involving high claims (De Nederlandsche Bank, 2017; Bellia et al., 2023b). Higher premiums, in turn, can reduce demand for insurance or make it unaffordable, leaving more assets uninsured (Tesselaar et al., 2020c). Insurance markets and companies might also reduce the coverage they offer to avoid high-risk areas. This has been observed in the United States, for example, where major insurers have stopped issuing new policies in wildfire-ravaged California, and options in Florida have been reduced by a combination of insurers' restrictions and bankruptcies (Hill, 2023).

The risk of a widening protection gap could further affect the financial sector through unexpected depreciation, higher loan default risks and, in extreme cases, downgrading the creditworthiness of companies and states. When extreme events occur in areas where there is a protection gap, in some instances public finances may be used to, at least partially, compensate incurred losses.

Related to this are risks to real estate portfolios exposed to climate hazards. There is evidence, for example, that homes exposed to sea level rise in the United States are selling at a discount (Bernstein et al., 2017). This information is starting to be considered by real estate investors and funds (UNEPFI, 2019). Real estate prices can affect the investment portfolios of insurers and banks, as well as banks' ability to recover their credit losses when real estate is used as collateral.

A range of national schemes can modify how real estate exposes different types of actors (e.g. banks, individuals, public finance) to the costs of climate impacts. For example, for France, there is a mandatory public risk transfer scheme for natural catastrophes (the so-called CATNAT Regime) that complements private insurance on residential real estate, and some mechanisms are also in place to reduce the impact of real estate price fluctuations on French banks' housing loan portfolios.

**Figure 17.4 Summary of transmission channels in the insurance sector from the selected references**




**Source:** Adapted from Zhou et al. (2023) and cited papers.



## 17.4 Future risks to the fiscal and financial system in a changing climate

### *17.4.1 Risks to public finances*

There is established literature on the future economic costs of climate change in Europe (Tröltzsch et al., 2018), though different levels of potential impact are reported with different studies. The CO-designing the Assessment of Climate CHange costs (COACCH) study estimates that by mid-century (2050) in the RCP4.5-SSP2 (high investment mobility) scenario, average annual climate change impacts would exceed 2.5% of GDP in most European countries (COACCH, 2021). The PESETA IV study estimates that exposing the present EU-27+UK economy to global warming of 3°C would result in an annual welfare loss of at least EUR 175 billion (1.38% of GDP), while in a 2°C scenario, the annual loss would be EUR 83 billion (0.65% of GDP) (Szewczyk et al., 2020). However, the PESETA IV impacts for central-southern Europe and especially southern Europe are much higher – the latter with annual welfare loss of over 2.5% of GDP under 3°C. It is stressed that these are annual costs and the impacts in individual years, or for individual countries or regions, would be very much higher.

There are some studies that have considered the impacts of these future effects on public finances. The COACCH project modelled the impact of climate change on public finances in Austria, Spain and the Netherlands (Preinfalk, 2021). The analysis projects significant impacts from climate change by 2050 due to climate-induced disruptions to the tax base, such as from reduced revenues from lower productivity, as well as increases in public expenditure.

The EC Fiscal Sustainability Report 2021 also included an extreme event stress test to assess the risks to public finances (EC, 2021h; Gagliardi et al., 2022). This looked at potential future climate change impacts of extremes, looking at the deviation from the EC's 10-year baseline debt-to-

GDP projections. The stress tests found non-negligible fiscal impacts in some countries, with progressively higher debt-to-GDP projections in the future, especially for some Mediterranean and eastern European countries ([26]) even under 1.5°C and 2°C scenarios, though the analysis concludes that the risk remains manageable. However, it also reports that an increase of global temperatures of 3°C would lead to more abrupt (non-linear) impacts. This analysis only considered extreme events and not the compounding impacts of slow-onset climate change, and the report acknowledges 'our results are likely to represent an underestimation of the expected fiscal impact'.

Several studies have investigated the potential impact of climate change on sovereign ratings globally (S&P Global Ratings, 2014; Moody's Investors Service, 2016; ICBS and SOAS, 2018; Kling et al., 2018; Volz et al., 2020; Cevik and Jalles, 2022; Climate Finance Advisors, Benefit LLC, 2020; Klusak et al., 2021) and found low risks to Europe in the near term (with minimal impact on credit ratings and bond spreads). Some, however, find high risks in the long term, especially under high-emission pathways (Klusak et al., 2021), and also show differentiated risks by European region (Boitan and Marchewka-Bartkowiak, 2022). As noted earlier, impacts on credit ratings of countries outside Europe could also cascade back to the EU.

Many current studies use generic climate risk assessments or focus on extreme events only, and may therefore underestimate the potential risks, especially the rising frequency and intensity of very large extremes, and the cascading and compounding effects, as well as the need to consider the potential combined effects with transition risk (Cheng et al., 2023). These also have implications for EU solidarity mechanisms; studies have identified the pressures on these under climate change (RECEIPT, 2023).

### *17.4.2 Risks to financial market stability*

The ECB's 2021 climate-related stress test of the euro area banks clarified that physical climate risk can be a significant source of systemic risk in the absence of transition policies, and with concentration of the risk in significant institutions in certain geographic exposures (Alogoskoufis et al., 2021). However, more in-depth analysis is needed. Earlier studies had found that European financial markets are exposed to moderate risks from climate change impacts in Europe or abroad, with potential effects on specific high-risk sectors, such as commodity trading markets, or some vulnerable sectors, for example residential and commercial property investment (The Economist, 2019; South Pole Group, 2016).

The ECB has found that physical climate risks to the European banking system are still underestimated, and this line of research is still in its infancy. This aligns with recent analysis that considers the climate change scenarios used in financial services to be underestimating risk (including physical climate risk (Institute and Faculty of Actuaries, 2022) and compounding with various types of risks (NGFS, 2023)).

The lack of granular data from counterparties is a key limitation. A recent study using granular plant-level data for a sample of listed firms located in Mexico, for example, found that the computation with aggregated firm data led to an underestimation of climate-related losses of up to 70% (Bressan et al., 2022). Some risk transmission pathways are also poorly explored. For instance, the loss of corporate economic output is seldom addressed, but it may play a much larger role in the future, as disruptions to productivity are amplified through increasing trade and economic interconnectedness. This caveat relates also to a lack of transparency on investments by sector and on international supply chains (Gardner et al., 2019).

Risks from climate change outside the EU may be underestimated, too. The Network for Greening the Financial System (NGFS) has found that countries with less economic

([26]) With an increase in the ratio of public debt to GDP of around 5 percentage points in Czechia and Spain, 3-4 percentage points in Greece, Hungary, Poland and Romania, and around 2.5 percentage points in Italy.

diversification, less climate-resilient public infrastructure, less capital market flexibility and lower capacity to adapt will be at greater risk from climate change impacts than the EU. European markets may be exposed to these risks through their portfolios (NGFS, 2019). There is evidence of significant connections between EU financial markets and the United States and East Asia, for instance (Ehrmann et al., 2005). One study found that EU-27 financial actors have an estimated USD 9.8 trillion of cross-border portfolio investments outside the EU, with a relatively large part of debt securities. The study also highlighted that EU and US investors are the main buyers of insurance-linked securities, in which real estate at risk from hurricanes in Florida is securitised. As explained above, there is also an underestimation of cascading effects through corporates' international supply chains reducing their economic output. Concerning banks, the ECB and ESRB (2023) showed that global systemically important banks in the Single Supervisory Mechanism area could lose more than 50% of their total capital by 2050, in an RCP8.5 scenario, when taking account of cross-border transmission of physical risks, global value chains with limited capacity to reorganise across trading partners, and contagion.

Financial markets could also exacerbate or accelerate the impacts of climate change on the real economy. The main idea is that financial market participants might be largely mispricing physical risks, creating the premises for financial markets' abrupt repricing. This could lead to impacts on the companies' cost of capital, on the value of savers' portfolios, and ultimately on public finance. Evidence is patchy and mixed on the pricing of physical climate risks in financial markets, such as in municipal and sovereign bond markets (OECD, 2022).

More research is needed on the integration of climate projections in asset pricing (International Monetary Fund, 2020). An early analysis found that, under more extreme climate scenarios, short-term shifts in market sentiment and anticipation could lead to up to a 45% loss in an equity investment portfolio value (and a 23% loss for fixed-income portfolio), of which around half would be hedgeable and half not – the latter meaning investors and asset owners are exposed unless some system-wide action is taken to address the risks (CISL, 2015).

Other mechanisms need clarification and integration in simulations, such as the combined effects of different risk factors (ECB and ESRB, 2023). For example, first-round effects of climate impacts on the real economy can be amplified by the lack of adaptation strategies, the insurance protection gap and limited government budgets (Anisimov and Magnan, 2023). Potential mitigating factors need to be better understood as well (BCBS, 2021). For instance, it is worth exploring whether the lack of insurance and reinsurance could potentially be alleviated to some extent with insurance-linked securities and catastrophe bonds, or innovation in the field of hedging (BCBS, 2021).

### *17.4.3 Risks to insurance markets and property portfolios*

As highlighted above, the insurance and real estate markets raise particularly large concerns when it comes to future climate risks to financial systems. As with markets overall, there are large uncertainties that point to a pressing need for further study. However, the current projections reinforce the protection gap concern.

Analysing non-life solo insurance undertakings, the EIOPA concludes that even in a mild 2°C global warming scenario, cascading effects from climate change could impact a range of European insurers' business lines. The line of business most exposed to weather-related disaster risk is fire and other damage to property insurance, which represents 20% of European insurers' portfolio (EIOPA, 2022).

One study found that under a single climate scenario, the average flood insurance premium in the EU could double between 2015 and 2055 (Hudson et al., 2020). The authors proposed that governments could offer reinsurance in combination with insurance purchase requirements and financial incentives for consumers to take adaptation measures that limit flood risk. Another study building on the same model projected that flood insurance premium increases due to climate change would be especially high in hard reinsurance markets and might occur in years with many severe disasters (Tesselaar et al., 2020b).

Another study analysed the potential for a socio-economic tipping point in European flood insurance, when premiums become so unaffordable in some places that demand almost disappears. It found that such a tipping point appears in the highest number of European regions under a high climate change scenario with regional economic inequalities (RCP8.5-SSP3) (Tesselaar et al., 2020c).

In the Netherlands, meanwhile, De Nederlandsche Bank found that changing weather patterns put upward pressure on insurance premiums, leading to potential shock-induced price increases. The study also found uninsured flood risks, with losses to be covered by the government (De Nederlandsche Bank, 2017).

An in-depth analysis of the links between physical climate risks and financial risks found insurers have significant expertise in dealing with natural catastrophes, but events and losses could rise unexpectedly (IAIS, 2018). As suggested by the discussion in the Section 17.3, future climate change may well result in less, rather than more, coverage; a Bank of England report found that severe weather events have previously led to withdrawals from property insurance (Bank of England, 2015).

### *17.4.4 Risks to the overall financial system*

In summary, the limited current literature indicates that the risks of financial shocks and the risk to financial stability from climate change in the EU are only low to moderate, though there will still be large economic or financial costs, and important sector or regional impacts, with potential political risks. However, these climate risks are likely to be higher when a system perspective is taken. For example, Europe has experienced unforeseen financial and fiscal shocks over the last 20 years, and the risk transmission pathways for these events are complex and difficult to predict. These often arise from cascading and compounding risks that act as risk multipliers, as well as interconnections, which have not been considered here.

It is unlikely that the markets alone will address these increasing risks – or, more to the point, that they will do so in a way that aligns with the EU's overall policy objectives. Instead, they might reflect these risks in pricing, or reducing their exposure by divesting and exiting high risk sectors, regions or investments. This is likely to mean some financial risks and costs could fall to the public sector, or that the public sector could end up as a lender (of last resort). This is already being found in some OECD countries in relation to coastal property risks, e.g. in the United States (McKinsey Global Institute, 2020).

Moreover, the financial markets may act early in anticipation of climate change impacts. This could result in financial impacts propagating through markets and potentially causing financial instability before the expected climate risks materialise, effectively bringing impacts forward (Kemp-Benedict et al., 2019). In effect, private actors' perceptions of climate risks can change the risk itself. At the same time, in cases where there is no good risk information, an orderly market reaction might be unlikely, leading to the potential for later and more chaotic herd reactions.

Finally, there are system linkages between physical climate risk and transition risks, and the impact of climate change on natural capital and the effects on financial stability (ECB and ESRB, 2023). Therefore, at the system level, this assessment finds the severity of the risks faced by the EU to be high (critical), even in the near term (2021-2040), and very high (catastrophic) in the medium term.

## 17.5 Policy readiness

### *17.5.1 Risk ownership*

The large and interconnected landscape of economic and financial risks means there is not one single risk owner for risks to the stability of financial markets or public finances. System-level risks are owned by a combination of financial institutions (in Europe but also outside), as well as by Member States and other sovereign bodies. Nonetheless, there are important opportunities – and responsibilities – for EU institutions to act to mitigate these risks, working with the Member States. The main actors at the European level are the EC, financial supervisors (ECB, EBA, EIOPA, ESMA), European and international financial institutions (EIB, EBRD, etc.) and, in the Member States, central banks, ministries of finance, market regulation and financial authorities, and national development banks.

### *17.5.2 Policy readiness for protecting public finances*

The EC Fiscal Sustainability Report 2021 (DG ECFIN) included an extreme event stress test to assess the risks to public finances (EC, 2021h). This is a key first step in policy readiness. The results showed that climate change may pose risks to fiscal (debt) sustainability in some countries. The risks were deemed to be manageable in low global warming scenarios, but more serious with higher warming. However, the stress test only considered extreme events, not slow-onset climate change impacts, and the report acknowledged that it likely underestimated risks even for extreme events, as it only extended to 2032. The report highlighted the importance of adaptation measures such as insurance and climate-resilient debt instruments to enhance financial resilience to climate-related events and dampen the fiscal impact, thus reducing potential debt sustainability risks. It also highlighted the need for robust disaster risk management frameworks and financing strategies.

The EU adaptation strategy (EC, 2021e) covers many relevant areas, including integrating climate resilience in national fiscal frameworks, which highlights the need for macro-fiscal resilience and highlights potential areas for consideration. The proposal for a council directive amending Directive 2011/85/EU on requirements for budgetary frameworks of the Member States (EC, 2023r) contains provisions to promote the accountability of public budgets and increase the transparency of fiscal risks vis-à-vis climate change. This includes requirements to assess the risks deriving from climate change and the implications of climate policies on public finances. It also includes requirements for Member States to publish data, to the extent possible, on disaster- and climate-related contingent liabilities, as well as on economic losses incurred from natural disasters and climate-related shocks (and for the latter, the fiscal costs borne by the public sector and the instruments used to mitigate or cover the shocks would also be reported). The EC also launched the Climate Resilience Dialogue in 2022 (EC, 2022) to identify solutions to narrow the climate protection gap (the difference between how much is lost and how much is insured) and to find ways to stimulate investment in good adaptation.

With respect to solidarity mechanisms, several studies have noted the need for higher capitalisation of the EUSF, as well as to enhance other solidarity mechanisms and cohesion policy. There has also been analysis of evidence and discussion on relevant concepts for the design of a disaster risk financing strategy (Radu, 2021), and recent work has identified a suite of policies for increased preparation and preparedness as well as showing the high economic returns these provide (IBRD, 2021).

### *17.5.3 Policy readiness for addressing risks to banks, insurers and financial markets*

EU banking and insurance regulations were recently revised to require banks and insurers to explicitly integrate environmental, social and governance (ESG) risks into their risk management systems. Banks will be required to internally stress test their resilience to climate-related risks.

Bank supervisors are tasked to review banks' exposure to and management of ESG risks, including how banks will perform in the context of transition to the relevant EU sustainability objectives and broader transition paths over the short, medium and long term.

As for insurers, the EC proposed in the Solvency II review that, if materially exposed to climate-related risks, they should perform scenario analysis with two different temperature scenarios (one below and one above 2°C). The adequacy of banks and insurers' management and risks profile in terms of ESG exposures or sustainability risks is also to be reflected in their respective regular supervisory reviews (Supervisory Review and Evaluation Process, SREP) and their Own Risk and Solvency Assessments (ORSAs), which may impact their individual capital add-on requirements.

### *Microprudential and macroprudential approaches*

Microprudential supervision, if used to ensure individual institutions' soundness amid climate change, can contribute to systemic stability, insofar as the destabilisation of individual banks can have systemic consequences. As part of its climate strategy and pluriannual action plan, the ECB set supervisory expectations in 2020 on how euro area banks should address climate change (e.g. forward-looking assessment of climate risks to business strategy) ([27]). It took corrective actions on climate as part of the SREP for the first time in 2022.

The ECB also conducted a bottom-up stress-test in 2022 to assess banks' readiness to manage climate risks and found that banks had made 'considerable progress', but there were still 'many deficiencies, data gaps and inconsistencies' across institutions (ECB, 2022, p. 5). Based on information on 41 significant banks, looking at a 1-year horizon, the stress test found potential for 'non-negligible losses': EUR 17 billion just from exposure to drought and heat risks through corporate loans and to flood risks through mortgage and commercial real estate loans. However, the ECB mentions that results are likely underestimated due to data scarcity, limitation in portfolio coverage, in scenarios' transmission pathways and banks' projection modelling.

The SREP is a promising avenue to stimulate a better integration of climate risks in banks' internal processes. It is important for banks to further analyse climate risk propagation channels in the real economy and compounding effects, including potential spillover effects from private financial actors' physical risk management. The contribution of specific tools such as additional capital requirements in the microprudential framework can also be discussed. These have been developed with a focus on ensuring the banks' resilience, should a crisis occur. However, they are not explicitly seeking to mobilise the banks in defusing the risk arising from climate impacts in the real economy, for instance by financing vulnerable/impacted counterparties. Additional tools may be needed to address this latter aspect explicitly.

The ECB has also conducted top-down stress tests to provide a macroprudential perspective on climate risks to the financial system: on banks in 2021 (Alogoskoufis et al., 2021) and on banks, insurance and investment funds in 2022, with attempts to model contagion mechanisms in an interconnected system (ECB and ESRB, 2022), and a third exercise including a focus on repeated flooding events not allowing for full recovery (ECB and ESRB, 2023). This work clarified that physical climate risk can be a significant source of systemic risk, and with concentration of the risk in significant institutions in certain geographic exposures. It also showed that the perceptions and actions of banks, insurance and investment funds may change the level of risk.

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([27]) The areas are: assess the macroeconomic impact of climate change and mitigation policies on inflation and the real economy; improve the availability and quality of climate data to better identify and manage climate-related risks and opportunities; enhance climate change-related financial risk assessment (including climate stress tests); consider options for monetary policy operations and assess the impact of climate change on monetary policy; analyse and contribute to policy discussions to scale up green finance; increase transparency and promote best practices to reduce the environmental impact.

This work also advanced knowledge, data and modelling capacities on climate change implications for financial stability

The ECB considers it a first step on its roadmap towards a comprehensive climate stress-testing framework. Other non-stress-test ECB work is making progress on identifying the fiscal effects of climate change. The ECB and ESRB (2023) consider that the amount of collected evidence is sufficient to build a macroprudential strategy considering the policy options they formulate (e.g. systemic risk buffer, borrower-based measures) in spite of remaining uncertainties. It is now important to have a clear action plan for prudential authorities. This includes: the need for policies targeting not only reactive crisis management, but also stimulating proactive physical risk reduction; keeping to explore further macroprudential policy approaches for addressing systemic impacts of climate change; address better systemic risk and amplification mechanisms also beyond banks, including for example non-banking financial intermediaries; and help organise and coordinate a broader policy mix, including macro- and microprudential policies and other actions targeting the real economy. In parallel, financial authorities may foster collaborations with scientists to keep improving simulations of compounding risks in the financial sector (NGFS, 2023) and the integration of tail risks.

### *Disclosure requirements*

The EU requires disclosures from financial actors on sustainability issues through several policies, including the Benchmark Regulation, the Sustainable Finance Disclosure Regulation (SFDR), and Pillar 3 requirements under the Capital Requirements Regulation. The Corporate Sustainability Reporting Directive (CSRD) also covers financial and non-financial companies (including listed SMEs). With the CSRD, data including physical climate risks will be provided by 49,000 companies. This is a first step to help with financial stability as it will help improve assessments of financial actors' exposure to climate risks. The delegated regulation to the CSRD requires reporting on adaptation policies, actions, targets, if any, physical climate risks and related financial effects for the company as well as information on the resilience of the strategy and business model related to those risks. Companies are mandated to conduct a double materiality assessment, looking at their impact on the environment as well as the impact of the environment on them. This could serve as a basis to make progress on managing physical climate risks at financial institutions while monitoring consequences such as access of vulnerable actors to finance.

More transparency is also needed on how financial institutions can help proactively defuse the risks, and what they are doing in this area. For example, the CSRD standards do not yet ask companies to explain the interplay of both branches of double materiality in decision-making (e.g. the interaction between the decisions of financing adaptation and the management of exposure to financial risks arising from physical climate impacts and adaptation). Sectoral standards under development will also condition the relevance of information provided by financial institutions and their counterparts active in different sectors. For the financial sector in particular, there will be more specific reporting requirements for banking, insurance and asset management, including the value chain, i.e. impacts and risks of investees and policyholders. The manner in which Member States implement the CSRD at the national level, including potential sanctions, will determine how effective these disclosure requirements are at changing companies' behaviour.

It would be relevant for financial regulators to foster clarifications of how climate-related proactive risk-reduction, and not only reactive crisis management, can be integrated in the EU's broader financial sector policies, including on non-banking financial intermediaries.

## 17.6 Aggregated risk assessment

This section presents the outcomes of the structured risk assessment for the major climate risks identified in this storyline. This assessment builds on the analysis in the whole chapter, even though only a brief motivation is provided in the tables below. The initial risk assessment was conducted by the authors of this storyline whereas the final assessment results reported here represent the consensus of the EUCRA risk review panel. Further methodological information is available in Annex 2.

### Table 17.1 Risk assessment for climate risk to public finances leading to a financial crisis

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)**<br>• **high warming**<br>• **low warming** |
|---|---|---|---|
| **Risk severity** | **Substantial**<br>Current/near-term risks assessed as substantial at EU level, but potentially critical for some countries (debt-to-GDP ratio to 2032). However, likely underestimation of risks and additional risks from slow-onset, and from cascading and compounding risks, especially post 2030. | **Critical**<br>Combination of more frequent/ intense extremes coupled with slow-onset likely to mean EU-wide critical severity (similar order to previous financial or debt crisis) and catastrophic for some regions. Some potential for sovereign downgrades for highly vulnerable EU regions. Potential for more significant risks from cascading and compounding effects. | **Catastrophic**<br>Likely highly critical impacts on all aspects of public finances.<br><br>**Critical**<br>See mid-term |
| **Confidence** | **Medium**<br>Risk pathways are complex but there is broad agreement from the literature on magnitude of risks from multiple studies (evidence). However, it is possible the literature underestimates severity. | **Medium**<br>Multiple studies show increasing economic costs and high risks for public finances, with very high risks in some regions. High uncertainty around exact level of impact, and also does not include cascading and compounding effects. | **Medium**<br>Confidence on further increasing severity for high warming is strong (robust finding in all studies), even though the exact size of effect is uncertain. |
| **Risk ownership** | **Co-owned**<br>Complex risk landscape, involving European financial policy actors (ECB, ECFIN, FISMA), European and international financial institutions (EIB, EBRD, etc.) and Member States (central banks and ministries of finance, national development banks, etc.).<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Maastricht Treaty convergence criteria<br>• DG ECFIN stress test on public finances<br>• EC fiscal sustainability reporting<br>• European Semester<br><br>At the national level, the main policies of relevance include those relating to:<br>• Economic affairs<br>• Public finance<br>• Financial regulation<br>• Coalition of finance ministers to assess climate risks as part of comprehensive vulnerability assessments | | |
| **Policy readiness** | **Medium**<br>European Semester process and existing stress tests undertaken on public finances, but no additional action in place to manage long-term risks.<br>Long policy and decision lifetimes are involved, which are not yet considered in policies. | | |

| | |
|---|---|
| **Policy horizon** | **Medium term**<br>Path dependency. Increase in adaptation investment and reconfiguration of public finances likely needed by mid-century, which will take time. |
| **Urgency to act** | **More action needed** |

**Source**: EEA.

### Table 17.2 Risk assessment for climate risk to the viability of the European solidarity mechanisms

| | **Current/near term (2021-2040)** | **Mid-term (2041-2060)** | **Long term (2081-2100)**<br>• **high warming**<br>• **low warming** |
|---|---|---|---|
| **Risk severity** | **Critical**<br>Historically, the EUSF has managed levels of climate extremes. There are likely to be large and unprecedented climate disasters (individual and compounding) in the near term and increasing calls on the EUSF. Current storylines already indicate that the EUSF has insufficient funds for impacts in Europe and from overseas territories. | **Critical**<br>Intensity and frequency of climate-related extremes are projected to increase compared to the current period. | **Catastrophic**<br>Further increases of climate-related extremes and impacts<br><br>**Critical**<br>See mid-term |
| **Confidence** | **High**<br>Wide agreement on current and upcoming pressures on the fund and likely undercapitalisation. | **Medium**<br>General agreement on higher levels of natural hazards and undercapitalisation, though exact levels are uncertain. | **Medium**<br>General agreement on higher levels of natural hazards and undercapitalisation, though exact levels are uncertain. |
| **Risk ownership** | **Co-owned**<br>The EUSF is managed by the EC, although it combines EU and Member State capitalisation (EC, 2020c). There are also strong linkages with EC activities related to civil contingencies (broader).<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Multiannual Financial Framework<br>• Capital Requirements Regulation (575/2013)<br>• Capital Requirements Directive (219/878)<br>• Regulation on Credit Rating Agencies (1060/2009)<br>• EU Solidarity Fund<br>• Social Cohesion Fund<br>• Solvency II Directive (2009/138)<br>• EU financial regulations<br>At the national level, the main policies of relevance include those relating to:<br>• EU affairs<br>• Fiscal policy/public finance<br>• Civil protection and emergency preparedness (EC, 2020d) | | |
| **Policy readiness** | **Medium**<br>Current plans are insufficient to deal with the increase in natural disasters projected. Likely to require either major increases in capitalisation and/or alternative mechanisms to continue solidarity principles. | | |
| **Policy horizon** | **Short term**<br>Action to agree increased capitalisation is needed and negotiation likely to take some time. | | |
| **Urgency to act** | **Urgent action needed** | | |

**Source**: EEA.

**Table 5.3 Risk assessment for risks to European financial markets from climate impacts in Europe and beyond**

| | Current/near term (2021-2040) | Mid-term (2041-2060) | Long term (2081-2100)<br>• high warming<br>• low warming |
|---|---|---|---|
| **Risk severity** | **Substantial**<br>Most literature identifies low to moderate risks to financial markets from impacts in Europe and internationally. However, there could be additional risks from cascading and compounding impacts that are not well understood, as well as the amplifying effect of market anticipation, which could bring risks forward. Possible interactions with transition risk (compounding factors) and progress on transition will affect market perception of physical risk levels. Risk management by financial actors could lead to impacts on the real economy. | **Critical**<br>Literature indicates rising international risks (developing countries), though financial markets can act to reduce exposure. Greater potential for disruption of financial markets in some European regions or sectors, especially due to market anticipation. Potential increase in stranded assets for some investments.<br>Catastrophic events could lead to shifts in market sentiment. | **Catastrophic**<br>Very high risks projected internationally and in Europe.<br><br>**Critical**<br>See mid term |
| **Confidence** | **Low**<br>Some literature but very complex pathways and lack of quantification. | **Low** | **Low** |
| **Risk ownership** | **Co-owned**<br>Complex risk landscape, involving financial supervisors (ECB, DG ECFIN, DG FISMA, EBA, EIOPA, ESMA), European and international financial institutions (EIB, EBRD, etc.) and Member States (central banks and ministries of finance, market regulation and financial authorities, national development banks, etc.).<br><br>At the EU level, the main relevant policy frameworks and initiatives include:<br>• Corporate Sustainability Reporting Directive (2022/2464)<br>• Corporate Sustainability Due Diligence Directive (2019/1937)<br>• Insurance Distribution Directive (2016/97)<br>• Solvency II regulatory framework (2015/35)<br>• ECB's 2022 climate agenda<br>• ECB's 2020 supervisory expectations<br>• ECB's 2022 bottom-up climate stress test<br>• ECB's 2021 top-down climate stress test<br>• ECB/ESRB project task force's 2022 macro climate stress test<br>At the national level, the main policies of relevance include those relating to:<br>• Economic policy<br>• Industrial strategy<br>• Fiscal policy/public finance<br>• Financial regulation<br>• Monetary affairs (in some Member States) | | |
| **Policy readiness** | **Medium**<br>Existing policy focus on stress tests and disclosure of physical climate risks, hence better information on pricing risks. Financial stability policies alone might not be enough to manage the risks to financial stability arising from a lack of adaptation in the real economy. | | |
| **Policy horizon** | **Short term**<br>Generally short term. However, financial investment cycles vary, and some have a medium-term horizon, ECB/ESRB stress test assumes financial actors will time-discount future climate impacts. | | |
| **Urgency to act** | **Further investigation needed** | | |

**Source**: EEA.

## Table 17.4 Risk assessment for climate risks to European property or insurance markets

| | Current/near-term (2021-2040) | Mid-term (2041-2060) | Long-term (2081-2100)<br>• high warming<br>• low warming |
|---|---|---|---|
| **Risk severity** | **Substantial**<br>(possibly critical in some regions)<br>Some pricing of risk already emerging in property portfolios. Literature highlights increasing risks, though risks vary across the EU because of differences in national insurance policies. The forward-looking impact of other (climate) risk drivers might have been underexplored, compared with the large number of studies on specific hazards such as floods. | **Critical**<br>(possibly catastrophic in some regions)<br>Literature indicates increasing climate risks to property and insurance markets in some European regions/countries. Potential pathways of rising unaffordability and private insurance withdrawal (especially for some countries). This might also lead to greater liability falling back to the public sector. | **Catastrophic**<br>Literature identifies major insurance problems (affordability and coverage) in long-term high warming scenarios (especially for some countries)<br>**Critical**<br>See mid-term |
| **Confidence** | **Medium**<br>Consistent findings in the literature that identifies property as a particularly vulnerable sector, though uncertainty around scale of risks. | **Medium**<br>Several flood modelling studies and growing insurance literature indicate increasing risk levels, but large uncertainties remain. | **Medium** |
| **Risk ownership** | **Co-owned**<br>The EU and its Member States have both legislative responsibilities relating to critical infrastructure and the services that they provide.<br><br>At the EU level the main relevant policy frameworks and initiatives include:<br>• Insurance Recovery and Resolution Directive (2021/582)<br>• Insurance Distribution Directive (2016/97)<br>• Solvency II Regulatory Framework (2015/35)<br>• EIOPA insurance stress test<br>• Floods Directive (2007/60)<br>• EU Solidarity Fund<br>• Social Cohesion Fund<br>• Union Civil Protection Mechanism<br><br>At the national level the main policies of relevance include those relating to:<br>• National insurance, insurance regulations and disaster payments<br>• National adaptation funding<br>• Spatial planning and infrastructure<br>• River basin management<br>• Civil protection and emergency preparedness | | |
| **Policy readiness** | **Medium**<br>At the EU level policies leave large regulatory discretion with regard to objectives and measures for the assessment and management of flood risks, there is a lack of binding and measurable flood risk standards and targets. The objectives are not quantified and measurable hindering the estimation of the level of effort, the estimation of costs and the cost-effectiveness of measures. There is still limited funding, insufficient implementation of measures, insufficient integration of adaptation objectives and river basin management plans objectives with sectoral plans. Current and future climate risks are not sufficiently addressed in river basin management plans. | | |
| **Policy horizon** | **Medium-term**<br>Reconfiguration of the insurance landscape, including the role of private insurers and public actors, may take considerable time | | |
| **Risk urgency** | **More action needed** | | |

Source: EEA.

# Part D: From climate risks towards societal preparedness

# 18 Synthesis: major climate risks for Europe

## 18.1 Key messages

- EUCRA has followed a systematic risk assessment process to identify, analyse and evaluate major climate risks for Europe, including the urgency to act.
- The EUCRA factsheets and storylines have identified and assessed 36 major climate risks for Europe, which are grouped into five clusters to facilitate the analysis of policy priorities.
- Climate change acts as a risk multiplier that can aggravate existing risks and crises. Climate impacts and risks can cascade from one system, region or cluster to another along a variety of transmission pathways, including from outside Europe.
- EUCRA confirms the key findings of the chapter on Europe in the IPCC Sixth Assessment Report, but it refines and extends the IPCC assessment in several ways.
- Southern Europe, low-lying coastal regions and the EU Outermost Regions are hotspot regions for multiple climate risks in Europe.
- The risk clusters related to ecosystems, food, health, and the economy and finance include climate risks that are at critical levels already. More than half (21 out of 36) of the key climate risks for Europe identified in this report need more action now, with eight of them being particularly urgent.
- All major climate risks for Europe identified in EUCRA are increasing over time. The increase will be larger in a high warming scenario than in a low warming scenario.
- In the absence of additional adaptation actions, almost all (34 out of 36) climate risks would reach critical or even catastrophic levels during this century in a high warming scenario.
- Adaptation planning needs to account for the lead times of adaptation actions and the lifetime of adaptation decisions, because the long policy horizons of many adaptation policies may require urgent action now to avoid critical climate risks further in the future.
- Southern Europe is a hotspot region for multiple climate risks from the increasing impacts of heat and water scarcity. Low-lying coastal regions, including many densely populated cities, are hotspot regions for multiple risks caused by sea level rise. The EU outermost Regions are hotspot regions for multiple climate risks owing to their remote location, weaker infrastructure and limited economic diversification.

## 18.2 Introduction

The thematic factsheets and risk storylines in this report (Chapters 3 to 17) identify 36 major climate risks for Europe, which may require action at the European or transnational level to avoid severe impacts on citizens, the economy or ecosystems of international importance in Europe. Chapter 10 additionally identifies three major climate risks for the EU Outermost Regions, which are not discussed in the remainder of this chapter. All factsheets and storylines apply a structured approach to assess the severity of these climate risks over time as well as key policy characteristics, involving an independent risk review panel. In a final step, the results of the risk analysis and indicative policy analysis are combined to assess the urgency for EU action for each major risk. The results are presented in structured risk evaluation tables. This process is described in more detail in Annex 2. There are some thematic overlaps between individual factsheets and storylines, and some risks draw on information from more than one factsheet or storyline. In those cases, the risk evaluation table is presented in one chapter only, even though it may draw on information from two chapters.

This chapter presents the aggregated findings of the structured risk assessment for all 36 major climate risks for Europe, which are grouped into five clusters. These clusters, and the links between them, are illustrated by an impact chain diagram. The final section discusses the outcomes of the EUCRA risk analysis in the context of the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6).

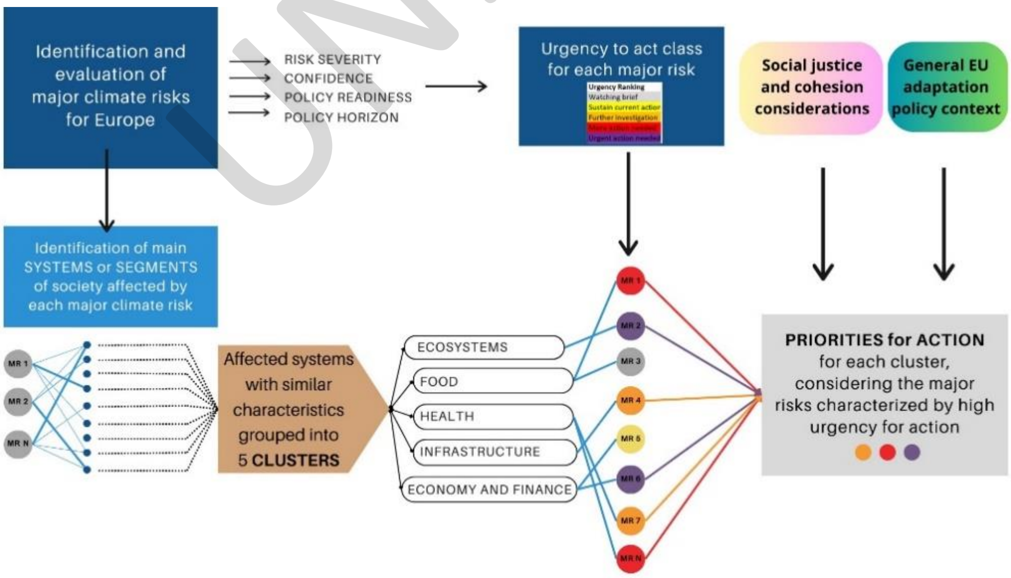
## 18.3 Clusters and cascades of major climate risks for Europe

The selection and structuring of the thematic factsheets and risk storylines in this assessment were informed by the structure of the IPCC AR6 and the key risks for Europe identified within it, considering also the delineation of EU policy areas. This process resulted in the selection of eight factsheets (including one focusing on the EU Outermost Regions) and seven storylines.

To facilitate a strategic discussion of climate risks and policy priorities in Europe, the 36 major climate risks for Europe identified in EUCRA are grouped into five broad clusters of interrelated risks that affect similar human or natural systems. These clusters highlight the links between individual climate risks identified in EUCRA and larger systems and policy areas. Their identification is the result of an in-depth analysis of the factsheets and storylines, which comprised the following steps (see Figure 18.1):

1. Identification of the main systems or segments of society affected by each climate risk.
2. Grouping of affected systems with similar characteristics into a cluster.
3. Assigning each major risk to one of the five clusters, based on the most direct or important impacts. Some risks cut across clusters, as shown in Figure 18.1, but tabular presentations, such as Table 18.1, list each risk once only under the main cluster.

**Figure 18.1 Approach to clustering major climate risks and determining priorities for action**

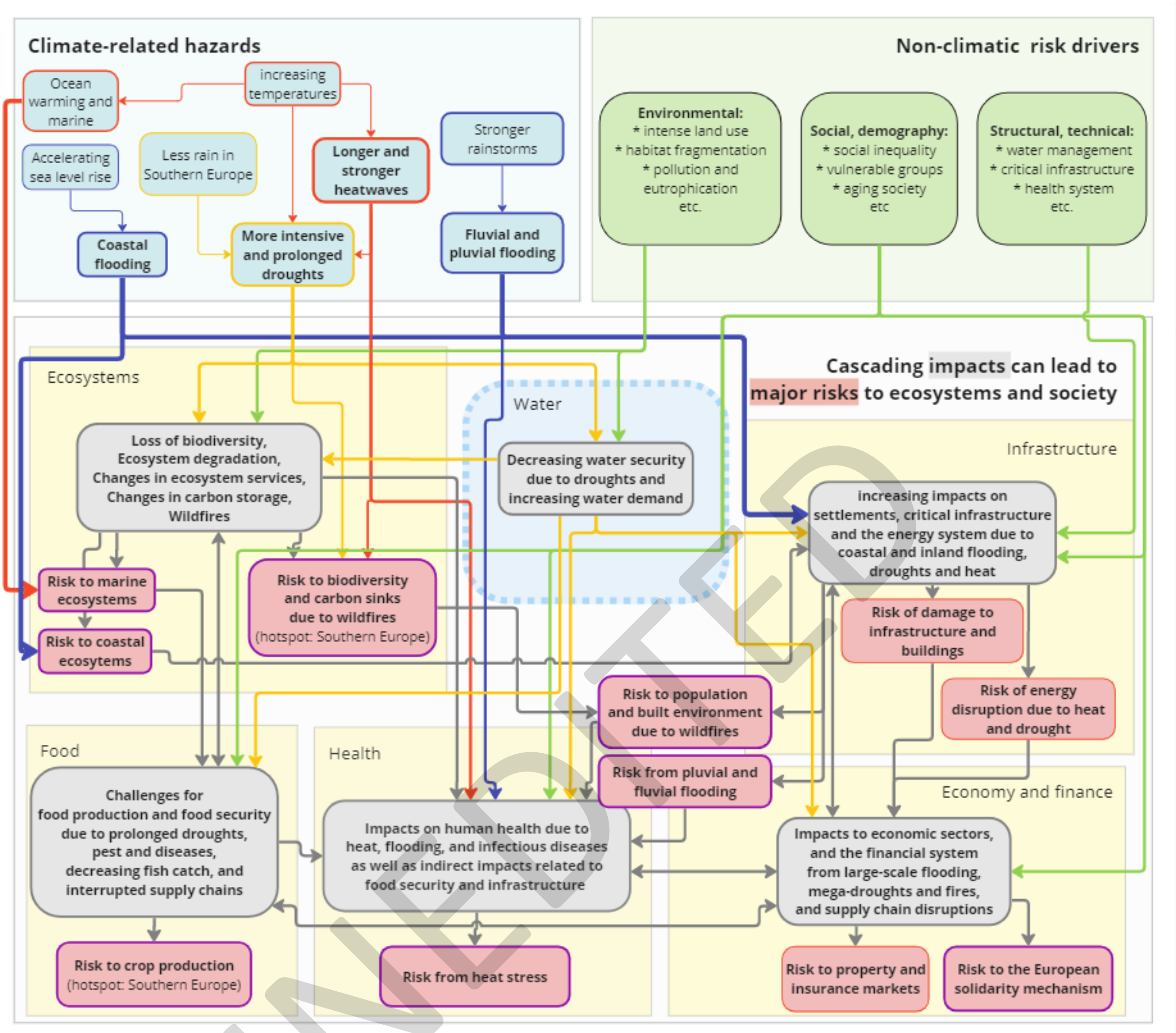



**Source**: EEA

Each EUCRA factsheet and several storylines used impact chain diagrams as a tool to analyse the transmission pathways from climate-related hazards and non-climatic impact drivers to direct and indirect impacts and risks on different subsystems. Figure 18.2 applies the same approach to clusters of climate risks. The figure illustrates how different climate-related hazards and non-climatic risk drivers create impacts and risks in individual clusters, and how risks originating in one cluster can cascade to others along various transmission pathways. Examples of risk cascades include:

- **Ecosystems:** climate impacts on terrestrial, freshwater and marine ecosystems can cascade to food production and security, human health, infrastructure and the wider economy.
- **Food:** climate impacts on food production (hotspot region: Southern Europe) can cascade to human health, rural livelihoods and the wider economy.
- **Health:** climate impacts on human health and well-being can affect labour productivity, and thus the wider economy.
- **Infrastructure:** climate impacts on critical infrastructure, such as energy or transport infrastructure, 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 a network can also cascade to other regions and countries.
- **Economy and finance:** many climate impacts can affect the economy and the financial system, from where they can cascade further to other policy areas that may be deprived of financial resources.

**Figure 18.2 Impact chain including cascading impacts and risks across five risk clusters**






**Note:** The diagram shows the links between key climate-related hazards, non-climatic risk drivers, direct impacts and the risk of these risk drivers according to five clusters, and cascading impacts and risks between the clusters. The diagram also includes a selection of the most urgent climate risks (red boxes).

**Source:** EEA

## 18.4 Structured risk assessment for major climate risks for Europe

Table 18.1 presents the aggregated results of the risk analysis, indicative policy analysis and urgency evaluation of all 36 major climate risks in EUCRA, grouped by cluster. Risks with substantially higher risk levels in one of the four subcontinental European regions (see Annex 2) are presented twice, once with the score for the 'hotspot region' and once with the pan-European score. This affects six risks, with the hotspot region always being Southern Europe.

For presentational purposes, the illustrations in Chapters 18 to 21 (including Table 18.1) and the Executive Summary use abbreviated names for the major risks identified in the EUCRA factsheets and storylines. Table 18.2 explains the correspondence between the short risk names in these illustrations and the long risk names in the underlying chapters, as well as the relevant chapters.

## Table 18.1 Risk assessment for 36 major climate risks for Europe

| Climate risks | Urgency to act | Risk severity: Current | Risk severity: Mid-century | Risk severity: Late century (low/high warming scenario) | Policy characteristics: Policy horizon | Policy characteristics: Policy readiness | Policy characteristics: Risk ownership |
|---|---|---|---|---|---|---|---|
| **Ecosystems** | | | | | | | |
| Coastal ecosystems | | +++ | +++ | +++ | Medium | Medium | Co-owned |
| Marine ecosystems | | +++ | +++ | ++ | Medium | Medium | EU |
| Biodiversity/carbon sinks due to wildfires (hotspot region: southern Europe) | | +++ | ++ | ++ | Medium | Medium | Co-owned |
| Biodiversity/carbon sinks due to wildfires | | +++ | ++ | ++ | Medium | Medium | Co-owned |
| Biodiversity/carbon sinks due to droughts and pests | | +++ | ++ | ++ | Long | Medium | Co-owned |
| Species distribution shifts (*) | | +++ | ++ | ++ | Medium | Medium | Co-owned |
| Ecosystems/society due to invasive species | | +++ | ++ | ++ | Medium | Medium | Co-owned |
| Aquatic and wetland ecosystems | | +++ | ++ | ++ | Medium | Medium | Co-owned |
| Soil health (*) | | +++ | ++ | ++ | Medium | Medium | Co-owned |
| Cascading impacts from forest disturbances | | + | + | + | Long | Medium | Co-owned |
| **Food** | | | | | | | |
| Crop production (hotspot region: southern Europe) | | +++ | ++ | ++ | Short | Medium | Co-owned |
| Crop production | | +++ | ++ | ++ | Short | Medium | Co-owned |
| Food security due to climate impacts outside Europe (*) | | ++ | ++ | + | Short | Medium | EU |
| Food security due to higher food prices | | ++ | + | + | Short | Medium | Co-owned |
| Fisheries and aquaculture | | ++ | + | + | Short | Medium | Co-owned |
| Livestock production | | ++ | ++ | + | Short | Medium | Co-owned |
| **Health** | | | | | | | |
| Heat stress — general population | | +++ | +++ | +++ | Long | Medium | National |
| Population/built environment due to wildfires (hotspot region: southern Europe) | | +++ | +++ | +++ | Medium | Medium | Co-owned |
| Population/built environment due to wildfires | | +++ | ++ | ++ | Medium | Medium | Co-owned |
| Well-being due to non-adapted buildings (**) | | ++ | ++ | ++ | Long | Medium | Co-owned |
| Heat stress — outdoor workers (hotspot region: southern Europe) | | +++ | +++ | +++ | Short | Medium | Co-owned |
| Heat stress — outdoor workers | | +++ | +++ | +++ | Short | Medium | Co-owned |
| Pathogens in coastal waters | | + | + | + | Medium | Medium | Co-owned |
| Health systems and infrastructure | | +++ | ++ | ++ | Medium | Medium | National |
| Infectious diseases | | +++ | ++ | ++ | Short | Advanced | Co-owned |
| **Infrastructure** | | | | | | | |
| Pluvial and fluvial flooding | | +++ | +++ | ++ | Long | Medium | Co-owned |
| Coastal flooding | | +++ | +++ | +++ | Long | Advanced | Co-owned |
| Damage to infrastructure and buildings (**) | | ++ | ++ | ++ | Long | Medium | Co-owned |
| Energy disruption due to heat and drought (hotspot region: southern Europe) | | ++ | ++ | ++ | Medium | Medium | Co-owned |
| Energy disruption due to heat and drought | | ++ | ++ | + | Medium | Medium | Co-owned |
| Energy disruption due to flooding | | ++ | ++ | ++ | Long | Advanced | Co-owned |
| Marine transport | | ++ | ++ | ++ | Medium | Medium | Co-owned |
| Land-based transport | | ++ | ++ | ++ | Medium | Medium | Co-owned |
| **Economy and finance** | | | | | | | |
| European solidarity mechanisms | | +++ | ++ | ++ | Short | Medium | Co-owned |
| Public finances | | ++ | ++ | ++ | Medium | Medium | Co-owned |
| Property and insurance markets | | ++ | ++ | ++ | Medium | Medium | Co-owned |
| Population/economy due to water scarcity (hotspot region: southern Europe) | | ++ | ++ | ++ | Medium | Medium | Co-owned |
| Population/economy due to water scarcity | | ++ | ++ | ++ | Medium | Medium | Co-owned |
| Pharmaceutical supply chains (*) | | ++ | + | + | Short | Medium | EU |
| Supply chains for raw materials and components (*) | | ++ | ++ | ++ | Short | Medium | EU |
| Financial markets | | + | + | + | Short | Medium | Co-owned |
| Winter tourism | | +++ | +++ | ++ | Medium | Advanced | National |

**Legends and notes**

Urgency to act: Urgent action needed; More action needed; Further investigation; Sustain current action; Watching brief

Risk severity: Catastrophic; Critical; Substantial; Limited

Confidence: Low: +; Medium: ++; High: +++

(*) Wide range of evaluations by authors and risk reviewers.
(**) Urgency based on high warming scenario (late century).



**Source:** EEA

**Table 18.2 Correspondence between major climate risks as presented in this chapter and the Executive Summary, and information in the underlying factsheets and storylines**

| Major climate risk (short name) | Major climate risks (long name) | Chap-ters |
|---|---|---|
| **Cluster 'Ecosystems'** | | |
| Coastal ecosystems | Risk to coastal ecosystems from coastal erosion and inundation from climate change in combination with other anthropogenic drivers | **4**, 12 |
| Marine ecosystems | Risk to marine ecosystems from climate change in combination with other anthropogenic drivers | **4**, 22 |
| Biodiversity/carbon sinks due to wildfires | Risks to biodiversity and carbon sinks from increased frequency and intensity of wildfires | **3**, 13, 11 |
| Biodiversity/carbon sinks due to droughts and pests | Risk to forest ecosystems and the carbon sink from more severe and frequent hot-dry events and related insect pest outbreaks | **13**, 11 |
| Species distribution shifts | Risks to food web dynamics and related ecosystem services due to phenological changes and species distribution shifts | **3** |
| Ecosystems/society due to invasive species | Risk to ecosystems and society from climate-induced species invasions | **3** |
| Aquatic and wetland ecosystems | Risks to aquatic and wetland ecosystems and their services due to reduction of low flow in rivers | **5**, 3 |
| Soil health | Climate risks to soil health related to direct impacts on soil parameters and to soil erosion | **3** |
| Cascading impacts from forest disturbances | Large cascading impacts across sectors originating from unprecedented forest disturbances | **13**, 15 |
| **Cluster 'Food'** | | |
| Crop production | Risk to crop production in Europe from adverse weather conditions due to climate change | **6**, 11 |
| Food security due to climate impacts outside Europe | Risk to food security in Europe from climate impacts on agricultural production and supply chains outside Europe | **16**, 6 |
| Food security due to higher food prices | Risk to food and nutrition security from increasing food prices due to climate impacts on food production in Europe | **6**, 11 |
| Fisheries and aquaculture | Risk to fisheries and aquaculture in Europe and international waters from changed environmental conditions due to climate change and related ocean acidification | **6**, 4 |
| Livestock production | Risk to livestock production in Europe from direct climate change impacts and increased spread of pests and diseases | **6** |
| **Cluster 'Health'** | | |
| Heat stress - general population | Risk to human health from heat stress increased by climate change | **7**, 11 |
| Population/built environmnent due to wildfires | Risk to population and built environment from wildfires facilitated by drought and heat | **11**, 7 |
| Well-being due to non-adapted buildings | Risk to human well-being from climate change impacts on residential and non-residential buildings | **9**, 7, 11 |
| Heat stress - outdoor workers | Health risks to outdoor workers from increased heat stress | **7**, 11 |
| Pathogens in coastal waters | Risk to human health from the emergence of harmful algal blooms and pathogens | **4**, 7 |
| Health systems and infrastructure | Stress to health systems, including health infrastructure, from climate change | **6**, 15 |
| Infectious diseases | Risk from geographic expansion and increased transmission of infectious diseases | **6**, 14 |
| **Cluster 'Infrastructure'** | | |
| Pluvial and fluvial flooding | Risk to population, infrastructure and economic activities from pluvial and fluvial flooding | **12**, 7 |
| Coastal flooding | Risk to population, infrastructure and economic activites from coastal flooding | **12**, 15 |
| Damage to infrastructure and buildings | Risk of damage to infrastructures and buildings due to slow-onset climate change and extreme climate events | **9**, 12 |

| | | |
|---|---|---|
| Energy disruption due to heat and drought | Risk of electricity disruption due to the impacts of heat and drought impacts on energy production and peak demand | **8**, 11 |
| Energy disruption due to flooding | Risk of energy disruption due to damage to energy transportation or storage infrastructure following coastal or inland flooding | **8**, 12 |
| Marine transport | Widespread disruption of marine transport | **15** |
| Land-based transport | Widespread disruption of land-based transport | **15**, 12 |
| **Cluster 'Economy and finance'** | | |
| European solidarity mechanisms | Climate risk to the viability of the European solidarity mechanisms | **17** |
| Public finances | Climate risk to public finances leading to a financial crisis | **17** |
| Property and insurance markets | Climate risks to European property and insurance markets | **17** |
| Population/economy due to water scarcity | Risks to population and economic sectors due to water scarcity | **5**, 11 |
| Pharmaceutical supply chains | Risk of a public health crises due to interrupted pharmaceutical supply chains caused by extreme weather events outside Europe | **16** |
| Supply chains for raw materials and components | Risk of business disruptions in key industrial sectors in Europe due to supply chain disruptions for critical raw materials or components from outside Europe | **16** |
| Financial markets | Risks to European financial markets from climate impacts in Europe and beyond | **17** |
| Winter tourism | Risks to winter tourism and countries or regions strongly depending on it | **5** |

**Note:** The left-most column shows the risk with the short name used in Chapters 18 to 21. The middle column shows the risk with the full name as used in the underlying factsheet or storyline. The right-most column indicates the underlying chapters, whereby the first number (in bold) corresponds to the chapter containing the risk assessment table.

**Source:** EEA

## 18.5 Cross-cutting results of the EUCRA risk assessment

### Risk severity

- Risk severity indicates the potential of a given risk to cause a major crisis in Europe as a whole or for one of the four subcontinental regions (see Annex 2). Risk severity and its confidence level were assessed for three different time horizons, using common criteria.
- Several major climate risks are already at critical levels now, either in Europe as a whole or in the 'hotspot region' southern Europe.
- All EU-wide major climate risks are increasing over time, and almost all of them (34 out of 36) could reach critical or even catastrophic levels during this century.
- Five risks (marked with *) show a considerable heterogeneity in the risk assessment across the authors and the members of the risk review panel.
- For most climate risks (27 out of 36), risk severity in late century is assessed as substantially higher under a high warming scenario than under a low warming scenario.

### Policy horizon

- The policy horizon indicates how important risk levels further in the future are for current adaptation decisions, depending on the lead time of adaptation actions and the lifetime of current adaptation decisions.
- Many climate risks are characterised by long policy horizons, meaning that more action may still be needed now even if current risk severity is not yet critical.

### Policy readiness

- Policy readiness indicates the preparedness of policies in Europe to manage a specific climate risk.
- Readiness was assessed primarily based on the coverage of risks in EU policies. Evidence on implementation effectiveness and coverage of national policies was additionally considered where available, but coverage is patchy. Therefore, the assessment of policy readiness in the first EUCRA should be considered indicative only.
- Readiness of most policies was considered as 'medium', which was the default option in this assessment.
- Policy readiness for some climate risks, where new or strengthened policies and measures were recently adopted (e.g. under the European Green Deal), was assessed as 'advanced'. This assessment must be considered as preliminary, because experience with the effectiveness of these policies and measures is largely lacking.

**Urgency to act**

- The urgency to act suggests the urgency and type of policy responses required to avoid critical or catastrophic risks for Europe now and in the future. It considers risk severity over time, confidence in the severity assessment, the policy horizon and policy readiness.
- The assessment of the urgency to act does *not* consider the availability, feasibility and effectiveness of adaptation actions, which are discussed in the IPCC AR6 (see Section 18.7).
- Risks evaluated as 'Urgent action needed' and 'More action needed' are those where additional policies and/or improved implementation are needed to prevent critical or catastrophic impacts in Europe. They should receive the highest priority from policymakers.
- 'Further investigation' indicates that the current evidence base appears insufficient for adopting specific new policies. Priority should be given to improving the knowledge base, including through targeted research activities, monitoring of risk levels, and a review of the policy framework.
- Substantial residual climate risks may remain even with additional policies and actions, because the effectiveness of adaptation actions can be limited for some climate risks (e.g. related to ecosystems).
- While risk severity in late century is assessed to be substantially higher under a high warming scenario than under a low warming scenario for most climate risks, assumption of the low warming scenario only decreases the urgency to act for two climate risks (marked with **).

**Hotspot regions**

- Southern Europe is a hotspot region for climate risks from the increasing impacts of heat and water scarcity on agricultural production, outdoor work, summer tourism and fire risk. Within southern Europe, rural areas and local economies dependent on ecosystem services are particularly at risk.
- Low-lying coastal regions, including many densely populated cities, are a hotspot for risks from flooding, erosion, and saltwater intrusion caused by sea level rise, and for ecosystem disruptions caused by sea level rise and ocean warming.
- The EU Outermost Regions are another hotspot, facing particular risks as a result of their remote location, weaker infrastructure and limited economic diversification.

## 18.6 Key findings of the EUCRA risk assessment for risk clusters

- **Ecosystems:** climate change is one of the main drivers of biodiversity loss and ecosystem degradation in Europe. Among climate risks related to ecosystems, risks to coastal and marine ecosystems have the highest severity in the current period as well as the greatest urgency to act.
- **Food:** Europe faces multiple challenges to food production and food security, including reducing its environmental impact. Crop production is already facing substantial climate risks in Europe as a whole, and critical risk levels in Southern Europe.
- **Health:** climate change poses major risks to human health systems. Risks related to heat are already at critical levels in southern Europe.
- **Infrastructure:** extreme weather events are posing increasing risks to the built environment and infrastructure in Europe, and the services they provide. Such events can disrupt essential services, including energy supply, water supply and transport networks.
- **Economy and finance:** the European financial system faces critical risks from the impacts of climate change, both within Europe and abroad. Serious sector- and region-specific risks to Europe could catalyse a systemic financial shock.

## 18.7 Climate risk assessment in EUCRA compared to the IPCC

EUCRA builds on the IPCC AR6, in particular its chapter on Europe, in several ways (Bednar-Friedl et al., 2022b). EUCRA implements several new features of the IPCC AR6, including the explicit consideration of non-climatic risk drivers; a stronger focus on compounding, cascading, cross-sectoral and cross-border risks; and the explicit consideration of dimensions of distributional justice related to climate change impacts and adaptation. It also builds on the assessment of climate impacts and risks in the IPCC AR6.

The IPCC AR6 chapter on Europe includes systematic overviews of climate impacts and risks for most, but not all, climate-sensitive sectors and systems addressed. For each impact/risk, this overview includes the driving climatic hazards and, in most cases, the interacting non-climatic hazards, affected systems and processes. It also shows the direction of change in these risks as well as the confidence in the assessment. The direction of change is presented for four subcontinental regions, which differ somewhat from the EUCRA regions, and for two future climate scenarios, which are consistent with the EUCRA scenarios (see Chapter 2). In most, but not all, cases the direction of change for the recent past and for Europe as a whole is also presented.

Out of the 26 sectoral 'risks' presented in the IPCC AR6 chapter on Europe (Sections 13.3 to 13.7), 19 are increasing in Europe, seven do not show a clear trend, and none are decreasing. In Section 13.10, these 26 sectoral risks are aggregated into four 'key risks' and nine sub-risks that are assessed semi-quantitatively, and, separately, into eight 'economic risks'. The 36 major climate risks identified in EUCRA show large overlaps with the sectoral 'risks', 'key risks' and 'economic risks' identified in the IPCC AR6 chapter on Europe. However, there are also important differences in the scope and approach between this report and the IPCC AR6.

The main goal of the structured assessment of major climate risks in this report is to support the identification of priorities for action related to climate risks in Europe. To this end, EUCRA extends the risk assessment in the IPCC AR6 chapter on Europe in several ways:

- The risk storylines in this report assess various 'complex' climate risks related to international supply chains or the financial system that are not assessed in the IPCC AR6.

- EUCRA identifies and semi-quantitatively assesses 36 major climate risks for Europe and three additional climate risks for EU Outermost Regions, compared with four key risks and nine sub-risks in the IPCC AR6.
- EUCRA assesses key policy aspects for each major climate risk, such as the policy horizon (lead time and decision horizon), risk ownership and policy readiness.
- EUCRA determines the urgency to act for each major climate risk based on the outcomes of the risk and policy analysis.
- EUCRA assesses the EU policy context for each major climate risk, including exposed EU policies and EU policy areas that can help reduce the risk. In contrast, the IPCC AR6 chapter on Europe conducts a systematic review of the effectiveness and feasibility of the main adaptation options for climate risks using adaptation pathways.

A full comparison of the aggregated risk assessments in this report and the IPCC AR6 is not possible owing to differences in the underlying methodologies and scopes, but there is very good agreement among these key findings:

- All major climate risks identified for Europe are increasing over time and with additional warming (at a pan-European level, with deviations possible for a few risks in specific regions).
- The assessment of risk severity for different time periods and warming levels in this report is in very good agreement with the semi-quantitative assessment of 'level of risk' in the nine 'burning embers' for the key risks in the IPCC AR6, assuming low to medium adaptation (Bednar-Friedl et al., 2022b, Figure 13.28).
- Southern Europe is a hotspot region for multiple climate risks, including economic risks, in particular those related to water scarcity and heat. Low-lying coastal regions are another hotspot for climate risks. Neither EUCRA nor the IPCC AR6 show a clear west-east gradient for the countries included in EUCRA (i.e. the 38 EEA member and cooperating countries).
- Adaptation planning needs to account for the lead time of adaptation actions and the lifetime of adaptation decisions, because long lead- and lifetimes can require urgent action now to avoid critical climate risks further in the future.

# 19 Social justice and cohesion

## 19.1 Key messages

- The repercussions of climate change disproportionately affect the most vulnerable. Its effects are felt unevenly across European regions, sectors and specific social groups.
- Inequalities and vulnerability work in a vicious circle where one worsens the other, leading to systemic, deeply ingrained disadvantages or discrimination. These inequalities reduce the capacity to recover from climate-induced disasters or to adapt to the changing climate, often leaving the most vulnerable and marginalised groups in more poverty-stricken and hazard-prone areas.
- Existing European policies and plans give limited attention to just resilience. Most focus is on distributive, and to some extent procedural, justice, with little to no attention on recognition justice.

## 19.2 Introduction

The impacts of climate change and future climate risks are not equally distributed across European sectors, regions and vulnerable groups. As extreme weather events occur more often, and will become more severe in the future, the poorest, marginalised and already vulnerable people and communities are those most affected by the impacts, both within Europe and beyond. These are also the first groups affected by long-term climate change dynamics such as rising sea levels or warming temperatures. A growing body of evidence demonstrates that these people and groups typically have the least capacity and capabilities to adapt, and are less likely to benefit from collective adaptation action, due to structural inequalities and limited political and economic capabilities (Bednar-Friedl et al., 2022a; UNEP, 2022). Adaptation action can exacerbate existing inequalities or create new risks. Although climate change risks affect us all, not everyone is able or willing to participate in decision-making processes, nor are all voices heard equally. Consequently, in the last couple of years justice has emerged as a key perspective in research and policy on climate impacts, adaptation and vulnerability, and it figures prominently in societal and political debates around the transition towards just resilience.

Although advancements have been made in operationalising and analysing justice, comprehensive and agreed assessment frameworks are lacking (Lager et al., 2023). Capturing social justice is often done by analysing financial or economic metrics, but it is becoming increasingly clear that non-economic aspects are critical to consider when assessing social justice. This chapter therefore adopts a broader perspective on social justice (see Section 19.3).

This chapter aims to synthesise evidence presented in earlier sections of the report and recent insights from scientific literature. It builds on comprehensive studies done in recent years, including the European Topic Centre on Climate change adaptation's report *Just Resilience for Europe* (Lager et al., 2023) and the chapter on Europe in the IPCC's Sixth Assessment Report (Bednar-Friedl et al., 2022a), and includes new insights where possible. At the same time, key knowledge gaps are signalled as is the need for further research on almost all aspects of social justice and cohesion.

First, the perspective on social justice used in this chapter is introduced (Section 19.3), followed by a comprehensive assessment of the key insights from previous chapters (Section 19.4). Next, Section 19.5 focuses on the role of social justice from a European cohesion perspective. This is followed by a broader perspective on how social justice is connected to cascading and transboundary climate risks, EU policy impacts on third countries, and EU policy more broadly (Section 19.6).

## 19.3 Unpacking the interplay between climate risks, actions and social justice

There are two main arguments for dealing with justice in EUCRA: (i) justice considerations are moral imperatives in line with the EU's core values, and (ii) scientific evidence shows that climate risks exacerbate structural inequalities and injustices, and adaptation to these risks can be more effective when justice is considered (IPCC, 2022b; Bednar-Friedl et al., 2022; Lager et al., 2023). In this chapter, justice is made operational by looking at both the drivers of risks and the risks emerging from responses to those risks, focusing on three core dimensions of justice (see Table 19.1). While there are many angles of justice, including environmental and climate justice, EUCRA refers primarily to social justice, unless otherwise specified.

Two intersecting drivers of risk are considered:

- **Climate risks:** climate-induced changes are not experienced equally across geographical regions, genders, income levels, classes, ethnicities, ages or physical abilities (IPCC, 2022a). The unequal distribution of climate impact and risk is driven by uneven exposure to hazards, pre-existing inequalities, and differences in adaptive capacities and capabilities (including e.g. socio-economic, historical and intersectional injustice) that result in exacerbated impacts and increased vulnerabilities. This inequality is further exacerbated when considering compounding and cascading risks.
- **Adaptation actions:** adaptation responses can redistribute, shift, reinforce or create new vulnerabilities/inequities now or in the future, generating 'winners' and 'losers'. Near-term adaptation responses shape future inequalities, poverty, livelihood security and overall well-being (IPCC, 2022g). When social justice dimensions are not adequately considered, adaptation actions can lead to maladaptation.

Climate change risks and responses are not happening in a vacuum. There are historical contexts to consider as well as other changes in society, including shifting resources, new dependencies, technological advancements and changing social structures and institutions. Within this context, this chapter uses three core dimensions of justice (IPCC, 2022i, 2022g; Lager et al., 2023):

- **Distributive:** refers to the unequal burdens and benefits from climate change impacts and risk among individuals, organisations, nations and generations, and the allocation of resources, benefits and burdens for adaptation actions and resilience-building activities. This is the major focus of this chapter.
- **Procedural:** refers to the increasingly recognised need to address the fairness and legitimacy of the decision-making process, including transparent processes, inclusive and meaningful participation, and respect for participants' rights. Procedural justice is linked to distributive justice as fair processes can lead to fair distribution outcomes.
- **Recognition:** refers to both a normative and functional principle that addresses the underlying causes of distributive and procedural injustices, as it addresses issues of what is valued and safeguarded. It often refers to respect, fair consideration of and robust engagement with diverse values, perspectives, cultures and worldviews in assessing the impacts of climate change and adaptation actions.

Other aspects of social justice, including restorative justice, are important to consider, but were not systematically assessed in this chapter due to limited evidence.

**Table 19.1 Examples of links between climate risk and dimensions of social justice**

| | **Unequal burdens (climate impacts and risks)** | **Leaving no one behind (adaptation actions)** |
|---|---|---|
| **Distributive justice**<br><br>*Conceptual description (the link between the two)* | **Who is impacted and how**<br>Climate impacts and risk affect people and places unequally, interacting with existing vulnerabilities in the allocation of burdens and benefits among individuals, nations and generations. | **Who is affected (and how) by adaptation action**<br>Adaptation action and resilience building can have unequal outcomes, creating 'winners' and 'losers'. It can redistribute, shift, reinforce or create new vulnerabilities and inequities (maladaptation). |
| *Example (the link between the two)* | **Unequal distribution of assets' value losses and income losses**<br>Certain groups are disproportionately affected by, for instance, flooding or heat because of geographical location, such as those operating or living in coastal areas and along rivers, farmers and people engaged or employed in the tourism industry, particularly in southern Europe. | **Energy savings in housing require dedicated policies to ensure affordability**<br>Adaptation to extreme heat is particularly relevant for vulnerable populations at risk. This requires dedicated policy packages, which frequently rely on incentives for the private sector. The public policies that incentivise these necessary investments by the private sector are generally reserved for homeowners and tend to exclude tenants, thus creating a high risk of inequity. |
| **Procedural justice**<br><br>*Conceptual description (the link between the two)* | **Due procedures and meaningful involvement of those affected by climate impacts (directly and indirectly)**<br>The way procedural justice interacts with unequal burdens is through the involvement of marginalised groups or individuals and increased transparency in the assessment of climate impacts and risks, as well as through recognition of rights and values. | **Who is heard and how in the adaptation process**<br>Addresses the fairness and legitimacy of the decision-making process, including fair and transparent processes, inclusive and meaningful participation and respect for participants' rights. |
| *Example (the link between the two)* | **Loss of natural capital and stakeholder participation in evaluating risk and losses**<br>Loss of natural capital and land use change pose a risk to livelihoods and cultures in Europe that are closely linked to ecosystem services and natural land use, and cause loss of intrinsic natural values, history, memories and benefits from biodiversity. Procedural justice requires the meaningful participation of the groups affected in the assessment and evaluation of risk and damage from climate change, defining what is at risk and what is valued. | **Participatory planning: recognising and involving vulnerable groups**<br>Citizen participation in choosing and evaluating adaptation options can include measures such as education and champions, as well as collaboration with different departments, agencies and vulnerable groups to help design adaptation policies and actions.<br>Such approaches can ensure a just set-up of participation processes for adaptation planning and managing hazards, through focusing on recognition and active participation, and address power inequalities within communities. |
| **Recognitional justice**<br><br>*Conceptual description* | Basic respect, robust engagement with and fair consideration of diverse needs, cultures and perspectives relevant to the climate impact/risk or adaptation measure. Addresses the underlying causes of distributive and procedural injustices, as it focuses on issues of what is valued and safeguarded. | |
| *Example* | **Stakeholder practices and power inequalities**<br>Stakeholder engagement does not automatically guarantee effective and fair adaptation outcomes, even if all those who have 'stakes' in the matter discussed are present. Stakeholder involvement processes often fail to consider diversity and power issues within communities, nor do they investigate how these diversities affect people's possibility to engage in participatory spaces in an egalitarian and meaningful way. The explicit recognition of climate change as a matter of social justice could help address power inequalities in communities. | |

**Note:** Conceptual demarcations and concrete examples to consider the link between aspects of climate risk and dimensions of social justice. The examples aim to illustrate the link between drivers of risk (climate impacts and risks and adaptation actions) and the three core dimensions of justice discussed in this chapter. As such, the example descriptions are not exhaustive and do not represent all aspects of a certain risk or intervention.

**Source:** Based on EUCRA thematic factsheets and risk storylines (Chapters 3-17).

## 19.4 Assessment of social justice across climate risks and adaptation actions

This section is based on the content in EUCRA's thematic risk assessments/factsheets and risk storylines (Chapters 3-17) addressing climate risks and social justice.

*Societal groups particularly vulnerable to climate risks and adaptation actions*

Certain groups of people are disproportionately impacted by climate change. In general, evidence on justice in climate change risks and adaptation in European policy sectors repeatedly identifies specific groups as especially vulnerable and at particular risk of having less influence on decision-making processes. These groups include the young (infants and children) and the elderly, people with disabilities, poor or low-income households, people in poor health, people with limited social networks, immigrants, ethnic minorities and indigenous peoples (EEA, 2022m). In 2022, approximately 22% of the EU population was at risk of poverty or social exclusion, with women (compared to men), young adults (compared to other age groups) and people with a low level of educational attainment at greater risk (Eurostat, 2023e). These groups thus provide a starting point where sector- or context-specific analysis or evidence are not available. An overview of these vulnerable social groups is given below. However, this summary is not exhaustive, and it is important to note that people often have several identities and belong to a range of different groups, which may exacerbate or lessen their vulnerability. Overall, social disadvantage-specific vulnerabilities are often mediated through spatial characteristics. Vulnerable groups are at increased risk when located in particularly exposed regions. Certain European regions are unevenly exposed to climate impacts; this interacts with vulnerabilities to create pronounced risks, including for southern Europe, geographically low-lying areas, certain remote and rural regions and livelihoods (e.g. EU outermost regions, Sámi herding communities, mountain environments). Spatial inequalities are also apparent at a smaller scale, such as urban neighbourhoods with less access to urban nature and greater impacts from air pollution (Venter et al., 2023).

**Group-based vulnerabilities:** Immigrants, ethnic minorities and indigenous peoples are subject to structural and historically embedded inequalities, rendering them particularly vulnerable to climate risks and maladaptive interventions, yet few studies have examined ethnicity-based vulnerabilities in the European context. For example, the chronic exclusion of indigenous communities from decision-making processes tends to reinforce maladaptive pathways and existing vulnerabilities and inequalities, which leads to sustained lack of recognition (including of rights, needs, interests, culturally specific perspectives and traditional knowledge), as demonstrated in the case of the Sámi in the European north (Bednar-Friedl et al., 2022a; Löf, 2013; Rasmus et al., 2022). Initiatives such as the Sámi Climate Council, recently established in Finland under the country's Climate Act, are therefore important to acknowledge, but large gaps still remain in mapping and understanding adaptation needs from the perspective of multiple and interacting vulnerabilities and identities (Johnson et al., 2022).

**Gender-based vulnerabilities:** Gender inequalities are one of the most widespread forms of group-based inequalities, as women, girls and gender minorities face disproportionate climate impacts and often have less say in decision-making processes. For instance, gendered social norms often dictate women's greater burden of family care-giving responsibilities, restrictions on mobility, and lower access to resources, including training and educational opportunities (e.g. learning how to swim), which can lead to disproportionate climate impacts (Borgonovi et al., 2022). Women conduct more paid (e.g. as medical staff and long-term care workers) and unpaid care work and thus may face significant work burdens during extreme events such as heatwaves. Gender norms may also dictate men's greater involvement in certain forms of work that increases vulnerability, such as work outdoors exposed to the sun or indoors with machinery that generates heat (Van Daalen et al., 2022). Heat stress is expected to reduce the summertime work capacity of outdoor workers in southern Europe by up to 60%, and this may particularly affect men and households with sole income earners. This requires gender-sensitive responses, including empowerment of women and marginalised groups, and ensuring rights, voices and leadership opportunities for those most affected, including engaging men in designing such responses. These responses are needed to reduce gender inequalities at all levels, from the local to the global climate policy level (Huyer et al., 2020).

**Socio-economic and occupation-based vulnerabilities:** Low-income households are likely to suffer more from climate change due to tighter financial constraints that limit their adaptive capacities (Breil et al., 2018). In many EU countries, more vulnerable communities tend to live in dense urban environments and, therefore, may be exposed to higher temperatures than others due to urban heat island effects (EEA, 2018d; Osberghaus and Abeling, 2022). Adaptation strategies adopted by wealthier social groups, such as air conditioning for heatwaves, are not always available to lower-income groups with tighter financial constraints. Lower-income households will also be disproportionally more sensitive to rising food and water prices resulting from climate change as these represent a much higher share of their budgets (Breil et al., 2018; EC, 2023f). Workers with some specific occupations are particularly exposed to climate risks, both from direct exposure to climate-related hazards (e.g. outdoor workers in agriculture, construction and emergency services, such as firefighters) and indirectly through impacts on their livelihoods (e.g. workers in tourism). Climate risks affecting educational facilities can exacerbate social inequalities by disproportionately impacting students from marginalised communities who attend schools located in hazard-prone areas (see also Chapter 7).

**Age- and health-based vulnerabilities:** Existing health conditions (e.g. cardiovascular, respiratory and kidney disease, obesity and diabetes), disability status and age are important biological risk factors for several climate-related health impacts (e.g. heatwaves as associated health risks and vector-borne diseases). For instance, pregnant women, infants, young children and the elderly are more vulnerable to heat extremes due to biological factors (Winklmayr et al., 2023), which may also interact with social factors such as discrimination (Van Daalen et al., 2022). Many children and young people, who face long-term implications of climate impacts, report significant climate anxiety which affects their daily functioning at a critical point in their psychological and physical development (Hickman et al., 2021).

### *Key findings from the thematic risk assessments (factsheets)*

The societal implications of climate change risks for Europe are unevenly distributed between regions and between societal groups, and climate-induced impacts are not felt uniformly across communities. The impacts of climate change vary according to socio-economic and socio-demographic characteristics, such as age, gender, race and ethnicity, income and wealth, health status and occupational setting. In general, higher vulnerability is associated with less access to political and economic resources, which raises distributive, procedural and recognition justice concerns in relation to the consequences of climate change risks.

Young children, the elderly, people with disabilities and low-income groups are identified as the most vulnerable in Europe for all the systems assessed. Immigrants with lack of access to citizenship rights and housing tenure, and those with limited local language and literacy levels are particularly vulnerable. For instance, lacking information directly compromises their capacity to effectively respond to early warning notifications of climate events. Within vulnerable groups, factors such as socio-economic, demographic and cultural circumstances influence individuals' level of vulnerability and can put some people at more risk than others in the same group.

In rural areas, individuals and communities who are more reliant on ecosystem services are more affected by climate-induced disruptions of these services. In urban areas, vulnerable groups usually benefit from services provided by urban green spaces, but the neighbourhoods with less and lower quality green spaces are typically found in communities of lower socio-economic status, overlapping with and exacerbating pre-existing vulnerabilities. Traditional lifestyles closely dependent on ecosystems are also at risk. With a clear hotspot in northern regions, Europe's indigenous Sámi people are witnessing threats to cultural and traditional livelihood practices, such as fishing and reindeer-herding activities. Shifts in seasonal patterns, snow and ice cover affect livelihood security and occur within the context of an historical and ongoing loss of land and reduced flexibility in land use due to increasing competition with other land uses. Other hotspots are in EU Outermost Regions, which already have low socio-economic standards in comparison to Europe's mainland, with critical services lacking. In addition, outermost regions are highly vulnerable to climate change impacts that will only exacerbate the socio-economic inequalities. Including indigenous and local knowledge is key in these regions to restore justice and make them more resilient to climate change.

Food security and food poverty also intersect with socio-economic inequalities, especially for self-provisioning people and low-income and minority groups. In this sense, self-provisioning people face the difficulty of reduced ecosystem services due to climate change effects. Moreover, the affordability of healthy food poses the largest challenge for economically deprived households: these spend relatively high shares of their budgets on food and, if climate change-related impacts increase food prices, poor households may buy less food or shift to less healthy diets. This would result in a lower intake of essential nutrients, or greater pressure on their finances.

The labour market will face challenges in a changing climate, in particular outdoor occupations (e.g. construction workers, farmers and fishers), which are at greater risk due to high exposure to heat. The food production workforce, including farmers and fishers, is impacted by multiple stressors as production or catch is highly sensitive to climate hazards and market responses to variations in supply and production quality. Interlinked impacts of climate change on energy prices and supply add to the burden for food-related professions. Workers in the farming and forestry sectors are also at increasing risk of infectious vector-borne diseases and wildfires in southern Europe. Besides the disproportionate greater effect on outdoor workers, heat stress will affect highly exposed indoor sectors, such as manufacturing. Sectors like construction, logistics and some commercial activities can also expose workers to heat stress or force them to engage in costly adaptation measures, such as changing their work schedules. This might lead to distributional consequences in terms of inequality and poverty since incomes in these sectors (e.g. agriculture and construction) are relatively lower.

In general, climate change impacts on workers' health – through increased temperatures, exposure to ultraviolet radiation, contact with pathogens, indoor and outdoor air pollution, and extreme weather – can result in higher health costs, reduced quality of life, production losses and threats to livelihoods. As stated above, heat stress affects both the health and human capital of workers: their health is negatively affected through increasing levels of discomfort and decreased cognitive functioning; simultaneously, those exposed to high heat will typically reduce their work output by taking more unplanned breaks or working at a slower pace.

Impacts exacerbate lack of justice, notably on different systems can also in closely linked sectors such as human health, the built environment, water and food security, and energy. When extreme climate events directly impact buildings and critical infrastructure – e.g. transport systems, energy plants, industry, water supply networks and health infrastructure – they can lead to cascading impacts on system's functioning, affecting livelihoods and economies. For example, direct impacts on buildings may worsen the expected damage from flooding, leading to physical harm to urban assets. Similarly, the indirect impacts caused by the loss of functionality of health facilities and the effects of heatwaves can give rise to a range of health problems, including increased mortality and morbidity rates. Another example is water security and energy: these have a strong nexus, since hydro- and geothermal electricity (which account for a significant portion of renewable energy in the EU) are highly dependent on the water regime. Water and food security are also intimately linked. The food supply chain and food security strongly depend on freshwater, and water quality has a direct effect on food systems through irrigation and processing.

*Key insights from the risk storylines*

Below, several recurrent pathways across the risk storylines are identified, which demonstrate the interconnectivity of climate risks, adaptation responses and key dimensions of social justice.

**The risk of losing home equity from property price deflation.** There is robust evidence that property prices do not entirely reflect the level of climate (notably flood and wildfire) risks to which properties are exposed; lower-income households are more likely to live in risk-prone areas and thus be negatively affected by the capitalisation of risk in property prices. This, combined with rising property values and rents in safer areas, can drive climate-related gentrification, as low-income households may be forced to relocate to more affordable but risk-prone neighbourhoods (De Koning et al., 2020). Limited affordable housing can also force low-income households to stay in risk-prone areas.

**The risk of widening the risk protection gap.** Climate-related gentrification is also driven by limited access to or low affordability of risk insurance. The risk protection gap is the difference between the level of financial or insurance protection that households and businesses should have in place, to adequately protect themselves against various risks, and the actual coverage. Some insurers and reinsurers are increasingly withdrawing from high wildfire and flood-prone areas, or they may consider doing so as climate change makes risk calculations more uncertain and erodes insurers' confidence. Higher insurance premiums coupled with reduced cover can further strain households with lower incomes.

**The risk of regional economic growth deceleration and recession.** All risk storylines in EUCRA provide compelling examples of how climate extremes can affect local and regional economies. These effects are mediated by the severity of disrupted livelihoods, productivity, critical infrastructure and supply chains, and are propagated through inflation and reduced purchasing power, declining tax revenues, lower public expenditure for social protection, loss of social cohesion and other factors that undermine resilience. Low-income and materially deprived households, as well as other marginalised social groups, face a disproportionate burden resulting from economic turmoil and societal disruptions.

**Reliable access to and affordability of essential services.** Essential services, such as public safety, healthcare and social protection, education, water and sanitation, electricity, transport, communication, banking and financial markets, digital infrastructure and public administration, are crucial for the wellbeing, overall quality of life and functioning of communities. Disruptions in essential services induced by climate extremes can push vulnerable social groups into poverty and social exclusion (EC, 2023t).

**The risk of unequal access to safe, healthy and nutritious food.** EUCRA storylines and factsheets show that compounding climate impacts of extreme events, drought, heat and water scarcity within Europe – particularly in southern and eastern Europe – can lead to lower food production, greater risk of failed harvests, higher food prices and less nutritious foods. Climate impacts on food production outside Europe can have direct consequences for global markets and lead to price volatility. This disproportionately affects already vulnerable groups and low-income households across all European regions.

**Responses to large-scale flooding can introduce new risks and associated inequalities.** Floods are known to disproportionately impact disadvantaged groups due to a range of factors, such as socio-economic status, access to information, housing conditions, disability or chronic illness and migratory status; existing forms of social exclusion may be further reinforced due to flood-related losses or displacement. Importantly, prevention activities and responses to floods may be highly contested because they introduce further inequalities and social marginalisation in their outcomes. For instance, construction of flood-reduction measures in urban areas may have negative impacts on local businesses, and such cases would benefit from consultative processes (Bonati, 2022).

**Outdoor livelihoods and recreational activities put certain people at greater risk of increased pests and disease transmission.** Emerging pests can cause significant damage to agriculture and forests, with particular implications for communities reliant on agricultural and pastoral livelihoods. In the case of disease-carrying insects like mosquitoes and ticks, certain groups of people may be more exposed through outdoor work, such as farming or fishing, or frequent outdoor recreational activities. In regions where men have greater involvement in outdoor work and lower health-seeking practices due to socio-cultural norms, they may face increased risks (Van Daalen et al., 2022). Certain biological risk factors (e.g. age, pregnancy or pre-existing health conditions) put some groups at greater risk of vector-borne diseases like Zika, dengue, West Nile virus or malaria, which can interact with social factors, such as living in housing without window screens or air conditioning.

**The depth, scope and speed of climate adaptation actions differs across types of settlements and sectors** (Berrang-Ford et al., 2021). Smaller communities, municipalities and cities typically have less capacity to adapt than large cities. Although cities are increasingly planning for adaptation, the quality of plans is relatively low, particularly around procedural and recognition dimensions of justice (Reckien et al., 2023). Evidence is emerging that adaptation in certain sectors, including agriculture and critical infrastructure, may create path dependencies as a result of short-term planning, policies and instruments, which displaces climate risks to future generations (see also Section 19.5) (Groen et al., 2023; Teodoro et al., 2023).

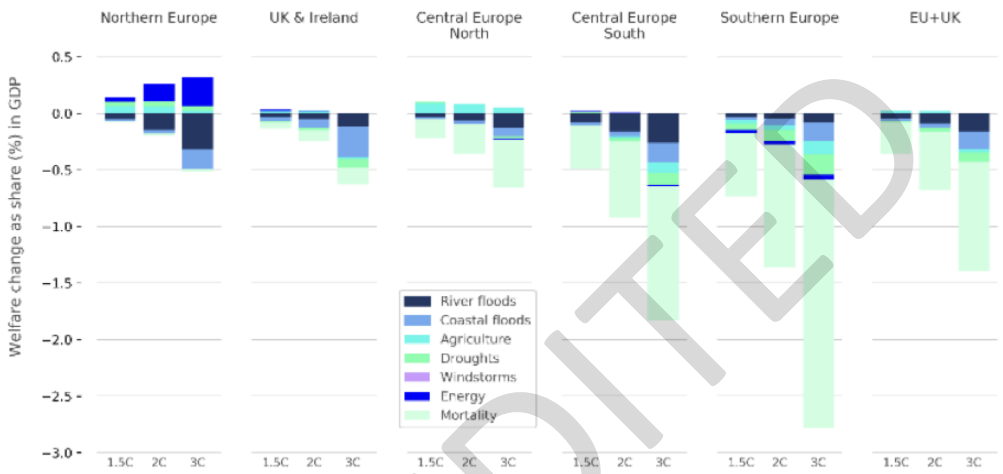
## 19.5 EU cohesion and social justice

EU territorial cohesion refers to the goal of achieving balanced and harmonious development across all regions of the European Union, covering social, economic and territorial dimensions. The EU has striven for economic and social cohesion, successfully reducing disparities between regions (European Commission, Directorate General for Regional and Urban Policy, 2022). Climate risks have the potential to exacerbate existing crises or create new ones, which may have additional impacts on cohesion in Europe. Spatial and territorial dimensions overlap with and amplify the vulnerabilities and exposure of different social groups. To consider this dimension of just transition, it will be important to go beyond comparisons of GDP per region with the average to fully reflect cohesion within territories.

*Physical risks of climate change as a challenge to EU social, economic and financial cohesion*

**Physical risks of climate change represent a challenge to EU cohesion, creating and reinforcing existing inequalities across territories.** They will be unevenly distributed geographically, reinforcing the existing north-south divide (Feyen et al., 2020c). Heatwaves and water shortages will unevenly affect Europe's southern territories, while northern countries could benefit in the short term from increasing temperatures (e.g. via a rise in agricultural output and hydropower). European-level estimations show that Cyprus, Greece, Malta and Spain could see a 40-fold increase in mortality from heatwaves if no adaptation and mitigation actions are taken. At the same time, floods will be a major risk for northern Europe, with the extent of damage dependent on adaptation interventions such as flood defence systems. Overall, welfare loss[28] as a percentage of GDP is estimated to be more than five times larger in southern Europe than in northern Europe in a 3°C warming scenario, exceeding -2.5% of GDP (Feyen et al., 2020c; see Figure 19.1).

### Figure 19.1 Welfare loss from climate impacts




**Note:** Welfare loss (% of GDP) from climate impacts considered at different warming levels by region. The results represent the change in welfare if warming levels would affect the current economy.
**Source:** (Feyen et al., 2020c)

**Climate risks can also affect financial cohesion across EU territories.** Financing conditions of small and medium-sized firms change across regions based on a region's exposure to floods (Barbaglia et al., 2023; Koetter et al., 2020).

**Climate risks can also superpose new inequalities on existing divides that already represent a challenge to EU cohesion.** Growing evidence highlights the difference in climate risk impacts for rural and urban citizens (European Commission, Directorate General for Regional and Urban Policy, 2022). For example, the close proximity to rivers that urban areas in Europe often have, as a result of the good transport connections these waterways offer to residents, leads to an increased risk of fluvial flooding. In addition, urban areas often see a combination of sewerage systems that are not fit to collect intense rain and densification resulting in increased soil sealing, which increases the risk of flooding. Moreover, the impact of heatwaves is felt particularly intensely in cities and towns (see Chapter 11) (European Commission, Directorate General for Regional and Urban Policy, 2022). The structure of regional economies also matters. Local economies, which are dependent on tourism, agriculture and forestry, such as the

[28] Welfare losses are measured in terms of consumption changes, using as input the direct damage estimates from the different impact categories. This includes damage to capital stock, sectoral productivity reduction, and changes in consumption. Welfare loss is in general larger than the direct damage because it accounts for indirect effects in other sectors of the economy (e.g. agricultural yield losses impacting the agro-food industry) (Feyen et al., 2020c).

Mediterranean region, the Alps, large parts of eastern Europe and Scandinavia, will be especially sensitive to climatic changes (ESPON Climate, 2011). By weighing on public finances (see Chapter 17), climate risk will also affect the social transfers from governments that help the most vulnerable, further increasing the vulnerabilities of these groups.

### *Adaptive capacities as a constraint for EU social, economic and financial cohesion*

In view of such unequal distribution of climate risks across Europe, adaptation measures will be key to ensure cohesion.

**However, adaptive capacities are not evenly distributed.** They are in fact often inversely proportionate to climate risk exposure (Diffenbaugh and Burke, 2019; Taconet et al., 2020; Tol, 2021). For instance, regions with populations of lower economic status are particularly affected by high temperatures, such as parts of Croatia, Greece, Italy and Spain where unemployment is high (EEA, 2018e). Adaptative capacities are strongly correlated with the state of public finances, since governments are still the main investors in adaptation projects (98% of adaptation finance that can be tracked is done by public actors (Climate Policy Initiatives, 2023)). As mentioned in Chapter 17, climate risks to public finances are substantial, while unevenly distributed geographically. Climate stress tests produce higher debt-to-GDP projections in Mediterranean and central-eastern European countries, even under 1.5°C and 2°C warming scenarios. Hence, Mediterranean and south-eastern European regions have the highest debt burdens and the smallest fiscal space to finance adaptive measures. In contrast, northern regions have high adaptive capacities that will allow them to compensate for the potential impacts of climate risks. The demographic changes affecting central-eastern Europe, particularly emigration and ageing, also contribute to a reduction of the region's adaptive capacity. This will not allow these regions to fully balance the negative impacts, resulting in medium to high levels of vulnerabilities (ESPON Climate, 2011).

### *Maladaptation as a challenge to EU cohesion*

There is increasing evidence that adaptation responses do not always reduce risks, but can displace them into the future, exacerbate existing risks or enhance vulnerability for certain groups (IPCC, 2022g).

**Maladaptation may pose a threat to territorial cohesion in the future.** For instance, seawalls and other infrastructure give people a false sense of security and encourage them to stay in locations or continue activities that make them vulnerable to climate change if the infrastructure is damaged (Nunn et al., 2021; Seddon et al., 2020). In a similar way, large-scale irrigation programmes protect intensive farmers from climate variability and price volatility, but also increase their exposure to present and future climate and market shocks because of larger cropping areas, higher water consumption levels and financial burdens (Albizua et al., 2019; Daliakopoulos et al., 2016). Also, from an institutional point of view, while increasing insurance coverage in agriculture is often cited as a key adaptation tool, it can lead to more farmer reliance on insurance and less resilience to climate change (Müller et al., 2017). These locally or regionally increased vulnerabilities and risks may in the long run contribute to greater disparity between regions across the EU.

**Maladaptation can enhance existing vulnerabilities and challenge social cohesion policies.** Adaptation requirements can also lead to increasing inequalities when necessary social buffers do not accompany the large investments needed (Lager et al., 2023; Albizua et al., 2019). For instance, costly adaptation regulations and measures often directly or indirectly increase real estate prices and rents. An example is the mandatory elevation of buildings to adapt to the risk of flooding, which is costly and can lead to the arrival of new social groups able to bear the high costs of the new developments. This increases the risk of gentrification and exclusion of the most vulnerable populations from the targeted areas (Lager et al., 2023). Large-scale irrigation programmes, for example, mostly benefited large-scale farmers as the high level of investment needed excluded smaller landowners (Albizua et al., 2019), and they can increase water insecurity if managed unsustainably, as described in Chapter 5.

**Maladaptation can emerge from conflicting scales of adaptation, threatening territorial cohesion.** What can be an appropriate adaptation strategy at a large scale can cause maladaptation risks at a lower scale. For example, European efforts for the green transition, particularly through renewable energy production and mineral extraction, may compete with limited land available for local-scale adaptation action, including nature-based solutions.

## *19.6* Social justice in climate-related EU policies and actions

From its inception, the EU has placed an emphasis on reducing disparities and inequalities across Member States. This commitment is underpinned by the Charter of Fundamental Rights of the European Union, which enshrines specific political, social and economic rights for EU citizens and residents. Over the decades, this commitment to equality has remained a cornerstone of the European project. Through cooperation and structural funds, the EU has strived to bridge the divide between advanced regions and those lagging behind. The Treaty of Lisbon expanded on the notion of social justice.

The United Nations' 2030 Agenda and the 'Leave no one behind' (LNOB) principle, which the EU has embraced, played a pivotal role in extending the application of principles of justice beyond solely social aspects. The European Pillar of Social Rights lays down 20 principles aimed at promoting equality and well-being across the EU. Serving as a dynamic guide to building a more just and inclusive society, it addresses aspects related to fair working conditions, gender equality, education, healthcare and poverty reduction. The European Consensus on Development underpins the EU's dedication to eradicating global poverty and promoting sustainable development worldwide. It emphasises economic growth, social inclusion, environmental sustainability and good governance as a core approach to international development cooperation. Addressing climate change was recognised as one of five strategic challenges for policy coherence for development. The EU's Just Transition Mechanism and Social Climate Fund are initiatives aimed at supporting those regions most affected by the transition towards a green economy, ensuring a fair and socially inclusive shift to a climate-neutral EU. The Council Recommendation on ensuring a fair transition towards climate neutrality (Council of the EU, 2022b) gives guidance to Member States on social, employment and skills policies for the green transition.

The 2021 EU adaptation strategy refers to social justice in the context of just resilience, the LNOB principle and the EU's external actions. It underscores the importance of collaborative efforts to attain both adaptation and social justice goals. Moreover, the strategy acknowledges that 'specific, tailored measures are required to tackle the unequal effects of climate change on vulnerable groups and human rights'. However, the specifics of these tailored measures are yet to be formulated. The strategy highlights procedural justice and the involvement of social partners in human capital investment planning. It advocates for economic diversification and transitioning workers to green growth sectors.

Addressing climate change risks and implementing adaptation measures equitably can present significant challenges for policymakers and decisionmakers. Without careful planning, adaptation actions have the potential to exacerbate inequalities by disproportionately benefiting economically privileged groups with access to resources and opportunities. If adaptation policies and measures place an unequal burden on some communities or sectors, it is essential to adopt effective remedies. Moreover, the extent to which adaptation can be successfully planned and implemented is critically determined by a complex interplay of contextual factors, including inequalities and disparities (Martin et al., 2022). Collectively, these factors shape the limits to adaptation.

Just resilience requires considering the principles of distributive, procedural and recognition justice. It aims to reduce vulnerabilities by addressing the root causes that create and perpetuate economic, social, political and environmental issues and inequalities (UNRISD, 2017). In doing so, it should give priority to the needs of marginalised and underprivileged segments of society. Procedural justice becomes pivotal in the pursuit of a more resilient and equitable Europe (see Box 19.1). The incorporation of participatory and transparent decision-making mechanisms is essential to empower all stakeholders and rights-holders to shape outcomes. Actively participating in political decision-making and involving everyone in adaptation policymaking can help reduce pre-existing inequalities that might be exacerbated by top-down approaches. Transformative change encompasses shifts in social structures, power dynamics, norms and institutions. Integrating local and indigenous knowledge into adaptation planning enhances resilience and helps prevent maladaptation. Youth engagement in climate and justice matters has also proven effective, underscoring the importance of recognition justice in boosting resilience (Pelling et al., 2015). In summary, it is important to prioritise the needs of marginalised groups when designing, planning and implementing adaptation measures, and actively engage their identities, experiences and knowledge systems to build a society resilient against climate change.



### Box 19.1 Climate litigation for social justice in Europe

Climate litigation is an emerging legal field in Europe, with currently close to 300 lawsuits in around half of European countries (Setzer et al., 2022). While still limited in number, adaptation cases are a body of case law that is growing, particularly under the 'failure to adapt and impacts of adaptation' and 'corporate liability and responsibility' categories[29]. The first classification involves cases seeking compensation for adaptation efforts that have caused damage, or injunctive relief for failing to adapt to known climate risks (UNEP, 2023). Globally, there are 14 cases (Setzer and Higham, 2023; UNEP, 2020) filed against governments or corporations, with three lawsuits in Europe (Setzer et al., 2022). The cases from the second category have been using the 'personal responsibility' strategy to incentivise the prioritisation of climate issues among public and private decisionmakers, by attributing personal responsibility for failure to adequately manage climate risks. Almost all personal responsibility cases documented to date are in Europe[30] (Setzer et al., 2022).

In general, climate litigation gives substance to claims from a social justice perspective. First, the cases above emphasise the disproportionate effect of detrimental social and economic impacts of climate change on individuals and communities who have contributed the least to climate change. They discuss the redresses available to victims for climate harms (Peel and Lin, 2019) and seek to foster equitable legal responses to climate change. Second, cases also have a bottom-up approach to decision-making processes and facilitate vulnerable groups' access to multilevel governance structures (De Jong et al., 2018), holding those responsible for climate risks accountable (Casper, 2019). Some cases have the potential to push broader societal shifts, and they may reshape public policies aimed at a safe climate through judges' decisions (Osofsky and Peel, 2013) and help to mobilise political action (Peel and Lin, 2019). Ultimately, climate litigation provides civil society with one possible avenue to address inadequate responses by governments and the private sector to the climate crisis (UNEP, 2023). Less than 20% of all climate lawsuits in Europe have targeted private

[29] Categories used by the United Nations Environment Programme.

[30] ClientEarth v. Shell's Board of Directors and McGaughey & Davies v. Universities Superannuation Scheme Limited.

actors, but at least 40% of them have been filed after 2020 (Setzer and Higham, 2023). This clear rising trend makes climate litigation a possible risk driver not only for governments but also for private actors.

Adaptation is less prominent in climate litigation due to some features of adaptation norms (Luporini, 2023). Although there is variation on the adaptation framework across countries, adaptation laws are usually fragmented and enacted through regulations spanning different sectors (Nachmany et al., 2019); they do not set precise targets, are context specific and have proven to be difficult to monitor and evaluate, which makes them rely on specific and non-generalisable legal statements (Luporini, 2023). From a legal standpoint, the Paris Agreement marked a step forward for adaptation within international law by pointing to the importance of adaptation to 'foster climate resilience' and in 'reducing vulnerability to climate change' (arts. 2 and 7) (UNFCCC, 2015). Regarding European legislation, human rights law may be useful to fill the gap in countries that do not have binding national laws on adaptation yet (Luporini, 2023). In this sense, the rights to life and to private and family life (arts. 2 and 8) of the European Convention on Human Rights (Council of Europe, 1953), combined with the fundamental right to a healthy environment enshrined in many national constitutions (De Vilchez Moragues and Savaresi, 2021), can serve to demand the enhancement of national adaptation plans and measures. Moreover, Article 5 of the EU Climate Law binds Member States to adopt and implement national adaptation strategies and plans (EC, 2021p). Along with the European Green Deal, these statements may play an important role as a source of domestic and regional obligations for future climate litigation.

Legal actions on the failure of governments and businesses to adapt to climate risks are likely to increase as the number of extreme weather events rises (UNEP, 2023) and climate impact attribution science matures further (IPCC, 2022g). As for the future, climate litigation is expected to increase before European courts led by new EU legislation, and it is likely to emphasise the duties and responsibilities of individual actors to integrate climate risks into decision-making processes (Setzer et al., 2022).



### *Outside EU context*

In a globalised world, economies and the resources that people and countries depend on are closely connected through trade, financial flows, the movement of people, and shared biophysical systems such as shared ecosystems (Hedlund et al., 2018; Challinor et al., 2017; Carter et al., 2021). For example, in trade and international supply chains (see Chapter 16), climate change impacts in one location can disrupt local economies and vulnerable people's livelihoods, while also affecting the price, quality and availability of goods and services on international markets (West et al., 2021; Dzebo and Adams, 2022). The past few years have seen growing awareness of the cascading and transboundary nature of climate risk. Transboundary and cascading effects of climate change may increase threats to international stability and security, and this affects people who are already in fragile and vulnerable situations (Lager et al., 2021).

There is far less awareness and knowledge of the potentially cascading and transboundary effects of adaptation actions. For example, resilience-building efforts, including market adjustment in the face of climate risk, and development interventions, such as those funded by the EU and other donors aimed at vulnerability reduction and climate adaptation, may inadvertently reinforce, redistribute or create new sources of vulnerability (Eriksen et al., 2021; Lager et al., 2021). This adds pressure on people and communities outside Europe whose capacity to respond or cope is already limited.

In Europe, there are two policy areas that consider international justice implications. Firstly, in development aid, where a few Member States are explicitly working on making their development assistance for climate resilience more just by supporting the least developed countries. Examples are climate proofing development aid to prevent maladaptation, and reducing inequalities, approaches carried out by Ireland and Finland (Lager et al., 2023).

Secondly, international dimensions are included in policies related to changing societies and the energy transition. The transformation of the economy, consumption patterns and geopolitics in the EU and elsewhere will have a significant effect on international trade, for example, affecting prices for food and agricultural products, energy and material inputs including metals, minerals and organic material (e.g. wood). Subsequently, poorer and the least developed countries will likely be disproportionately affected by these secondary impacts. To enable globally just resilience, it will be necessary to unlock adaptation investments and address political conflicts properly to lower barriers to adaptation for poorer and the least developed countries (Browne et al., 2022; Lager et al., 2021).

# 20 EU adaptation policies and risk ownership

## 20.1 Key messages

- The impacts of climate change are already compromising the ability of EU policies to meet their objectives. EU policies related to industry, public health, the environment and agriculture are particularly exposed to climate risks.
- Policy readiness was assessed as medium for most climate risks in this report, indicating considerable gaps in policy design or implementation. Recent EU policies have improved consideration of climate risks to the energy system, partly linked to efforts for climate mitigation, and around disaster prevention and preparedness, and for critical infrastructure.
- Most climate risks are co-owned by the EU and its Member States, requiring decisive and coordinated policy responses at both EU and national level. A complicated risk ownership landscape and a growing gap in adaptation finance is preventing robust and effective implementation of adaptation at both levels.
- Mainstreaming of adaptation and improved policy cohesion in EU policies related to biodiversity and ecosystems and to food and agriculture could significantly enhance Europe's resilience against multiple climate risks. Mainstreaming of adaptation into policies related to critical infrastructure and civil protection is also important.
- Most climate risks identified in this report have a medium- or long-term policy horizon, the latter particularly related to critical infrastructure and forest ecosystems. Therefore, current adaptation decisions related to these risks must account for the long lead times and decision horizons to avoid lock-ins into unsustainable pathways.

## 20.2 Introduction

Ever since the launch of the United Nations Framework Convention on Climate Change (UNFCCC) at the Rio Earth Summit in 1992, the EU has been widely regarded as a global frontrunner in international efforts to combat the threat of climate change, although EU policies were largely centred on climate mitigation in the decades that followed. Climate adaptation has however rapidly moved from being a nascent field of public policy to being high on the agenda within the European Green Deal. This reflects the growing awareness among EU institutions and Member States that global efforts have not been sufficient to limit global climate change. With the observed intensification of climate impacts and disasters in recent years, actions are now needed to prepare the EU for the consequences of climate change that are already locked in. The EU and its Member States have also become increasingly alert to the importance of dealing with the myriad physical climate risks facing the EU due to the increased frequency and severity of extreme weather events; these risks have already begun to have noticeable effects on Europe's economy, society and ecology.

The purpose of this chapter is to provide an overview of the EU policy environment in the context of climate change adaptation, and to outline some of the steps the EU has taken to mainstream adaptation across different policy areas. The chapter discusses some of the main challenges that are curbing the effectiveness of existing adaptation policies to safeguard Europe against the main climate risks identified in EUCRA. It also identifies some of the areas where a strong policy response is needed at EU and Member State level. Finally, the chapter highlights the importance of a systemic approach to strengthening climate resilience that considers cascading climate risks across sectors and policy interlinkages.

## 20.3 EU adaptation policy environment

### *20.3.1 Legal context*

The 2018 EU Regulation on the Governance of the Energy Union and Climate Action set out the initial legal foundations to ensure implementation of the EU's commitments on adaptation (alongside those on mitigation) under the UNFCCC and the Paris Agreement. It requires Member States to report on actions to adapt to climate change and to integrate adaptation goals into national energy and climate plans. Subsequently, the European Climate Law was introduced in 2021, which forms the current legislative backbone for EU policies and actions on climate adaptation, through Article 5, its provision on adaptation. Article 5 augments earlier regulations and commits EU institutions and Member States to strengthening their resilience to climate change in a policy-coherent and integrated manner, with Member States obliged to produce bespoke adaptation plans. In this context, the EU has begun to monitor progress by Member States on adaptation, in accordance with the European Climate Law.

Article 5 also required the European Commission (EC) to adopt a new adaptation strategy. This was launched the same year, as one of the central pillars of the European Green Deal, to improve the existing knowledge and management of the uncertainties associated with climate change and to step up efforts to bolster EU and global capacity to adapt to the impacts of climate change. Publication of the strategy came at a time when the physical impacts of climate change were intensifying and amid growing recognition that the earlier strategy from 2013 was no longer fit for purpose, with more transformative action needed to reduce the EU's exposure and vulnerabilities. Against this backdrop, the new adaptation strategy adopted an integrated approach to climate risk management and set out to mainstream adaptation across different policy areas. The strategy has introduced several new policy levers and institutional bodies to support climate risk assessments and management at EU and Member State level, and to leverage expertise and capabilities in existing EU institutions.

### *20.3.2 Implementation of the EU adaptation strategy*

The 2021 EU adaptation strategy set out to chart a blueprint for the EU to become a climate-resilient society that is fully adapted to the avoidable impacts of climate change by 2050, through four high-level objectives: smarter, faster, more systemic, and international adaptation to climate change. The strategy outlines 49 actions at EU level, to which the EC has committed, to deliver against the four objectives across a broader spectrum of policy areas and aligned with different time horizons. Together with the EC, several EU institutions play an instrumental role in implementing the strategy's actions to strengthen the evidence base and improve monitoring and management of climate risks across sectors at both EU and Member State level. These institutions include the EC's Joint Research Centre (JRC), the European Environment Agency (EEA) and the Copernicus Climate Change Service, among others.

Since the launch of the strategy, several important actions have been undertaken by the EC to improve the knowledge base of EU institutions and Member States on different climate risks and their impacts on European society (EC, 2023u). In conjunction with the inauguration of the strategy itself, the EC launched the European Climate and Health Observatory, its flagship initiative on 'smarter adaptation' that brings together the EC, the EEA and several other key organisations to facilitate cross-disciplinary collaboration around the monitoring and management of climate risks to human health. The observatory has, for instance, developed a near real-time monitoring tool for dengue outbreaks and, through this institutional partnership, enhanced the capability of health authorities in Member States to prepare for climate impacts on health across different time horizons. The EEA has worked on expanding the Climate-ADAPT knowledge exchange platform to strengthen the evidence base and improve monitoring and management of climate risks across sectors at both EU and Member State level. This includes the incorporation of evidence from different EU-funded projects on climate change and regular updates of relevant policy developments. The EEA has also developed the European Climate Data Explorer to facilitate the availability of, and access to, information on climate hazards and impacts.

The creation of the European Drought Observatory for Resilience and Adaptation by the JRC marked an important milestone: the early warning system brings together key drought indicators from different sources, including satellite Earth observation data from Copernicus, to aid public authorities and private sector actors to ameliorate the effects of droughts on water stress. The JRC has also implemented the adaptation strategy's action on establishing a Risk Data Hub, a web-based geographic information systems platform to help harmonise multi-hazard risk assessment data and methodologies across the EU and Member States; it is currently conducting the territorial risk assessment of climate in Europe (TRACE) project to assess the regional climate impacts in Europe across sectors.

The Destination Earth initiative will equip the EU and Member States with simulation capabilities to assess and predict environmental extremes at very high spatial resolutions. This initiative aims at enabling close-to-real-time decision-making and supporting adaptation policy through improved climate models, forecasting and preparation of tailored what-if scenarios for different sectors and users. A second EUCRA could make use of these capacities and provide Member States with novel tools to build resilience, anticipate environmental disasters and resultant socio-economic crises, and enhance the effectiveness of climate adaptation actions.

### *20.3.3 Recent and planned EU activities for mainstreaming adaptation*

One of the main objectives of the 2021 EU adaptation strategy is to adopt a more systemic approach to account for the systemic nature of climate risks and the interlinkages between both the affected policies and the policies that can play a mitigating role to address these risks. Against this backdrop, the EU has stepped up efforts to mainstream adaptation considerations in strategies and plans across different policy areas, to ensure that physical climate impacts are embedded into decision-making and planning at all societal levels and across sectors. The EC has been working with Member States to develop updated and expanded guidelines on their adaptation strategies and plans. These were published in 2023 to help Member States in developing comprehensive and effective climate risk assessment and adaptation strategies on a national level. The EC also established the Policy Support Facility, in partnership with the EU Covenant of Mayors, in 2021 to assist capacity building on climate action at subnational level, including adaptation; the European Climate Pact was launched the same year to provide information and tools to support grassroots mobilisation of climate action among European citizens.

The forthcoming EU Nature Restoration Law (adoption expected for spring 2024) has dedicated provisions on climate adaptation requirements; it also includes targets for urban, coastal, wetland and riverine habitats that support disaster risk reduction and climate adaptation. At the same time, the new EU forest strategy for 2030 outlines specific goals and measures for adaptation, including forestation and climate-resilient forestry. The EC proposed a revision of the Energy Performance of Buildings Directive that would make it mandatory for Member States to consider incorporating management of physical climate risks for both new and existing buildings; it also published technical guidelines on climate proofing of infrastructure and on enhancing buildings' climate resilience. Several EC activities have focused on integrating physical climate risks into macro-fiscal policies, in line with the actions outlined in the EU adaptation strategy. For instance, the EC carried out several exercises to assess national disaster risk management and disaster risk financing strategies across Member States, and proposed a reformed EU fiscal surveillance framework that would introduce new reporting requirements on macro-fiscal risks from climate change.

Other EU directives that are not referenced in the adaptation strategy also play an important role in strengthening resilience and facilitating adaptation in the EU. As an example, the EC adopted the Critical Entities Resilience Directive (Directive (EU) 2022/2557), which obliges Member States to better protect entities and services that are essential for the maintenance of vital societal functions and economic activities from a wide range of hazards, including climate-related and other natural disasters (EC, 2022c). The mainstreaming of adaptation has also become increasingly prevalent in the context of disaster risk management and is discussed in greater detail in Box 20.1.

Finally, the application of the 'Do no significant harm' principle across these and other EU policies and programmes also requires consideration of whether activities will lead to an increased adverse impact of current and future climate risks on the activities themselves, or on people, nature and assets (EC, 2021r).



**Box 20.1 Enhancing climate resilience through disaster prevention, preparedness and response**

The growing intensification and severity of extreme weather events in recent years underscores the importance of strong and robust EU-wide policies and capabilities around disaster risk management. As a result, the Union Civil Protection Mechanism (UCPM) is increasingly incorporating climate risks and scenario analysis into its work. In 2023, the EC adopted the Disaster Resilience Goals (DRGs) to better prepare the EU, Member States and UCPM participating states for different types of disasters. All the goals have some bearing on climate adaptation, directly or indirectly. DRG 1 (Anticipate) has a particularly important role in enhancing the EU's capacity to anticipate and withstand the effects of future natural hazard-related disasters accelerated by climate change: it is focused on improving risk assessment, anticipation and disaster risk management planning. DRG 2 (Prepare) is aimed at increasing the disaster risk awareness of the population and thus enabling people to be better prepared. DRG 3 (Alert) is focused on improving early warning systems. DRG 4 (Respond) is aimed at strengthening the response capacities for disaster events, which will be particularly important for climate-related hazards. DRG 5 (Secure) is concerned with the overall strengthening and future proofing of civil protection systems.

Designated flagship initiatives were announced, with the aim to deliver against each of the five goals. Under DRG 1, this includes the development of Europe-wide disaster scenarios to support planning and preparedness for disasters that transcend geographical and sectoral borders and consider both natural and human-induced drivers. This scenario-building exercise, currently under development, indicates that the UCPM is moving further into the realm of anticipatory policymaking, drawing on future climate projections to inform and adapt governance frameworks for disaster risk management.

Another activity linked to DRG 1, and regulated by the UCPM legislation, is the development of risk assessments at the national (or subnational) level by UCPM countries on a regular basis. Using the most relevant elements of these assessments and evidence from the EC's cross-sectoral policy work, the EC itself develops and updates an overview of the risks that the EU may face. The purpose of this overview is to capture the trends in the disaster risk landscape, foster a sound understanding of disaster risks facing Europe's population and inform decisions on risk management.

Despite these developments, wider efforts across different policy areas and financial instruments are urgently needed to enhance Europe's resilience. The UCPM was activated a record 130 times in 2023, depleting its resources faster than they could be replenished. This highlights the urgent need to invest in climate adaptation across all sectors.

### *20.3.4 International activities*

Alongside its efforts to strengthen the climate resilience of Member States, the EU has taken steps to enhance international climate adaptation in line with international agreements, such as the UNFCCC, the Paris Agreement, the United Nations Sustainable Development Goals and the Sendai Framework for Disaster Risk Reduction. For instance, the EC is currently working on supporting partner countries' efforts to develop and implement their nationally determined contributions, national adaptation plans, disaster risk reduction strategies and their reporting on Sendai Framework indicators for disaster risk reduction. The EC has also committed to advancing international efforts on adaptation, and it has joined and financially supported several international adaptation initiatives, including Adaptation Without Borders, the Africa Adaptation Initiative, the International Coral Reef Initiative and the All-Atlantic Ocean Research and Innovation Alliance.

## 20.4 Policy readiness, risk ownership and policy horizon

The latest EU adaptation strategy has played an important role in accelerating action on climate adaptation at both EU and Member State level and made marked improvements in mainstreaming physical climate risks into many essential policy areas.

Table 20.1 presents the aggregated findings of the indicative policy analysis from the thematic factsheets (Chapters 3-9) and risk storylines (Chapters 10-17) in this report. All the results of EUCRA's structured risk assessment, of which the policy analysis is a part, are presented in Chapter 18, and the underlying methodology is presented in Annex 2. The remainder of this section discusses selected findings from Table 20.1.

**Table 20.1 Key policy variables assessed for all major climate risks at EU level**

| **Major climate risks for Europe** | **Risk ownership** | **Policy readiness** | **Policy horizon** |
|---|---|---|---|
| Risk to population and built environment from wildfires | Co-owned | Medium | Medium term |
| Risk to society from inland flooding | Co-owned | Medium | Long term |
| Risk to society from coastal flooding | Co-owned | Advanced | Long term |
| Risk to ecosystem dynamics and carbon sinks from droughts and insect outbreaks | Co-owned | Medium | Long term |
| Cascading impacts from unprecedented forest disturbances | Co-owned | Medium | Long term |
| Risk of disruption of marine transport | Co-owned | Medium | Medium term |
| Risk of disruption of land-based transport | Co-owned | Medium | Medium term |
| Risk to food security from climate impacts outside Europe | EU | Medium | Short term |
| Health risks from interrupted pharmaceutical supply chains | EU | Medium | Short term |

| | | | |
|---|---|---|---|
| Risk to businesses from interrupted supply chains | EU | Medium | Short term |
| Risk to public finances | Co-owned | Medium | Medium term |
| Risk to the European solidarity mechanisms | Co-owned | Medium | Short term |
| Risk to European financial markets | Co-owned | Medium | Short term |
| Risk to European property and insurance markets | Co-owned | Medium | Medium term |
| Ecosystem risks from shifting climate envelopes | Co-owned | Medium | Medium term |
| Risk from invasive species | Co-owned | Medium | Medium term |
| Risk to ecosystem dynamics and carbon sinks from increased wildfires | Co-owned | Medium | Medium term |
| Risk to soil health | Co-owned | Medium | Medium term |
| Risk to coastal ecosystems | Co-owned | Medium | Medium term |
| Risk to marine ecosystems | EU | Medium | Medium term |
| Health risk from algal blooms in coastal waters | Co-owned | Medium | Medium term |
| Risk to aquatic and wetland ecosystems | Co-owned | Medium | Medium term |
| Risk to society due to water scarcity | Co-owned | Medium | Medium term |
| Risk to winter tourism | Co-owned | Advanced | Medium term |
| Risk to crop production in Europe | Co-owned | Medium | Short term |
| Risk to fisheries and aquaculture in Europe and internationally | Co-owned | Medium | Short term |
| Risk to livestock production in Europe | Co-owned | Medium | Short term |
| Risk to food security from increasing food prices in Europe | Co-owned | Medium | Short term |
| Risk to human health from heat stress | National | Medium | Long term |
| Risk from expansion of infectious diseases | Co-owned | Advanced | Short term |
| Risk to health systems and health infrastructure | National | Medium | Medium term |
| Risk to outdoor workers from heat stress | Co-owned | Medium | Short term |
| Risk of power cuts due to heat and drought | Co-owned | Medium | Medium term |
| Risk of energy disruption due to coastal or inland flooding | Co-owned | Advanced | Long term |
| Risk to infrastructure and buildings | Co-owned | Medium | Long term |
| Risk to well-being due to non-adapted buildings | Co-owned | Medium | Long term |

**Note:** The table presents the results of the indicative policy analysis from the thematic factsheets and risk storylines in this report.

**Source:** EEA.



### *20.4.1 Complex risk ownership for major climate risks*

Table 20.1 suggests that most major climate risks identified in this report (80%) are co-owned by the EU and its Member States. This means most policies that have a critical role in managing these risks fall either under the EU's shared competences or under multiple competence areas that are under the auspices of both the EU and its Member States. The 2021 EU adaptation strategy provides an overarching framework for European adaptation policies, but implementation occurs primarily through sectoral policies, many of which reside under the legislative remits of Member States. It is therefore important to recognise that while the high-level assessment of policy readiness conducted for EUCRA is focused on adaptation policies at the EU level, the primary legal responsibility for management of most climate risks identified in this report lies at the national (or subnational) level.

The complicated, and at times ambiguous, configuration of risk ownership presents a serious challenge for the implementation of robust and effective adaptation measures at the EU level, since the treaties that govern the EU's political and legal framework (vis-à-vis the EU competences and the subsidiarity principle) place significant constraints on the EU's ability to introduce binding legislation on adaptation. This is evident from the fact that the adaptation strategy is an EU communication, not a legal instrument, and thus is limited in its ability to set concrete and legally binding targets. Although some of the EU's commitments outlined in the adaptation strategy are legislatively underpinned by EU directives in relevant policy areas (e.g. the Water Framework, Floods and Energy Performance of Buildings Directives), many of its objectives and actions are vaguely defined, lack concrete proposals and must rely on voluntary commitments of Member States. As such, where there is a case for a stronger policy mandate for the EC to implement or enforce adaptation measures, the division of responsibilities may require reconfiguration, in line with the principle of subsidiarity and in agreement with European co-legislators.

EUCRA has identified the risk to marine ecosystems from climate change, in combination with other anthropogenic drivers, as a major risk that warrants an urgent policy response and where the EU can play a critical role for risk mitigation. While this risk mostly falls under the shared legislative responsibilities of the EU and its Member States, the cross-border nature of the risk and the affected systems means that the EU is best positioned to implement relevant adaptation measures through its common fisheries policy, in line with EU competences and the principle of subsidiarity. Three other major climate risks under the legislative auspices of the EU, relating to disruptions to supply chains for pharmaceuticals, critical raw materials, and agricultural products, require further investigation with respect to Europe's exposure and vulnerabilities.

### 20.4.2 Policy readiness analysis and its limitations

Table 20.1 suggests that, on their own, current EU policies are inadequate for managing the bulk of major climate risks identified in this report. Policy readiness was assessed as medium for most climate risks. This indicates limited consideration of climate hazards, short-term focus, lack of proactive actions, or a lack of clear targets. EU policies are more advanced around risks to the energy system, partly linked to efforts for climate mitigation, and around disaster prevention and preparedness, which are essential to ensure the resilience of the EU economy and society. However, this analysis should be considered indicative only, as its focus was on the paper-readiness of current EU policies. Owing to time and resource constraints, a systematic evaluation of policy readiness of Member States against the main climate risks was beyond the scope of the first EUCRA, but limited elements have been considered, in particular for risks owned at the national level.

While there have been positive developments around adaptation strategies and planning at national level, recent assessments suggest that adaptation in some Member States is not progressing sufficiently in keeping with the current urgency of risks facing Europe from climate change (Gram-Hanssen et al., 2023b, 2023a). Only a small number of Member States have introduced legal requirements to enforce horizontal policy integration across different policy areas and binding governance frameworks to ensure vertically harmonised adaptation planning across national and subnational levels (EEA, 2022b, 2023l). In contrast, most Member States have opted for national adaptation strategies and plans that adopt a soft-policy approach that relies on voluntary and informal cooperation, in the absence of legally binding commitments to enforce adaptation actions. As such, national adaptation policies in Europe have largely been incremental rather than transformative in nature.

### 20.4.3 Lead times, lifetimes and their implications for adaptation policy

Considering the policy horizon for any given climate risk is a central component of developing effective adaption policy. The policy horizon as assessed in EUCRA considers both the lead time for implementing effective adaptation actions as well as the decision horizon of current climate-sensitive decisions (see Chapter 18 and Annex 2 for further information). The policy horizon relates to the fact that it can be imperative to already account for long-term climate risks in current policy decisions and actions for certain key sectors, in a context where adaptation policies are likely to require longer lead times to implement (e.g. construction of coastal protection) or take effect (e.g. planting of forest species). Therefore, longer policy horizons may increase the urgency to act now, since actions may be required already in the current period, even if the climate risk is not expected to reach high severity levels until decades from now. Determining the policy horizon for climate risks is important, to avoid potential path dependence or lock-in of decisions made in the short term, which could increase exposure and vulnerabilities to climate impacts in the long haul.

EUCRA determined the policy horizon for each of the major climate risks identified at EU level, across three categories: short term (up to 2040), medium term (up to 2060) and long term (beyond 2060). Table 20.1 shows that nearly a quarter of the major climate risks for Europe were assessed to have a long-term policy horizon and almost half to have a medium-term horizon.

Longer policy horizons are particularly associated with major climate risks to infrastructure and forest ecosystems, whereas climate risks with medium-term horizons cut across most policy areas. On the other hand, nearly one third of the major climate risks identified were found to have short-term policy horizons. These climate risks relate largely to the impacts of climate change on food security, public health, supply chains and financial stability.

## 20.5 A systemic approach to strengthening climate resilience

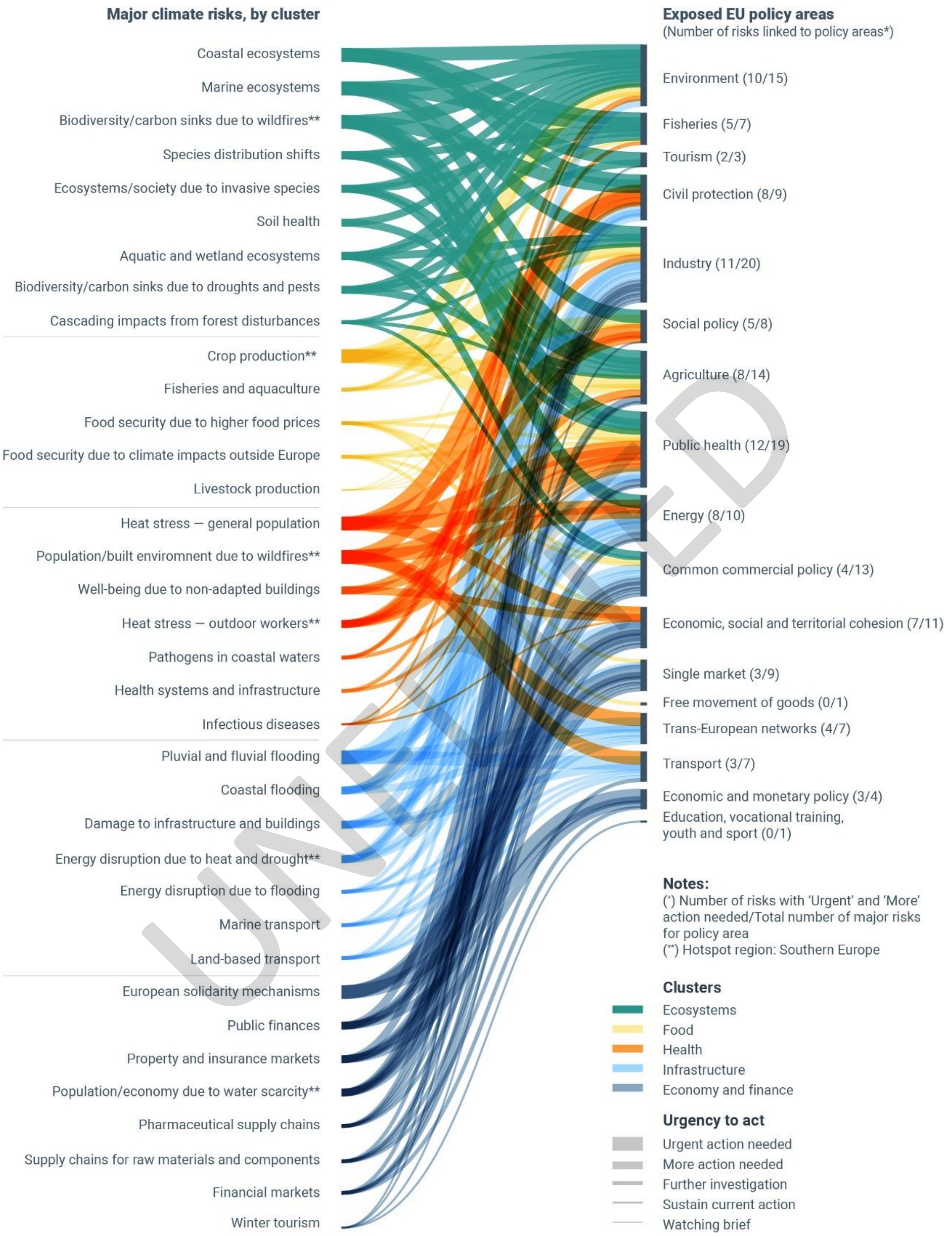
Based on the assessments of climate risks across the EUCRA factsheets and storylines, it is evident there is an urgent need for a holistic and integrated approach to effectively mitigate against the risks from climate change. Their systemic nature can yield compound and cascading impacts. This means that the most effective policy solutions for managing a climate risk can reside outside the policy area mostly affected by the risk. The cross-cutting nature of climate risks will often require horizontal integration and embedding of objectives and measures that cut across different policy areas and sectors.

### 20.5.1 Exposure of EU policy areas to major climate risks

The complex and systemic nature of climate change means that its impacts will transcend borders between countries, economic and societal sectors, and levels of governance. These climate impacts can also cause spill-over effects and feedback loops that act as risk multipliers for non-climatic threats, such as economic inequality, disease outbreaks and geopolitical conflicts. The effects of climate change are already compromising the ability and effectiveness of EU policies to meet their objectives, with serious implications for the EU economy and society.

Figure 20.1 shows the exposure of 17 EU policy areas to the major climate risks identified in this report, based on an expert assessment. The numbers in brackets refer to the number of major risks a given policy area is exposed to, whereby the first number only considers risks in the urgency categories ‘Urgent’ or ‘More action needed’. The policy areas most exposed to these ‘urgent’ climate risks are public health, industry and the environment, but agriculture, civil protection, energy and cohesion are also highly exposed. Therefore, a whole-government — or whole-EC — approach to strengthening climate resilience is urgently required.

## Figure 20.1 Exposure of EU policy areas to major climate risks for Europe




**Note:** The figure presents the exposure of 17 EU policy areas to the major climate risks identified in this report. The selection of EU policy areas is based on the Treaty on the Functioning of the European Union (TFEU) and focuses on those policy areas in which the EU has exclusive, shared or supportive competences (as defined in TFEU Articles 3, 4 and 6).

Source: EEA.

### *20.5.2 Stronger adaptation integration and policy coherence in key areas*

Despite significant EU efforts to mainstream climate adaptation across different policy areas, EUCRA has identified several policy areas where a stronger integration of adaptation would be particularly beneficial for enhancing climate resilience in Europe, through their potential to mitigate multiple climate risks.

Table 20.2 shows how often specific EU policies (including legal instruments, non-legal instruments and funding mechanisms) have been mentioned as relevant for addressing the major climate risks identified in EUCRA factsheets and storylines. EU policies that are centred on safeguarding the integrity of Europe's biodiversity, ecosystems and agriculture are shown to have particularly strong adaptation potential, and should be considered as policy areas where stronger integration of adaptation would be particularly beneficial for managing multiple climate risks. Since policy readiness at EU level was considered only 'medium' in these areas, there is a strong case for bolstering adaptation ambitions and actions through policy levers that fall under the biodiversity strategy for 2030, the farm to fork strategy, common agricultural policy (CAP), Water Framework Directive and the Nature Restoration Law, among others. Making progress on adaptation in these areas would also be in line with reports from Member States that have highlighted agriculture, forestry, water management and biodiversity as the sectors of greatest concern with respect to the impacts of climate change (EEA, 2022b). In fact, Member States that reported sectoral priorities for adaptation all emphasised that biodiversity is a high priority sector. Table 20.2 also underscores the key role for the Critical Entities Resilience Directive and the Union Civil Protection Mechanism in managing multiple climate risks, which corroborates the importance of existing EU efforts to strengthen the integration of adaptation in the context of critical infrastructure and civil protection.

**Table 20.2 EU policies with high adaptation potential, based on their links to major climate risks**

| EU policies with high adaptation potential | No of major risks linked to policy |
|---|---|
| Biodiversity strategy for 2030 | 11 |
| Critical Entities Resilience Directive | 9 |
| Forthcoming Nature Restoration Law (adoption expected in spring 2024) | 8 |
| Farm to fork strategy | 8 |
| Common agricultural policy | 8 |
| Union Civil Protection Mechanism | 8 |
| Water Framework Directive | 7 |
| Birds Directive and Habitats Directive | 7 |
| Forest strategy | 7 |
| Floods Directive | 6 |
| Renovation wave | 6 |
| Energy Performance of Buildings Directive and Energy Efficiency Directive | 6 |
| Corporate Sustainability Due Diligence Directive | 5 |
| Corporate Sustainability Reporting Directive | 5 |
| EU4Health | 5 |
| EU Solidarity Mechanism: Social Cohesion Fund | 5 |
| Marine Strategy Framework Directive | 4 |

**Note:** This table includes legal instruments (e.g. EU directives), non-legal instruments (e.g. strategies) and funding mechanisms, based on their mentions in EUCRA factsheets and storylines.

**Source:** EEA.

Alongside efforts to strengthen the integration of adaptation in these sectors, it is equally important to ensure that existing and future EU policies do not exacerbate climate change vulnerabilities. As an example, the CAP's coupled support payments in the agricultural sector can, under certain circumstances (e.g. cotton production in Member States facing water scarcity), increase water stress through heightening irrigation needs (EEA, 2019c; ECA, 2021b). In addition, support mechanisms under the CAP may, in some cases, aggravate climate risks by contributing to increased eutrophication, according to a study commissioned by the EC (Zhu et al., 2016).

### 20.5.3 Barriers to integration of adaptation in national policies

EU Member States have reported increased efforts to mainstream adaptation into national policy strategies, regulatory frameworks and planning processes across a broad range of sectors, with most efforts centred on sectors relating to water, agriculture, forestry and biodiversity (EEA, 2023l). However, there are several critical areas where integration of adaptation by Member States is lacking, including infrastructure and the economy. Harmonisation between adaptation and mitigation policies and measures is another area where progress has been limited.

Moreover, some significant governance barriers are hindering progress on mainstreaming adaptation. These relate to departmental silos between different governance structures that prevent effective coordination, constrained administrative capacity, and lack of accessible tools. One of the most important prerequisites for robust and effective policy integration is a coordinating body within a public authority with sufficient political mandate to supervise and, if necessary, enforce policy actions in sectors where implementation of adaptation measures is absent or insufficient (Gram-Hanssen et al., 2023a, 2023b).

### 20.5.4 Knowledge constraints for the development of systemic adaptation policies

Climate impact and risk assessments play a pivotal role in understanding climate risks and guiding sound policy decisions on adaptation. The EU has taken important steps to close critical knowledge gaps on climate impacts, risks and adaptation, including by increasing the availability of climate-related risk and losses data, and by improving climate risk assessment and management tools, as noted earlier in this chapter. However, the limitations of existing climate impact models and the lack of comprehensive climate risk assessments compromise the ability of policymakers at both EU and Member State levels to properly assess climate risks. Many climate impact assessments rely largely on extrapolations of historical data and trends. As a result, they perform poorly in accounting for non-linear climate change and tipping points, and largely neglect the compounding and cascading nature of climate risks. There is a growing body of evidence suggesting that the limitations of current climate impact models and risk assessments are resulting in a systematic under-estimation of climate risks (Newman and Noy, 2023a; Schwarzwald and Lenssen, 2022a; Stern, 2007). Since the IPCC's assessment reports and EUCRA draw largely on existing scientific studies and risk assessments for their own evaluations of risk severity, these analyses' findings are likely to suffer from the same limitations, resulting in conservative estimations of climate risks.

This problem is also reflected in the EEA's evaluation of adaptation progress at Member State level, where risk assessments are found to consistently fail to account for the interdependencies between climatic and non-climatic hazards, and for cross-border, cross-sectoral, compound and cascading climate risks (EEA, 2023l). A recent evaluation of adaptation policies in the Nordic countries similarly concluded that one of the major barriers to adaptation relates to the absence of holistic and integrated analyses that consider the socio-economic cost of climate impacts and the benefits of adaptation action and inaction (Gram-Hanssen et al., 2023a). The lack of such systemic assessments of climate risks will make it harder for the EU and its Member States to adopt a systemic and transformative approach to climate adaptation policymaking.

Many climate extremes and impacts that were previously projected to manifest further in the future are already happening today (Tollefson, 2022). Therefore, improved climate predictions and projections are essential to enhance adaptation planning and implementation at different levels and timescales. The EU should take further action to accelerate the development and use of next-generation climate models, climate impact models and risk assessments that can better account for complex, compounding and cascading climate risks.

## 20.6 Bridging the adaptation funding gap

The EU's budget is a fundamental policy instrument for the it to deliver against its climate objectives and targets. Funding for climate adaptation is mainstreamed through different policy areas and initiatives. The European Agricultural Fund for Rural Development (EAFRD) was previously the largest funding source earmarked for adaptation, with around EUR 10 billion allocated during the Multiannual Financial Framework (MFF) for 2014-2020, followed by the European Regional Development Fund (ERDF) and the Cohesion Fund (CF), with a total allocation of around EUR 4.3 billion

The EU is estimated to have allocated between EUR 13.9 billion and EUR 62.1 billion of funding to climate adaptation through its Structural and Investment Funds during the 2014-2020 MFF period. This includes the EAFRD, ERDF, CF, European Maritime and Fisheries Fund and the European Social Fund (EC, 2017b, 2018c). However, it is difficult to trace the allocation of EU budget expenditure to climate adaptation specifically, as the EC's tracking methods rarely differentiate between climate mitigation and adaptation objectives – the European Structural and Investment Funds being an exception (EP, 2020; ECA, 2021a). Moreover, there is even less transparency on adaptation investments at Member State level as there are no reporting requirements or tracking methods in place, including with respect to the mainstreaming of adaptation into existing funding instruments.

The EU has also financed adaptation projects through its framework programme for research and innovation and through the LIFE programme. Horizon 2020 funded 137 projects on climate adaptation for a total of EUR 848.4 million, whereas LIFE invested EUR 372.1 million across 158 projects on adaptation. More recently, the Recovery and Resilience Facility (RRF) – the centrepiece of the EU's post-pandemic recovery plan, NextGenerationEU – placed strong emphasis on climate action, with a 37% minimum target for spending on climate-related objectives.

The EC has launched the Mission on Adaptation to Climate Change (budget EUR 400 million) under the auspices of Horizon Europe. The aim is to help EU regions, cities and local authorities to: (1) better understand the climate risks they face, (2) develop pathways to be better prepared and cope with the changing climate, and (3) test and deploy innovative solutions needed to build resilience. Supported by the European Institute of Innovation and Technology's Knowledge and Innovation Community on Climate Change, the mission mobilises Horizon Europe funding to support the 311 regions, cities and local communities that have joined, to accelerate efforts to strengthen their climate resilience through innovation, in partnership with private companies and research networks.

Although the EU has increased the funding available for adaptation in recent years, adaptation investments have fallen far short of what is needed to safeguard Europe's economy, society and environment from climate change, as the European Investment Bank estimates that adaptation investment needs are in the range EUR 35-500 billion annually (European Investment Bank, 2021). In addition, while the RRF was primarily created as an instrument for recovery from the COVID-19 pandemic, albeit with a strong focus on the green transition, only around 5% of the total climate-related spending by the RRF was dedicated to climate adaptation (EC, 2022j).

The EU can play an important role in efforts to help bridge the adaptation financing gap, as its Member States are heavily dependent on financing instruments at EU level to support the implementation of adaptation measures at national and subnational levels (EEA, 2022b). Recent evaluations of adaptation policies in some European countries underscore that adaptation is seriously underfunded, receiving only a fraction of the financial resources available for mitigation (Gram-Hanssen et al., 2023b, 2023a).

# 21 Priorities for action

## 21.1 Key messages

- The EU and its Member States need to work together to reduce major climate risks effectively.
- Stronger EU policy action is urgently needed to manage several climate risks where the EU either has the legislative responsibility or is in the best position to act. The EU can also play an important role in improving the analysis of major climate risks identified in this report through legislation, monitoring, co-funding and technical support.
- A systems approach to adaptation and resilience building must be prioritised at both EU and Member State level to better account for cascading and compounding risks. Owing to limitations in current climate risk assessments, adaptation policies and actions should follow a precautionary approach to risk management.
- Addressing underlying social drivers of climate risks is essential to achieving just resilience. Inclusive decision-making processes that involve vulnerable and marginalised groups are essential to adaptation planning at national, regional and local levels.
- Stronger policy action in terms of ambition, scope and implementation is needed for each of the five clusters of interrelated risks assessed in this report: ecosystems, food, health, infrastructure, and economy and finance.
- Ecosystems: EU policies addressing risks to biodiversity and ecosystems need better coherence, and consideration of climate risks needs to be strengthened. Policy implementation and guidance to Member States for protecting ecosystems in a changing climate needs to be improved, with a focus on meeting concrete and operational targets. Reducing pollution from agricultural and industrial activities should be a priority for protecting Europe's ecosystems under climate change.
- Food: The consistency and coherence of key EU policies affecting food production and security needs to be improved. The common agricultural policy and common fisheries policy do not sufficiently address major climate risks and adaptation needs in their implementation. Production changes, dietary shifts and targeted social policies are further levers to ensure food security in a changing climate.
- Health: The climate risks to human health call for improved coordination of health policies at different levels and between Member States. The EU should design financial instruments and provide additional resources to shore up climate resilience in the healthcare sector, including cross-border support during emergencies. Many levers to reduce climate-related health risks lie outside classical health policies.
- Infrastructure: Priorities for national-level action include climate proofing existing infrastructure, and zoning and planning for new infrastructure. These actions can be supported by incorporating climate projections into the Eurocodes. Improved risk assessments should address risks to critical infrastructure at a systems level.

Furthermore, increasing resilience to climate change needs to be an essential part of EU climate and energy policies, including integrated national energy and climate plans.

- Economy and finance: Better integration of physical climate risks and adaptation needs is required for existing disclosure and due diligence frameworks. Stress tests need to better account for cascading, compounding and tail risks from climate change. European solidarity mechanisms that can be triggered in the case of climate-related disasters require additional funding. More action is needed to facilitate affordable access to and increase the purchase of weather-related insurance for homeowners and businesses.

## 21.2 Introduction

Throughout the chapters in this report, a set of major climate risks for Europe has been identified and evaluated based on their severity across time and the readiness of European policies to respond to these risks. The 36 major risks identified illustrate not only the complexity of climate risks facing Europe, but also the multi- and cross-sectoral nature of the responses needed to mitigate these risks. This chapter proposes priorities for action, comprising both policy- and knowledge-oriented action, to mitigate the most significant climate risks that Europe faces and will face in the future, based on the findings in the previous chapters.

This chapter is structured as follows. First, the inputs that informed the development of the priorities for action in EUCRA are highlighted. Second, the major climate risks for each of the five clusters described in Chapter 18 are presented, and priorities for action for each cluster are identified. The final section presents several cross-cutting priorities and considerations for action beyond individual risk clusters.

## 21.3 Inputs for identifying priorities for action

The priorities for action have been developed based on inputs from all chapters within this report as well as ad hoc input from various external stakeholders, ensuring the reliability of the risk assessment and its policy relevance. The urgency to act for major risks identified in EUCRA constitutes the core result from the structured risk assessment process. The approach adopted in EUCRA builds and expands on the methodology developed in recent national climate risk assessments (see Annex 2).

The identification of priorities for action was also informed by the findings of the policy analysis presented in Chapter 20, which draws on findings from all thematic factsheets and storylines in this report. This chapter discusses general characteristics, strengths and weaknesses of existing EU adaptation policy, which serves as a backbone for the development of priorities for action. It also identifies the complex links between the major climate risks identified in EUCRA and EU policy areas. Taken together, these findings stress the need for increased attention to the cross-sectoral characteristics of the identified major climate risks for Europe.

EUCRA has also analysed social justice and cohesion within and across the report chapters. The central findings from this analysis are summarised in Chapter 18, which includes key insights from the factsheets and storylines in the context of the wider literature related to social justice and cohesion. These inputs have informed the process of identifying priorities for action and are signposted where relevant.

EUCRA has benefited from engagement and consultations with external actors throughout the process. This engagement has informed the process of identifying priorities for action, ensured the reliability of the risk assessment and improved the policy relevance of EUCRA. Consultations with a dedicated Commission working group on EUCRA provided important input from experts across many directorates-general of the European Commission (see Acknowledgements) on relevant key EU policies and topical policy processes. The European Environment Information and Observation Network provided further comments on draft versions of this report. EUCRA also engaged an external advisory group and a risk review panel, which provided input on the evaluation of major risks identified and the policy analysis. However, the findings in this report, including this chapter, are ultimately the responsibility of the EEA and do not reflect the position of any of the institutional stakeholders involved.

## 21.4 Clusters of interrelated risks

The 36 major climate risks for Europe identified in this report were grouped into five main clusters of interrelated risks (ecosystems, food, health, infrastructure, economy and finance) to facilitate the identification of cross-cutting policy priorities in Europe. This process is described in Chapter 18. The clusters highlight the interconnectedness of major risks to larger systems and multiple policy areas, stressing the need to focus on groups of risks, rather than individual major risks, to enhance policy integration across sectors and to minimise the risk of maladaptation. For example, the 'food' cluster comprises agriculture as well as mariculture, which, despite facing separate and potentially unique climate risks, both impact the ability to produce food for domestic consumption and international trade. For each cluster, the main exposed EU policy areas and EU solution policies that could mitigate the most urgent risks, according to the structured risk assessment, are identified.

The following text presents the results of the clustering analysis, outlining for each cluster what is at stake (including key non-climatic risk drivers and social justice concerns), the major risks assigned, and the priorities for action, distinguishing between 'policy action' and 'knowledge action'. Major risks assessed as 'urgent action needed' and 'more action needed' were assigned priorities for policy action, while those characterised by 'further investigation' were assigned priorities for knowledge action. The priorities for action identified focus on the EU level, although avenues for policy action in areas of co-owned risk ownership are also taken into consideration.

### *21.4.1 Cluster: ecosystems*

#### *What is at stake*

Failing to protect key ecosystems from climate risks would lead to large-scale disruption of biodiversity and ecosystem services that may involve biological or climatic tipping points. Such disruption of ecosystem services could critically impact the existing water cycle, food production and infrastructure – with repercussions on carbon sinks, human health and economic activities. People and communities who depend heavily on ecosystem services, including indigenous populations, are particularly vulnerable to the impacts of climate-induced disruptions of these services. In addition, many adaptation measures are reliant on nature-based solutions and the good functioning of ecosystems. Non-climatic drivers that affect ecosystems include land use planning and, particularly, land use management, inappropriate afforestation and deforestation, biodiversity loss, land degradation and unsustainable practices like excessive water use and intensive farming, which negatively affect soil health and water quality and quantity. Worst-case drought scenarios, involving more frequent and severe multi-year droughts (far worse than the 2018-2020 sequence of compound hot and dry summers), present the most severe risks, including widespread and irreversible damage to ecosystems. In colder regions, extinction rates of Arctic-Alpine species could accelerate significantly if tipping points related to a decrease in snow cover duration are transgressed.

*Current risk ownership*

**Co-owned:** The EU is responsible for the transboundary nature of ecosystems and the repercussions that loss of ecosystem services would have at the EU-wide level. However, the localised nature of ecosystems calls for implementation at the Member State level.

### Table 21.1 Major risks of the ecosystems cluster and linkages to policy

| Major risk and urgency class | Key exposed EU policy areas | Key current EU solution policies |
|---|---|---|
| Risks to biodiversity and carbon sinks from increased frequency and intensity of wildfires*<br>** More action needed (all Europe); urgent action needed (southern Europe)* | Environment; agriculture; civil protection; public health; energy | Birds Directive; Habitats Directive; EU biodiversity strategy; EU forest strategy; Union Civil Protection Mechanism; Regulation on Land Use, Land Use Change and Forestry; Plant Health Regulation; European Forest Fire Information System; EU Solidarity Fund; global health strategy |
| Risk to coastal ecosystems from coastal erosion and inundation caused by climate change in combination with other anthropogenic drivers | Environment; fisheries; tourism, civil protection | Marine Strategy Framework Directive; Habitats Directive; EU biodiversity strategy; Water Framework Directive; Floods Directive; Maritime Spatial Planning Directive; Floods Directive; action plan on protecting and restoring marine ecosystems; EU principles of integrated coastal zone management |
| Risk to marine ecosystems from climate change in combination with other anthropogenic drivers | Environment; fisheries; industry; social policy | Integrated coastal zone management; Maritime Spatial Planning Directive; Floods Directive; Marine Strategy Framework Directive; common fisheries policy; EU biodiversity strategy; action plan on protecting and restoring marine ecosystem; Birds Directive; Habitats Directive; proposed revisions of the Urban Wastewater Directive; proposed Regulation on Carbon Removal Certification |
| Risks to food web dynamics and related ecosystem services due to phenological changes and species distribution shifts | Environment; agriculture; fisheries; public health | Birds Directive; Habitats Directive; EU biodiversity strategy; EU forest strategy; common agricultural policy; farm to fork strategy; guidelines for defining, mapping, monitoring and strictly protecting EU primary and old-growth forests; Water Framework Directive; Floods Directive; Plant Health Regulation; Floods Directive; Regulation on Deforestation-Free Products; global health strategy; proposed Regulation on Carbon Removal Certification; Nature Restoration Law (forthcoming ([31])) |
| Risk to ecosystems and society from climate-induced species invasions | Environment; agriculture; public health; fisheries | Birds Directive; Habitats Directive; EU biodiversity strategy; EU forest strategy; common agricultural policy; farm to fork strategy; Invasive Alien Species Regulation; Plant |

([31]) The Nature Restoration Law was adopted in the European Parliament on 27 February 2024, but was not yet adopted by the Council of the EU at the time of concluding this report. The remainder of this text assumes that the outstanding adoption by the Council will occur.

| | | |
|---|---|---|
| | | Health Regulation; global health strategy; Nature Restoration Law |
| Climate risks to soil health related to direct impacts on soil parameters and to soil erosion | Environment; agriculture | Birds Directive; Habitats Directive; EU biodiversity strategy; EU forest strategy; common agricultural policy; farm to fork strategy; guidelines for defining, mapping, monitoring and strictly protecting EU primary and old-growth forests; Water Framework Directive; Floods Directive; EU soil strategy; proposed Directive on Soil Monitoring and Resilience; Nature Restoration Law; Revised Regulation on LULUCF; global health strategy |
| Risks to aquatic and wetland ecosystems and their services due to reduction of low flow in rivers | Environment; fisheries; common commercial policy; industry; public health | Water Framework Directive; Nitrates Directive; Groundwater Directive; farm to fork strategy; zero pollution action plan; EU biodiversity strategy; Environmental Quality Standards Directive; Habitats Directive; Nature Restoration Law |
| Risk to forest ecosystems and the carbon sink from more severe and frequent hot-dry events and related insect and pest outbreaks | Environment; industry; agriculture; tourism | Habitats Directive; EU biodiversity strategy; Nature Restoration Law; EU forest strategy; Union Civil Protection Mechanism; proposed Forest Monitoring Law |
| Large cascading impacts across sectors originating from unprecedented forest disturbances | Environment; agriculture; common commercial policy; industry | EU biodiversity strategy; Nature Restoration Law; EU forest strategy; Union Civil Protection Mechanism; proposed Forest Monitoring Law |

**Note:** The colour coding in the left-most column describes the urgency to act (see Chapter 18 and Annex 2 for further information). The major risks are derived from the 'Terrestrial and freshwater ecosystems', 'Marine and coastal ecosystems' and 'Water security' factsheets, as well as the 'Extreme heat and prolonged drought', 'Large-scale flooding', 'Forest disturbances and carbon sinks' and 'Disruptions of critical infrastructure' storylines.



### *PRIORITIES FOR ACTION*

EU awareness on ecosystems risk is high, with many policies in place to respond to risks to ecosystems and their services. However, some critical gaps exist, which reduce policy readiness. These gaps concern, in particular, the multiple roles of ecosystems in terms of the different (and sometimes conflicting) nature-based solutions for mitigation and adaptation. Such roles include acting as carbon sinks, preserving biodiversity, managing climate disturbances (e.g. wildfires, heat, drought and pests) and preserving multiple ecosystem services. A sectoral management approach to these multiple roles may lead to potential incoherence and a less efficient response to major climate risks, which might exacerbate loss of biodiversity and ecosystem services, or not take advantage of potential co-benefits. Inconsistencies in the existing policies also relate to different time horizons, for example, certain nature-based solutions may reach full maturity on a longer timeframe, whereas mitigation and adaptation actions need to be effective in the shorter term.

#### *Policy action*

The main need from the EU is to improve the implementation of existing policies with ambitious targets, in order to deal with the multiple roles of ecosystems in mitigation and adaptation, the transboundary nature of risks, the importance of ecosystems at the EU-wide level, and the different time horizons. The EU also needs to strengthen its guidance on achieving the concrete and operational targets that are the responsibility of Member States. To that effect, the EU will benefit from implementation of the Nature Restoration Law.

Further guidance to Member States is needed in terms of spatial planning and soil health. In addition, implementation and restoration of protected area networks – within and outside Natura 2000 – is needed to benefit climate resilience, adaptation and biodiversity, by increasing ecosystem connectivity, reintroducing green-blue corridors in cities and agricultural land-city networks, among others.

Carbon sequestration may offer a more limited mitigation potential than presently expected and considered in current policy strategies. The EU land use, land use change and forestry (LULUCF) sector has been a net sink for the last 30 years. However, the sink potential is decreasing because of various climatic and non-climatic factors, which are further exacerbated by climate change. These factors include the current state and age structure of EU forests, climate change impacts, land use changes, harvesting of wood for economic use and adaptation of the forest sector to climate change. Thus mitigation efforts in the European Green Deal, for example, should have further ambition on decarbonising society rather than increasing forest carbon sinks. Improved management of climate disturbances like wildfires, through prevention actions and increased suppression capacities at both national and EU level (e.g. via rescEU), is needed to increase the mitigation potential and adaptative capacity of the forest sector.

Freshwater ecosystems also need particular attention as they are most degraded, influence other ecosystems and many of their services, and are linked with both climate and anthropogenic drivers.

Actions should be adopted to support and strengthen Member State-level adaptation plans for European coastal ecosystems and the coastal vulnerability to erosion and sea level rise. A quarter of European coastal countries do not have specific planning, and there is limited information on sea level rise planning and policies for most countries in Europe.

#### *Knowledge action*

Improved knowledge on linking future climate change to biodiversity and ecosystems is needed on multiple topics, including climatic drivers in soil health, algal blooms, pathogens and invasive species, and the overall management of ecosystem shifts northward with changing climatic conditions. Further development of knowledge is needed on the long-term vulnerability of specific ecosystems (such as forests) to abrupt climate disturbances like wildfires and related goods and ecosystem services.

### *21.4.2 Cluster: food*

#### *What is at stake*

Food security in Europe is impacted by climate-related hazards in combination with non-climatic drivers such as land use change, loss of habitats and forage areas, unsustainable water use, intensive production systems threatening soil health, pests and diseases, and economic factors. Failing to address climate risks to food security could lead to lower food production, greater risk of failed harvests, higher food prices and less nutritious food, disproportionately affecting already vulnerable groups and low-income households across Europe. Climate impacts on food production are, above all, a risk for the farmers and others whose livelihoods depend on food production. They can also affect the sustainability of rural communities, in particular in southern Europe. Nutritional deficiencies related to limited access to healthy and affordable food can impact human health, educational achievements, labour productivity and societal wellbeing at large, thus potentially affecting a wide range of economic sectors. Disruptions in food production both inside and outside Europe, in combination with non-climatic risk drivers, can potentially cause disruptions of global food markets through a mismatch of supply and demand, and trigger further system-wide shocks to financial instruments (via agricultural subsidies, stocks and bonds).

### *Current risk ownership*

**Co-owned and EU**: Agriculture is a shared competence, whereas the preservation of marine ecological resources under the common fisheries policy (CFP) is an exclusive EU competence. In the common agricultural policy (CAP), budgets and general rules are set at the EU level. Member States outline in CAP strategic plans how they combine targeted interventions addressing specific needs and delivering on EU-level objectives, with most decisions on implementation taken by the Member States. Food risks related to international trade are primarily co-owned, as trade policies fall under EU responsibility. However, Member States are responsible for key policies affecting food security, including taxation, social policies for vulnerable groups and provision of relevant information.

**Table 21.2 Major risks of the food cluster and linkages to policy**

| Major risk and urgency class | Key exposed EU policy areas | Key current EU solution policies |
|---|---|---|
| Risk to crop production in Europe from adverse weather conditions due to climate change *<br>** More action needed (all Europe); urgent action needed (southern Europe)* | Agriculture; environment; industry; social policy; public health | Common agricultural policy; Water Framework Directive; farm to fork strategy; Regulation on Land Use, Land Use Change and Forestry; Regulation on Minimum Requirements for Water Reuse |
| Risk to fisheries and aquaculture in Europe and international waters from changed environmental conditions due to climate change and related ocean acidification | Fisheries; environment; industry; social policy | Common fisheries policy; Marine Strategy Framework Directive; Maritime Spatial Planning Directive; EU biodiversity strategy |
| Risk to food and nutrition security from increasing food prices due to climate impacts on food production in Europe | Common commercial policy; public health; agriculture; economic, social and territorial cohesion; single market; public health | Farm to fork strategy; common agricultural policy; Fund for European Aid to the Most Deprived; European Food Security Crisis preparedness and response Mechanism; SCAN monitoring tool (under the auspices of the Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs) |
| Risk to food security in Europe from climate impacts on agricultural production and supply chains outside Europe | Common commercial policy; agriculture; free movement of goods; public health | Farm to fork strategy; Fund for European Aid to the Most Deprived; European Food Security Crisis preparedness and response Mechanism; Corporate Sustainability Reporting Directive; Corporate Sustainability Due Diligence Directive; SCAN monitoring tool |



**Note:** The colour coding in the left-most column describes the urgency to act (see Chapter 18 and Annex 2 for further information). The major risks are derived from the 'Food production and food security' factsheet and the 'Disruption of international supply chains' storyline.

## *PRIORITIES FOR ACTION*

The changing climate has significant impacts on food production, which calls for novel approaches to securing food safety in a changing climate. Several EU policies are relevant for food production, food security and trade, but the coherence of these policies concerning food security is not yet fully ensured. Currently, there is underutilised potential of the common agricultural policy to address climate risks for agriculture. Some incentives, for example with regards to crop selection and irrigation, could even increase vulnerability further in the future. The new CAP (2023-2027) includes flexibilities for Member States to support climate objectives, but it is unclear whether these will be sufficient to manage future climate risks. The common fisheries policy sets rules for ensuring environmentally and economically sustainable fisheries, and a monitoring framework and policy awareness of climate change impacts exist, but these impacts are currently not well integrated into policy. The fisheries and oceans package published in 2023, including two communications and an action plan, identifies climate impacts as negatively influencing fisheries and aquaculture. The proposed Corporate Sustainability Due Diligence Directive (CSDDD) aims to foster sustainable and responsible corporate behaviour throughout their value chains inside and outside Europe.

### *Policy action*

More action is needed in Member States' CAP strategic plans to strengthen context-sensitive measures that address drought risks to crops. Currently, only two Member States fund climate- and drought-resilient crops or varieties through national interventions, despite significant vulnerability to drought, especially in southern Europe. A report from the Commission *Summary of CAP Strategic Plans for 2023-2027* (EC, 2023x) shows that less than 2% of CAP spending is allocated to risk management tools. This situation calls for improving awareness of the risks to water-intensive crop production, increasing allocation of spending to risk management tools and for promoting action to minimise risks to drought-sensitive crops. The new CAP includes a requirement for Member States that 25% of direct payments to farmers be allocated to eco-schemes, but these remain voluntary for farmers. Mandating farmers to participate in some eco-schemes should be considered.

Taken further, food security could be promoted in a more integrated fashion by developing and promoting transformational agricultural practices that enhance ecosystem resilience (e.g. that address and contribute to improved soil quality and health, enhance water retention and limit erosion). Diversifying agricultural practices and promoting conservation and regenerative agriculture is important to increase adaptive capacity and cope with climate extremes. For example, biophysical modelling has highlighted that agroforestry practices show promise in promoting adaptive capacity. Agroforestry is integrated into the CAP, but enhancing its implementation would require political prioritisation and specific guidelines.

### *Knowledge action*

Despite growing awareness of climate change impacts on fisheries as well as interlinkages between climate change and other risk drivers, the CFP is yet to present explicit instruments to tackle climate risks to fisheries. Given the compound and cascading nature of climate risks, these instruments would need to be guided by a system-level understanding of risks and ensure consistency across sectors.

The proposed CSDDD does not consider corporations' exposure to physical risks throughout their value chains (within and outside Europe), which narrows its scope of influence for ensuring food security. Including climate change as a potential disruptor of supply chains in the directive would promote better awareness and action towards increasing resilience across supply chains. Balancing between self-sufficiency of food production, international trade and the EU population's nutritional needs is key. Addressing food security thus goes beyond individual EU policies and relates to many separate policy areas, including trade, economic policies, social and territorial cohesion, and public health. A better understanding of the interlinkages between the different policy areas in terms of food security is needed, to avoid the risk of sustaining vulnerabilities or exporting them from one region or population group to another. Furthermore, certain climate impact pathways, such as the links between climatic factors, pest and disease outbreaks, and food security are currently not properly understood.

### 21.4.3 *Cluster: human health*

*What is at stake*

Failing to protect human health risks associated with climate change would lead to increases in morbidity and mortality related to heat, with southern Europe being particularly at risk. Furthermore, various disease vectors transmitting zoonotic diseases are expected to expand geographically or extend their active season in response to changing climatic conditions, such as increased temperatures, heat and humidity. Climate change can also impact human health more indirectly, e.g. through climate impacts on food security, water quality, health infrastructure or other critical infrastructure. Underinvestment in many Member States' national health systems risks pushing them over the limit against these growing climate risks.

Climate-related health impacts are strongly influenced by biological risk factors, including existing health conditions (e.g. pregnancy, pre-existing chronic illnesses, non-communicable diseases, mental illnesses), disability status and age (particularly children and the elderly); environmental factors (such as air pollution, access to green and blue areas); and social factors (e.g. poverty, discrimination, exclusion and access to healthcare).

*Current risk ownership*

**Co-owned:** Health policies fall largely under the responsibilities of Member States, although the EU is the legislative authority to manage cross-border health threats (e.g. infectious diseases). The EU has also derived special competences to support policymaking and actions in some areas of health under the principles of subsidiarity, such as in coordinating pandemic response.



**Table 21.3 Major risks of the health cluster and linkages to policy**

| Major risk and urgency class | Key exposed EU policy areas | Key current EU solution policies |
|---|---|---|
| Risk to human health from heat stress increased by climate change | Public health; civil protection; economic, social and territorial cohesion; energy; social policy | EU4Health programme; EU adaptation strategy; health emergency preparedness and response; Critical Entities Resilience Directive; EU renovation wave; Energy Performance of Buildings Directive; technical guidance on the climate proofing of infrastructure in the period 2021-2027; emergency framework regarding medical countermeasures; Drinking Water Directive; legal mandate of the Health Emergency Preparedness and Response Authority and the European Medicines Agency, and their initiatives |
| Risk to population and infrastructure from wildfires facilitated by drought and heat*<br>** More action needed (all Europe); urgent action needed (southern Europe)* | Civil protection; public health; energy; trans-European networks; transport; agriculture | EU forest strategy; Union Civil Protection Mechanism; European Forest Fire Information System; Emergency Response Coordination Centre; proposed revision of the Energy Performance of Buildings and Energy Efficiency Directive; Critical Entities Resilience Directive; EU renovation wave; EU biodiversity strategy; Nature Restoration Law |
| Risks to health and livelihood of outdoor workers due to increased heat stress (southern Europe) | Public health; social policy; agriculture; industry | EU strategic framework on health and safety at work; Occupational Safety and Health Framework Directive; emergency framework regarding medical countermeasures; |

| | | |
|---|---|---|
| | | EU4Health programme; legal mandate of the European Agency for Safety and Health at Work and its initiatives |
| Risk to human well-being from climate change impacts on residential and non-residential buildings | Public health; economic, social and territorial cohesion; social policy | Critical Entities Resilience Directive; technical guidance on the climate proofing of infrastructure in the period 2021-2027; renovation wave; Levels – sustainable buildings framework; Energy Performance of Buildings Directive |
| Risk to human health from the emergence of harmful algal blooms and pathogens due to alteration of ecosystem functioning | Public health; environment; maritime affairs and fisheries | Marine Strategy Framework Directive; EU4Health programme; health emergency preparedness and response; Water Framework Directive; EU biodiversity strategy; Birds Directive; Habitats Directive |
| Stress to health systems, including health infrastructure, due to climate change | Public health; civil protection | EU4Health programme; EU adaptation strategy; health emergency preparedness and response; Critical Entities Resilience Directive; EU renovation wave; Energy Performance of Buildings Directive; emergency framework regarding medical countermeasures; serious cross-border threats to health; technical guidance on the climate proofing of infrastructure in the period 2021-2027 |

**Note:** The colour coding in the left-most column describes the urgency to act (see Chapter 18 and Annex 2 for further information). The major risks are derived from the 'Marine and coastal ecosystems', 'Human health' and 'Built environment' factsheets as well as the 'Extreme heat and prolonged drought', 'Infectious diseases' and 'Disruptions of critical infrastructures' storylines.

### *PRIORITIES FOR ACTION*

Extreme heat poses a serious threat to citizens' health and to healthcare services in the EU. The risk to human health from heat stress is particularly grave for the elderly and other vulnerable groups. It is also a growing threat for outdoor workers, in particular in southern Europe. High temperatures are also projected to increase the prevalence of numerous diseases, including neurological, cardiovascular, respiratory and renal diseases.

In addition, the growing disease burden from extreme temperatures, infectious diseases and water-borne diseases due to climate change will result in serious strains on public healthcare systems across Europe. At the same time, intensifying climate impacts are likely to compromise healthcare services, via direct effects on physical infrastructure and operations. While these climate risks will affect the health of EU citizens and healthcare services all over Europe, the impacts will be disproportionately felt in the southern and eastern regions.

EU action should complement national policies and respect Member States' responsibilities for defining health policy and for the organisation and delivery of health services and medical care. However, the European Parliament and the Council of the EU, acting in accordance with the ordinary legislative procedure and after consulting the Economic and Social Committee and the Committee of the Regions, may also adopt incentive measures designed to protect and improve human health, through measures concerning monitoring, early warning of and combating serious cross-border threats to health. Regulation (EU) 2022/2371 on serious cross-border threats to health explicitly includes health threats of environmental origin, including those due to climate change. The legal instruments provided for in the regulation therefore apply to the health consequences of climate change.

*Policy action*

Because overall investment in many Member States' public healthcare systems is failing to keep up with the growing demands and pressures on them due to climate change, the EU should design financial instruments and provide additional resources to shore up climate resilience and capacity in the healthcare sector. This could include an emphasis on legislation and locally driven policy activities, along with commitments from national governments for increased resilience of healthcare systems; encouraging public engagement through campaigns addressing climate change risks; and increasing support to existing initiatives, such as the European Climate and Health Observatory, which provides critical information on climate and health. Greater consideration of climate change impacts on human health is also needed in directives and strategies relating to building and spatial planning – especially to minimise the effects of extreme heat in cities.

The EU should explore establishing a framework and capabilities to support cross-border mobilisation of medical personnel in climate emergencies, as part of the Union Civil Protection Mechanism. Measures to support the upskilling of healthcare workers to evaluate and treat patients for illnesses that have not previously been prevalent in their countries and regions are also needed. More attention must also be given to critical health issues that fall below the scope of an emergency response but are enhanced by climate change (cardiovascular diseases, diabetes, infectious diseases, respiratory illnesses and mental health).

Considerations of climate-related health risks need to be better integrated into other relevant policy areas as well. As an example, the EU should leverage its legislative authority through European labour law to put forward mandatory requirements and robust enforcement mechanisms to protect outdoor workers in agriculture, construction and other industries from extreme heat. As part of the Critical Entities Resilience Directive, the EU could introduce provisions to enhance the resilience of healthcare infrastructure to climate impacts.

*Knowledge action*

Some Member States have already introduced heat-health action plans with multi-tier warning systems and protocols tailored for different temperature ranges. However, healthcare systems in many Member States may struggle to manage the increased disease burden due to climate change, and to sustain effective healthcare operations. The EU should therefore take immediate action to gain better understanding of the current capacity and level of preparedness of Member States' healthcare systems to respond to the growing health threats from climate change and improve coordination of adaptation measures between Member States.

Underpinned by the Regulation on serious cross-border threats to health, the Health Emergency and Preparedness Response Authority and the European Centre for Disease Prevention and Control have played a key role in bolstering surveillance efforts on some infectious diseases (e.g. malaria and dengue) and developing medical countermeasures. In addition, the European Climate and Health Observatory has played a key role in developing an integrated evidence base on the interplay between climate and health risks, with a view to operationalising this knowledge to support surveillance and capacity building actions.

However, the EU should continue to develop the climate risk assessments carried out by its institutions to cover a broader range of specific viruses and other priority pathogens and improve data on key vectors through more systemic collection, while blood bank capabilities should be improved to screen for tropical diseases. The EU should also explore measures to further improve government surveillance systems to track climate-related changes in disease outbreak and migration patterns.

### 21.4.4 Cluster: infrastructure

#### What is at stake

Failing to protect infrastructure and the built environment from climate risks would increase the risk of large-scale disruption of central pillars of contemporary societies, which could critically impact human health, economic activities, living conditions and mobility. The risk from climate-related hazards, such as rising temperatures and increased coastal and inland flooding, can be exacerbated by non-climatic risk drivers, such as age-related degeneration of infrastructure and poor land use planning. The longevity of built infrastructure and its infrequent replacement can lead to lock-ins if long-term climate risks are not considered in current planning. Climate change is threatening energy security through impacts on its production, generation, transport, transmission and demand. This risk is particularly high in southern Europe during heatwaves in combination with prolonged droughts.

#### Current risk ownership

**Co-owned:** Member States have authority over zoning and planning at the subnational level, and have primary responsibility for identifying and protecting critical infrastructure at the national level and for ensuring the climate proofing of this infrastructure. However, the new Critical Entities Resilience Directive gives the EU an oversight and support role for risk assessment and management of critical entities, including related to climate risks. The EU also influences Member States through infrastructure-related strategies, and it plays a prominent role in the development of the various trans-European networks. Energy is a shared responsibility between Member States and the EU, where EU energy policy focuses on ensuring the security of energy supply and functioning of the energy market, among other things.

**Table 21.4 Major risks of the infrastructure cluster and linkages to policy**

| Major risk and urgency class | Key exposed EU policy areas | Key current EU solution policies |
|---|---|---|
| Risk to population, infrastructure and economic activities from inland (pluvial and fluvial) flooding | Civil protection; public health; energy; transport; trans-European networks; industry | Floods Directive; Water Framework Directive; Union Civil Protection Mechanism; Critical Entities Resilience Directive; Seveso-III Directive; EU Solidarity Fund; Social Cohesion Fund |
| Risk to population, infrastructure and economic activities from coastal flooding | Civil protection; public health; energy; industry; trans-European networks; common commercial policy | Floods Directive; Marine Strategy Framework Directive; Maritime Spatial Planning Directive; integrated maritime policy sea basin strategies; Water Framework Directive; Critical Entities Resilience Directive; Seveso-III Directive; EU Solidarity Fund; Social Cohesion Fund; Union Civil Protection Mechanism |
| Risk of electricity disruption due to heat and drought impacts on energy production and peak demand *<br>* Further investigation (all Europe); more action needed (southern Europe) | Energy; industry; economic, social and territorial cohesion; environment; civil protection | Just Transition Mechanism; energy union strategy; clean energy for all Europeans package; Renewable Energy Directive; Energy Efficiency Directive; Energy Performance of Buildings Directive; Regulation on Risk-Preparedness in the Electricity Sector; strategy for energy system integration; EU Green Deal's provisions on just transition |
| Risk of damage to infrastructure and buildings due to slow-onset climate change and extreme climate events | Energy; transport; trans-European networks; common commercial policy; industry; agriculture | EU renovation wave; voluntary green public procurement criteria; technical guidance on the climate proofing of infrastructure in the period 2021-2027; EU taxonomy; Eurocodes; Construction Products Regulation; Critical Entities Resilience Directive; Floods Directive; Construction Products |

| | | |
|---|---|---|
| | | Regulation; sustainable buildings framework |
| Risk of energy disruption due to damage to energy transportation or storage infrastructure following coastal or inland flooding | Energy; transport; trans-European networks; common commercial policy; industry | Just Transition Mechanism; energy union strategy; EU strategy on energy system integration; Regulation on Risk-Preparedness in the Electricity Sector; Critical Entities Resilience Directive; REPowerEU; Regulation on Guidelines for Trans-European Energy Infrastructure |
| Widespread disruption of marine transport | Transport; trans-European networks; common commercial policy; single market; industry; maritime affairs and fisheries | Critical Entities Resilience Directive; integrated maritime policy; EU sea basin strategies; revised EU maritime security strategy and action plan; trans-European network for transport Guidelines (currently under revision); EC technical guidance on infrastructure resilience |
| Widespread disruption of land-based transport | Transport; trans-European networks; common commercial policy; single market; industry | Critical Entities Resilience Directive; EU renovation wave; Energy Performance of Buildings Directive; Energy Efficiency Directive; Floods Directive; trans-European network for transport Guidelines (currently under revision);; EC technical guidance on infrastructure resilience; Union Civil Protection Mechanism |

**Note:** The colour coding in the left-most column describes the urgency to act (see Chapter 18 and Annex 2 for further information). The major risks are derived from the 'Built environment', 'Energy' and 'Human health' factsheets as well as the 'Extreme heat and prolonged drought', 'Large-scale flooding' and 'Major disruptions of critical infrastructure' storylines.

### *PRIORITIES FOR ACTION*

Ensuring ambitious national-level action is key for promoting resilience of infrastructure across Europe. The EU has taken important steps in addressing the need for climate proofing of infrastructure and enhancing resilience of critical infrastructure and buildings, most importantly through the new Critical Entities Resilience Directive, which includes a requirement for Member States to conduct risk assessments (including climate risks) and to identify critical entities by 2026.

#### *Policy action*

The compound nature of many climate risks coupled with complex infrastructure systems calls for increased attention to multiple, cross-sectoral and cascading climate impacts on infrastructure, including critical infrastructure. Horizontal coherence across sectors should be reinforced to ensure that climate risks and climate-proofing measures are addressed within EU- and Member State-level funded infrastructure projects. Public procurement policies can serve an important role here in integrating climate risks into infrastructure design and planning.

Eurocodes, a series of European standards that guide the structural design of buildings and civil engineering works, are currently being updated. Eurocodes identify various climate risks, but they have thus far been limited by being based on historical data. Including predictive data would be necessary to account for future compounding and cascading climate risks. Furthermore, developing guidance that builds on ISO adaptation standards and promotes systems- and network-oriented methods would be beneficial for improving the capabilities of infrastructure to cope with climate extremes and cascading effects at the national level. The second generation of Eurocodes aims to better consider future impacts of climate change and will, among other things, introduce new requirements for the assessment, re-use and retrofitting of existing structures.

Considering the risks to energy infrastructure due to water scarcity and droughts, the further development of hydrological forecasting and monitoring systems could contribute to more effective preparedness of energy infrastructure. In areas with high drought risk, promoting the development and planning of renewable energy solutions that are less water intensive would further enhance the resilience and reliability of power supply.

*Knowledge action*

The availability of climate data and data on climate risks to infrastructure and buildings has improved in recent decades, including through establishment of the Copernicus Climate Change Service. The transition from using static to continuously updated data in infrastructure planning could be assisted by developing tools for post-processing data and statistical modelling, as well as making relevant datasets available in the form of georeferenced data (such as the Copernicus Climate Data Store). Such data and tools can help support national standardisation bodies in updating Eurocodes and construction standards, and in promoting climate change adaptation more generally.

The interconnectedness of infrastructure systems calls for the development of network-based and system-level assessments of the impacts of infrastructure failure on society. Synergies may be identified by assessing climate-related risks jointly with other risks, including from malicious actions. This entails developing reliable assessment methods to gain a better understanding of infrastructure vulnerabilities and their susceptibility to climate extremes and slow-onset climate change, both within and across sectors (e.g. using a system-of-systems approach). Improving information exchange among sectors and actors, including operators and regulators, and awareness of individual assets and connections can help to expose vulnerabilities that compromise resilience.

### *21.4.5 Cluster: economy and finance*

*What is at stake*

Failure to improve the resilience of economic sectors, international trade and key components of the financial system to climate risks could lead to large-scale economic and social impacts, from conflicts around scarce water resources to the disruption of important international supply chains. In the worst cases, entire markets could cease, supply chains halt, or important components of the financial system falter. The physical effects of climate change can challenge public and private actors in the financial system in different ways. The EU Solidarity Fund (EUSF) has been repeatedly overdrawn; recent extensive floods have already stretched public finances at the national level. At the same time, insurance providers in various regions are increasing insurance premiums substantially or considering withdrawing coverage for climate-related hazards. Decreases in insurance coverage or losing home equity from property price deflation because of climate risks can particularly affect low-income groups. The interaction of climate-related hazards with non-climatic drivers, from pandemic outbreaks to geopolitical tensions, can further aggravate risks in the economy and finance cluster.

*Current risk ownership*

**Co-owned:** Legislative authority for the complex European financial system and the wider economy is shared between the EU and Member States. The EU's exclusive policy levers are centred on international trade (denoted in Table 21.5 under 'Common commercial policy'), competition, monetary policy (Eurozone) and the internal market, and thus reside with EU financial institutions such as the European Central Bank (ECB) and the Commission. Responsibilities related to the internal market are shared between the EU and its Member States; Member States have exclusive legislative responsibilities with regards to industry.

**Table 21.5 Major risks of the economy and finance cluster and linkages to policy**

| Major risk and urgency class | Key exposed EU policy areas | Key current EU solution policies |
|---|---|---|

| | | |
|---|---|---|
| Climate risk to the viability of the European solidarity mechanisms | Economic and monetary policy; economic, social and territorial cohesion; single market | EC reform proposals and Multiannual Financial Framework; Capital Requirements Regulation; Capital Requirements Directive; Regulation on Credit Rating Agencies; EU Solidarity Fund; Social Cohesion Fund; Solvency II Directive; EU Financial Regulation |
| Risks to population and economic sectors due to water scarcity*<br>** Further investigation (all Europe); more action needed (southern Europe)* | Public health; agriculture; industry; economic, social and territorial cohesion; energy | Urban Wastewater Treatment Directive; Nitrates Directive; Communication on Water Scarcity and Drought; Bathing Water Directive; Drinking Water Directive; Water Framework Directive; common agricultural policy; Regulation on Minimum Requirements for Water Reuse; Environmental Quality Standards Directive; Renewable Energy Directive; circular economy action plan; Blueprint to Safeguard Europe's Water Resources |
| Climate risk to public finances leading to a financial crisis | Economic and monetary policy; economic, social and territorial cohesion; common commercial policy; industry; single market | Stress tests (e.g. stress test on public finance in Fiscal Sustainability Report 2021); Maastricht Treaty's convergence criteria; fiscal sustainability reporting; European Semester |
| Climate risks to European property and insurance markets | Economic and monetary policy; economic, social and territorial cohesion; single market; common commercial policy; industry | Insurance Recovery and Resolution Directive; Insurance Distribution Directive; Solvency II regulatory framework; EIOPA insurance stress tests; Floods Directive; EU Solidarity Fund; Social Cohesion Fund; Union Civil Protection Mechanism |
| Risk of public health crises due to interrupted pharmaceutical supply chains caused by extreme weather events outside Europe | Public health; common commercial policy; single market; agriculture; industry | EU pharmaceutical strategy; Supply Chain Directive; Corporate Sustainability Reporting Directive; Corporate Sustainability Due Diligence Directive; proposed revisions of EU pharmaceutical legislation; EU FAB network |
| Risk of business disruptions in key industrial sectors in Europe due to supply chain disturbances for critical raw materials or components from outside Europe | Common commercial policy; single market; industry; energy; transport | Critical raw materials action plan; Critical Raw Materials Act; Corporate Sustainability Reporting Directive; Corporate Sustainability Due Diligence Directive; Supply Chain Directive |
| Risks to European financial markets from climate impacts in Europe and beyond | Economic and monetary policy; common commercial policy; industry; economic, social and territorial cohesion; single market; competition rules | Corporate Sustainability Reporting Directive; European Sustainability Reporting Standards; European Central Bank (ECB) climate agenda 2022; ECB's 2020 supervisory expectations; ECB's 2022 bottom-up climate stress test; ECB's 2021 top-down climate stress test; ECB/ESRB project taskforce's 2022 macro climate stress test |

**Note:** The colour coding in the left-most column describes the urgency to act (see Chapter 18 and Annex 2 for further information). The major risks are derived from the 'Water security' factsheet as well as the 'Disruption of international supply chains' and 'Financial crisis and instability' storylines.

### *PRIORITIES FOR ACTION*

The risk to the overall financial system in Europe from climate change stems from the direct climate impacts on the public finances of Member States, the stability of the financial market in the EU, and the real economy. However, there are strong interlinkages between these risks. Climate change poses a serious threat to Member States' public finances in the near term, and to the viability of the EU Solidarity Fund and other solidarity mechanisms. The implications of these climate risks could ultimately result in severe financial stress or a financial crisis in the worst case.

More broadly, the impacts of climate change both in the EU and internationally also present serious risks to the stability of the financial market in the EU, as these can propagate through finance and trade with consequences across borders and sectors. The risks from climate change to financial stability in the EU is particularly great in certain subsectors of the financial system, such as property, lending and insurance, while further examination is needed on the compounding effects of climatic and non-climatic drivers for the EU economy, including on the effective functioning of global supply chains.

Owing to the complexities of the European financial system and the wider economies, legislative authority resides at both EU and Member State levels. Member States are largely responsible for policies that relate to public finance, although the EU can exert some influence through its competence on internal markets. The EU has considerable policy levers at its disposal to enhance stability of the financial market in the EU. The EU and its Member States have legislative remits to manage climate risks in the real economy through trade and economic policies, respectively.

*Policy action*

To date, EU policies aimed at managing climate risks to financial stability have largely been centred on the introduction of rules for the prudent and sound management and supervision of sustainability risks, as part of the prudential frameworks of financial institutions. This includes disclosure requirements on climate risks for financial institutions and corporations in the EU (e.g. Corporate Sustainability Reporting Directive, Capital Requirements Directive IV and Capital Requirements Regulation, and CSDDD) and stress tests by EU financial institutions. The mandatory disclosure frameworks on climate risks are an important step to accelerate and improve physical climate risk analysis in financial institutions, and perhaps improve risk management practices more widely across the economy. However, the degree to which these disclosure requirements encourage an integrated approach to managing transition and physical climate risks, as well as how compliance with the requirements will be enforced, needs to be assessed further.

Against this backdrop, climate-related disclosure frameworks must be accompanied with robust compliance mechanisms and tools (capital requirements, accounting directive, credit ratings) and revised to encourage corporate disclosure by financial and non-financial actors on how transition and physical climate risks are being considered in an integrated way to identify mutual benefits, trade-offs and compounds. Disclosure frameworks must also ensure the disclosure of physical climate risks to financial institutions and corporations across their own operations and the wider value chain.

The EU must ensure a robust increase in the capitalisation of the EUSF and the Union Civil Protection Mechanism. New EU-level adaptation policies should also introduce insurance and climate-resilient debt instruments to ameliorate the effects of weather extremes on public finances and provide wider financial resilience.

Public policies at Member State level could also consider opportunities to leverage economic policies to strengthen climate resilience of businesses in the EU, by creating market incentives for private sector investments in climate adaptation, such as through public procurement mechanisms or dedicated adaptation funding for small and medium-sized enterprises.

*Knowledge action*

Stress tests carried out by EU financial institutions (e.g. ECB, European Investment Bank and European Bank for Reconstruction and Development) are instrumental to policy readiness, as they have given the financial sector a rudimentary insight into the risk from climate change to EU public finances and financial institutions' portfolios. However, current stress tests have serious limitations and are therefore underestimating climate risks to financial stability. In particular, they provide only partial coverage of climate hazards, account poorly for climate volatility, and insufficiently probe risk propagation channels in the real economy, thus neglecting cascading and compounding climate risks. In addition, current scenario planning tools rely primarily on historical climate data and can therefore underestimate climate risks, while baseline scenarios should account more for climate risks altogether.

EU adaptation policies should therefore focus on further improving financial institutions' stress tests, current scenario planning tools and baseline scenarios, as well as supporting research efforts to gain better understanding of exposure and vulnerability to cascading and compounding climate risks via financial and trade channels. Strengthening corporate disclosure for physical climate risks to financial institutions and corporations (including their value chains) could increase transparency and availability of data, while EU framework programmes for research and innovation should be mobilised to support assessments of cascading and compounding risks in strategic economic sectors.

## 21.5 Pivotal system-wide priorities for action

In addition to the priorities for action for each cluster presented in the previous section, this report identifies three critical priorities that cut across all risks and clusters: (1) promoting systems-based thinking in climate risk management to address cross-sectoral linkages; (2) improving climate risk assessments to inform a precautionary policy approach; and (3) promoting transformational adaptation. Furthermore, considerations of social justice and just resilience are central to managing climate risks, as discussed in detail in Chapter 19.

### *21.5.1 Promoting systems thinking to address cross-sectoral linkages*

This report finds that the EU needs to step up its policy ambitions and actions substantially to achieve climate resilience by 2050. The assessment indicates that policy readiness is insufficient to meet most of the serious climate threats facing the EU in the coming years. To date, public policies on adaptation in Europe have mostly been incremental and focused on proximate hazards, but largely ignored the more systemic and cascading risks stemming from climate change. A critical part of moving beyond the limitations of current adaptation policies entails adopting a whole-systems or 'system-of-systems' approach to climate risk management. Such an approach is based on the understanding that individual elements, such as policy areas and sectors, are interlinked yet managed independently. Changes in one element of a system can have significant and unexpected impacts on other elements, which becomes critical when risk ownership is not defined at the system level. The latest EU adaptation strategy recognises the importance of mainstreaming adaptation across every sector of society, and thus every policy area. However, it is essential that climate risks be integrated earlier in the design phase of a policy, and not merely in the implementation stage. This means EU policymakers should consider at the outset whether a specific policy increases or decreases exposure to climate change.

The tables earlier in this chapter identify key exposed EU policy areas as well as key potential EU solution policies for the major climate risks, grouped by cluster. A summary figure of the links between the climate risks and exposed EU policy areas is provided in Chapter 20. Several EU policies could mitigate multiple major climate risks presented in this report, thus playing a crucial role in promoting system-wide and horizontal integration of adaptation. The EU biodiversity strategy, the Critical Entities Resilience Directive, the Nature Restoration Law, the farm to fork strategy, the Union Civil Protection Mechanism, the common agricultural policy, the Water Framework Directive, the forest strategy, and the Birds and Habitats Directives were assessed to have the potential to address 7-11 of EUCRA's major risks each. Realising the full potential of these policies and ensuring their successful implementation at national and subnational levels will be of utmost importance for promoting policy integration and addressing cross-sectoral linkages in a coordinated way. Another key component in advancing climate resilience is ensuring that EU funding programmes, such as the Cohesion Fund and the Recovery and Resilience Facility, include explicit adaptation-related priorities and are implemented in a way that promotes integration of climate change adaptation across sectors at the regional and local level.

*Avoiding maladaptation*

A systematic and integrated approach to developing and implementing adaptation policies is instrumental to avoid reinforcing, redistributing or creating new vulnerabilities. Costly adaptation actions, such as elevating buildings to adapt to flood risks, or implementing nature-based solutions in urban settings, which increases the value of properties and rents, can have unintended demographic impacts and push socially vulnerable groups out of these areas (Tozer et al., 2020; Anguelovski et al., 2022). Such changes may take many years to realise, are not always easily detectable, and can create maladaptive pathways that are challenging and costly to reverse. Adaptation actions designed with the best intentions can therefore run the risk of generating maladaptation and unintended consequences.

The question of whether a particular policy action should be considered as maladaptation can be context specific and depend on critical nuances. As a case in point, there has been growing recognition of the insurance sector's important role in enhancing climate resilience, as it provides protection from the financial impacts of climate-related disasters. Insurers also communicate clear risk signals through the marketplace to governments, businesses and households, thereby incentivising adaptation. However, insurance can also become maladaptive, for example, when primary insurance markets provide flat-rate premiums that do not consider the true risk to businesses and households. Such insurance premiums might disincentivise actions to minimise risk exposure or vulnerability of assets and properties, and they could sustain further urban development in high-risk areas.

Maladaptation could also stem from the use of economic and trade policies aimed at increasing domestic production capacity in strategic sectors to reduce the risk of supply chain disruptions caused by climate change. While such policies may reduce the EU's dependency on imports from climate-vulnerable third countries, they could undermine livelihoods and reduce communities' resilience in third countries and exacerbate other climate risks in Europe. For instance, efforts to bolster domestic production in agriculture and the pharmaceutical sector in Europe could further increase water demand in regions already exposed to water stress. These examples, alongside others highlighted in this report, underscore the importance of careful consideration of the side effects of adaptation policies when considering other policy objectives (e.g. overseas development). In addition, ensuring that local and, where relevant, indigenous groups and knowledge are integrated into adaptation planning helps to prevent maladaptation and provides space for developing agency and adaptive capacity at the local level.

*Applying a One Health approach to adaptation policies*

An integrated policy response is instrumental for European policymakers to better understand and identify the complex, cascading and compounding effects of climate change. This is well demonstrated in how climate impacts permeate through the interplay between human, animal and environmental health. Around three quarters of all infectious diseases originate from animals, but animal diseases can also compromise human health through worsened food security and quality. Biodiversity and habitat loss can force closer contacts between animals and humans, increasing the probability of infectious disease transmission. Therefore, it is important that adaptation measures consider and mitigate the effects of climate change on human health – including through zoonotic diseases, food security and water quality – in the context of non-climatic stressors, such as increasing antimicrobial resistance.

The growing recognition of these interdependencies between humans, animals and their environments has brought about a 'One Health' approach in the analysis of the health-climate change nexus and fostered greater cross-disciplinary collaboration. The EU has made progress on the topic, as illustrated by the recent adoption of the Council Recommendation on stepping up EU actions to combat antimicrobial resistance in a One Health approach and the European Commission's Better Training for Safer Food training initiative. Yet, more action can be taken to better integrate the environmental component of the three One Health elements in EU policies.

### *21.5.2 Improving climate risk assessments to support a precautionary approach*

There is a growing body of evidence suggesting that most current climate risk assessments are inherently conservative and tend to underestimate the impacts of climate change (Stern, 2016; Schwarzwald and Lenssen, 2022b; Newman and Noy, 2023b). In this context, the requirement for EU adaptation policies to be underpinned by sound scientific evidence could limit actions taken, if it were to be interpreted narrowly and evidence restricted to quantitative climate impact or risk assessments. Despite best efforts, most climate impact assessments based on so-called computable general equilibrium models and integrated assessment models fail to sufficiently account for climate volatility (e.g. extreme weather events), indirect economic impacts (such as a run on the markets), compound effects (e.g. interplay with other climatic and non-climatic drivers) and tipping points. This is not surprising as it is challenging, if not impossible, to forecast the complex impacts of climate change with spatial and temporal precision.

This report puts a focus on interlinkages between major risks within and across sectors, as well as on cascading risks across sectors. Furthermore, it stresses the importance of non-climatic risk drivers, which often increase the vulnerability and exposure of affected systems. The EUCRA storylines attempt to describe some of the complexities of climate risks, with respect to their compounding and cascading effects, and offer some plausible scenarios of how the interplay between different climatic and non-climatic drivers could pan out for the EU. The report's structured risk assessment is based on the best available data and evidence as well as a first-order policy analysis but it is a largely qualitative process conducted by experts, who may have underestimated some major climate risks that are more complex and systemic in nature due to the difficulties in quantifying their severity.

Future assessments of physical climate risks should include more stochastic elements and incorporate a broader range of scenarios to better anticipate different climate futures and potential surprises, through a comprehensive assembly of both quantitative climate models and qualitative expert judgements.

The IPCC's Sixth Assessment Report recognised the importance of not confining adaptation policies to managing the biophysical impacts of climate change, but also addressing the underlying drivers of vulnerability (IPCC, 2022h). Many non-climatic risk drivers can be influenced by policies (e.g. exposure to flooding by land use and spatial planning). These drivers could be more explicitly addressed in the identification and description of climate risks, and in scenario and policy analysis. Considering distinct scenarios for non-climate risk drivers can also help in identifying barriers and enabling conditions for transformational and just adaptation.

It is standard practice in insurance and the wider financial industry to focus on low-probability, high-impact scenarios (so-called tail risks). In contrast, current adaptation policies in Europe and beyond largely centre on middle-of-the-road scenarios. Considering the considerable chance that climate change impacts are exceeding available model-based assessments, it is imperative that adaptation (and mitigation) policies designed by the EU and its Member States hedge against extreme scenarios. The effectiveness of policies in building adaptive capacity to future extremes, for instance by promoting effective governance and collaboration at the European level as well as access to health and social services at the local level, could make the crucial difference in avoiding catastrophic impacts under a pessimistic or worst-case scenario. It is thus essential that adaptation policies take a precautionary approach in considering the tail risks of climate change, and that policies are introduced which enhance resilience, including under extreme scenarios.

### *21.5.3 Need for transformational adaptation*

Climate risks that are subject to long lead times or decision horizons may require urgent action now to avoid lock-ins into unsustainable pathways and very severe impacts in the long term. This is important, among others, for long-lived infrastructure, spatial planning and long-lived ecosystems, such as forests (see also Chapter 20).

Incremental measures and responses will become increasingly insufficient in addressing the major climate risks facing Europe, in particular under extreme scenarios. As the impacts of climate change become ever more severe, transformational adaptation needs to be considered. Transformational adaptation is especially required for risks with long policy horizons and in cases where major shifts in social and ecological conditions, driven by climate change, are expected to change the fundamental attributes of a system. Transformational adaptation can help to shift from accommodating change to deliberately implementing more sustainable strategies that consider climate risks not only in the near term, but also in the medium and long term.

Transformational adaptation requires the ability to envision various scenarios and involve all relevant stakeholders in a process aimed at undertaking fundamental shifts that address the root causes of vulnerability in the long term (Hölscher and Frantzeskaki, 2020). Transformational adaptation can require large initial investments in terms of human, financial and time resources, but it avoids having to resort repeatedly to even more costly emergency solutions in the long run (Fedele et al., 2019; Kates et al., 2012). So far, the EU and its Member States have rarely implemented transformational adaptation measures or strategies to reduce the impacts of climate change (Bednar-Friedl et al., 2022b). Institutional barriers that may hinder the adoption of transformational adaptation include resource and budgetary constraints, uncertainties relating to climate risk assessments and climate impact modelling, unclear responsibilities between different departments and levels of government, and inertia of professional and organisational norms (Munck Af Rosenschöld and Rozema, 2019).

To speed up the adoption of transformational adaptation measures, the EU should facilitate the mainstreaming of major climate risks in the near, medium and long term into existing planning and budgetary processes. Developing or improving monitoring systems for climatic tipping points and social tipping points related to climate risks could improve assessments of where and when transformational adaptation is needed. Planning and implementing transformative adaptation also require investment in capacity building at the community, institutional and governmental levels.

For each risk cluster discussed in this report, further information is needed regarding what transformational adaptation entails, when to consider this type of approach, and what it looks like in practice. Limited knowledge on these aspects prevents the implementation of transformational adaptation and misses opportunities to invest in solutions that can reduce climate change risks effectively in the long term. The EU should promote research and develop the knowledge base on transformational adaptation. It should be included in the EU's adaptation policy agenda in a systemic way, so that transformational adaptation becomes a real and viable solution that Member States can pursue.

# Annex 1 Abbreviations and units



| | |
|---|---|
| ALARP | As low as reasonably practicable |
| AMR | Antimicrobial resistance |
| API | Active pharmaceutical ingredient |
| AR6 | Sixth Assessment Report |
| CAP | Common agricultural policy |
| CER | Critical entities resilience |
| CF | Cohesion Fund |
| CFP | Common fisheries policy |
| CID | Climatic impact driver |
| CoR | European Committee of the Regions |
| CPR | Construction Products Regulation |
| CSDDD | Corporate Sustainability Due Diligence Directive |
| CSP | CAP strategic plan |
| CSRD | Corporate Sustainability Reporting Directive |
| C3S | Copernicus Climate Change Service |
| DestinE | Destination Earth |
| DG CLIMA | Directorate-General for Climate Action |
| DRG | Disaster Resilience Goal |
| DT | Digital twin |
| EAAP | Expected annual affected population |
| EAD | Economic annual damage |
| EAFRD | European Agricultural Fund for Rural Development |
| EC | European Commission |
| ECB | European Central Bank |
| ECI | European critical infrastructure |
| EEA | European Environment Agency |
| EFFIS | European Forest Fire Information System |
| EIOPA | European Insurance and Occupational Pensions Authority |

| | |
|---|---|
| EP | European Parliament |
| ERDF | European Regional Development Fund |
| ESF+ | European Social Fund Plus |
| ESG | Environmental, social and governance |
| ESM | Earth system model |
| EU | European Union |
| EUCRA | European Climate Risk Assessment |
| EU-OSHA | European Agency for Safety and Health at Work |
| EUSF | European Union Solidarity Fund |
| EU-27 | 27 EU Member States |
| FD | Floods Directive |
| FEAD | Fund for European Aid to the Most Deprived |
| GCM | Global Climate Model |
| GDP | Gross domestic product |
| GHG | Greenhouse gas |
| GPP | Green public procurement |
| GWL | Global warming level |
| ha | Hectares |
| HANZE | Historical Analysis of Natural Hazards in Europe |
| HERA | Health Emergency Preparedness and Response Authority |
| IAS | Invasive alien species |
| IPCC | Intergovernmental Panel on Climate Change |
| JRC | Joint Research Centre |
| LNOB | Leave no one behind |
| LULUCF | Land use, land use change and forestry |
| masl | Metres above sea level |
| MFF | Multiannual Financial Framework |
| MPA | Marine Protected Area |
| Mt CO2e | Million tonnes of $CO_2$ equivalent |
| NBS | Nature-based solutions |

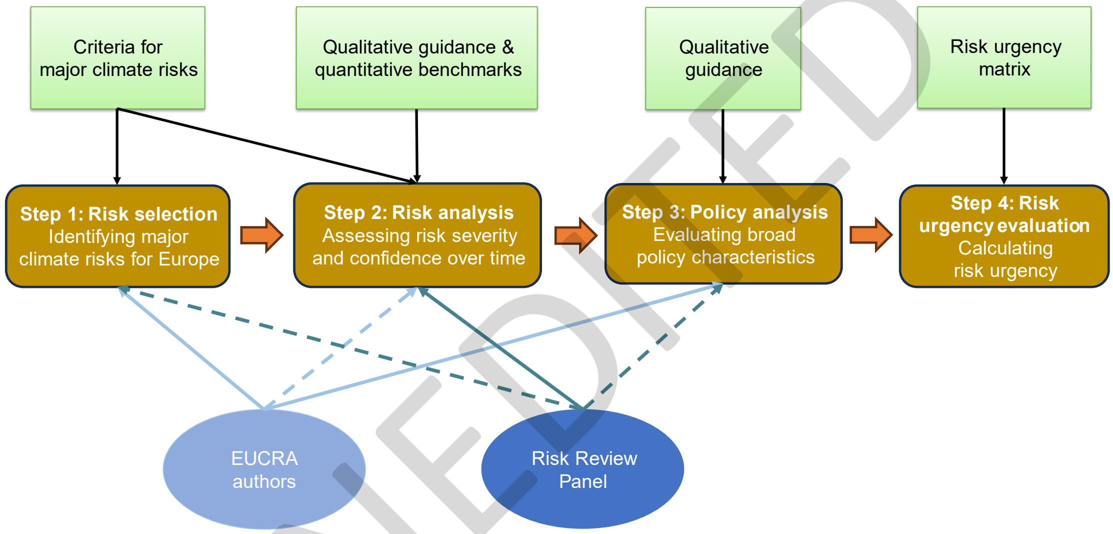
| | |
|---|---|
| NCID | Non-climatic impact driver |
| NEB | New European Bauhaus |
| NECP | National energy and climate plan |
| POSEI | Programme of options specifically relating to remoteness and insularity |
| PV | Photovoltaic |
| RBMP | River basin management plan |
| RCP | Representative Concentration Pathway |
| RRF | Recovery and Resilience Facility |
| RVF | Rift Valley fever |
| SEAR | Solidarity and Emergency Aid Reserve |
| SME | Small and medium-sized enterprise |
| SREP | Supervisory Review and Evaluation Process |
| SSP | Shared Socioeconomic Pathway |
| SST | Sea surface temperature |
| TBE | Tick-borne encephalitis |
| TEN-T | Trans-European transport corridors |
| TFEU | Treaty on the Functioning of the European Union |
| TSI | Technical Support Instrument |
| TSMC | Taiwan Semiconductor Manufacturing Co. |
| UCPM | Union Civil Protection Mechanism |
| UHI | Urban heat island |
| UNFCCC | United Nations Framework Convention on Climate Change |
| WASH | Water, sanitation and hygiene |
| WFD | Water Framework Directive |
| WHO | World Health Organization |
| WNV | West Nile virus |

# Annex 2 Method for structured risk assessment

## 1 Overview and involvement of risk review panel

For the European Climate Risk Assessment (EUCRA), a structured risk assessment was conducted to support the transparent identification of priorities for policy action. This involved several steps, as shown in Figure A2.1. The risk selection identified major climate risks for Europe based on common criteria. The risk analysis classified these risks according to their potential for severe consequences for Europe; it was complemented by an indicative policy analysis. The risk urgency evaluation determined the urgency for EU action based on the outcomes of the risk and policy analysis.

**Figure A2.1 Structured risk assessment in EUCRA**






**Note:** The strength of the arrows indicates the importance of EUCRA authors vs the risk review panel in the different steps of the structured risk assessment (solid lines indicate lead role).

**Source:** EEA.

The structured risk assessment involved both the author teams of the relevant EUCRA chapters and an independent risk review panel, composed of senior experts in risk assessment with a cross-disciplinary background (see Acknowledgements). Involvement of the risk review panel had the following objectives:

- ensuring the **comparability** of the analysis of major climate risks for Europe within and across storylines and factsheets;
- ensuring the **legitimacy** of the risk assessment by drawing on the competence of a large group of experts with cross-cutting expertise in risk assessment.

Details of the risk review panel's involvement are described in the following sections.

## 2 Risk selection

The risk selection identified **major climate risks for Europe** by an initial screening of the relevant scientific literature (see Chapter 1). This screening and the risk analysis in the following step was guided by the following criteria, which were adopted from the criteria for 'key risks' in the Intergovernmental Panel on Climate Change's Sixth Assessment Report (IPCC AR6) (O'Neill et al., 2022):

- high **magnitude** of potential adverse consequences in the present or future;
- high **likelihood** of severe consequences;
- high **irreversibility** of consequences (e.g. due to crossing of tipping points);
- high **potential for cascading effects** beyond system borders, either geographically (e.g. from one region to the whole of Europe) or to other systems and sectors;
- **aggravating effect of climate change** over time, at least in some European regions.

The risk selection was conducted by the author teams of EUCRA factsheets and storylines. They received guidance for distinguishing risks based on the subsystem affected, the key impact chain and the main EU policies concerned. Nevertheless, some of the major climate risks in EUCRA are more comprehensive than others. The role of the risk review panel in this step was limited; it focused on reframing selected risks and merging overlapping risks from different factsheets and storylines.

## 3 Risk analysis

The risk analysis focused on assessing the **risk severity** for each major climate risk according to four risk severity classes (see Table A2.1).

**Table A2.1 Risk severity classes in EUCRA**

| Risk severity | Description |
|---|---|
| **Catastrophic** | Very large and frequent damage, very large extent or very high pervasiveness, irreversible loss of system functionality, systemic risk. |
| **Critical** | Large and frequent damage, large extent and high pervasiveness, long-term disturbance of system functionality, cascading effects beyond system boundaries. |
| **Substantial** | Substantial losses, moderate extent or pervasiveness, temporary or moderate disturbance of system functionality. |
| **Limited** | Limited or rare losses, no significant disturbance of system functionality. |

**Source:** EEA.

The assessment of risk severity was guided by quantitative benchmarks aimed at increasing the comparability across storylines and factsheets. These benchmarks took into account the magnitude of impacts on the economy, people, land and other systems as well as the likelihood or frequency of the impacts. Further information is available in Section 6. The EUCRA risk severity assessment assumed current adaptation policies.

The assessment of risk severity was performed for three different time periods:

- current (up to 2040);
- mid-century (2041-2060);
- late century (2081-2100).

These periods correspond to the near-term, mid-term and long-term periods used in the IPCC AR6. The severity assessment for the late century distinguishes two broad climate change scenarios: a low warming scenario with global warming up to 2°C, which is compatible with the Paris Agreement, and a high warming scenario with global warming during late century in the range of 3-4°C (see Chapter 2). In line with the IPCC AR6, the period 2061-2080 is not explicitly covered by any of the three periods above.

Risk severity was assessed for Europe as a whole, understood as the 38 EEA member and cooperating countries (EEA, 2022h). However, some information sources do not cover all countries. Furthermore, EUCRA considers four subcontinental (land) regions shown in Table A2.2 (for a map, see Chapter 2). This regionalisation was adapted from the United Nations Geoscheme for Europe (UNSD, 2022), with some adaptations to cover all 38 EEA member and cooperating countries, and to avoid confusion with region names applied in the IPCC AR6.

A risk that critically affects a large European region is considered to be relevant for the EU as a whole. Therefore, if risk severity in one of the EUCRA subregions is substantially higher than the European average, authors were asked to make a separate assessment for this 'hotspot region'. If the risk urgency evaluation depends on the risk severity in a 'hotspot region' rather than Europe as a whole, this is explicitly noted when presenting the results of the risk assessment.

**Table A2.6 Four EUCRA regions, defined based on climatic and socio-economic conditions**

| **EUCRA region** | **Northern Europe** | **Western Europe** | **Central/ Eastern Europe** | **Southern Europe** | |
|---|---|---|---|---|---|
| | | | | *EEA member country* | *EEA cooperating country* |
| **Countries** | Denmark<br>Estonia<br>Finland<br>Iceland<br>Ireland<br>Latvia<br>Lithuania<br>Norway<br>Sweden | Austria<br>Belgium<br>France<br>Germany<br>Liechtenstein<br>Luxembourg<br>Netherlands<br>Switzerland | Bulgaria<br>Czechia<br>Hungary<br>Poland<br>Romania<br>Slovakia | Croatia<br>Cyprus<br>Greece<br>Italy<br>Malta<br>Portugal<br>Slovenia<br>Spain<br>Türkiye | Albania<br>Bosnia and Herzegovina<br>Kosovo (under UNSCR 1244/99)<br>Montenegro<br>North Macedonia<br>Serbia |

The risk severity assessment for each period was complemented by an assessment of **confidence** according to three broad categories:

- high;
- medium;
- low.

This assessment indicates the confidence of the risk assessor that a climate risk in a given time period falls into the chosen severity class. It was informed by the type, amount, quality and consistency of evidence as well as the level of agreement across that evidence. It may also take into account the influence of non-climatic risk drivers on risk severity, including their predictability.

The author teams of the EUCRA factsheets and storylines conducted an initial risk analysis for the risks in their chapters. This initial analysis was reviewed independently by at least five members of the risk review panel who were tasked with ensuring a consistent evaluation of risk severity and confidence according to the guidelines provided. In dedicated meetings, panel members reached a consensus on the risk analysis for all major climate risks, thereby ensuring a homogeneous risk assessment across the EUCRA report. The risk review panel had the lead role in this step. Those risks where there was a wide range of evaluations from authors and members of the risk review panel are indicated by a note when presenting the results.

## 4 Indicative policy analysis

The policy analysis assessed the policy horizon, risk ownership and policy readiness according to broad categories. The outcomes are considered indicative given the limited scope and depth of this analysis in the first EUCRA.

The **policy horizon** indicates the future time horizon that needs to be considered in current adaptation decisions related to a particular risk. It considers two aspects: lead time and decision horizon. The lead time describes how long it takes to plan and implement effective adaptation actions. For example, lead time is short when adjustments to current practices can be implemented quickly, but it is long when complex new infrastructure needs to be built. The decision horizon describes the lock-in potential of current decisions related to climate-sensitive systems. Long decision horizons are typical for long-lived infrastructure and long-lived ecosystems, such as managed forests.

The policy horizon is categorised according to three classes, which correspond to the time periods of the risk analysis:

- short (up to 2040);
- medium (up to 2060);
- long (up to 2100).

The longer the policy horizon of a climate risk, the more important risk severity is further in the future for current adaptation decisions. When the policy horizon is medium or long, urgent policy action may already be needed now to avoid severe risks in the future, even if current risk severity is not yet critical.

**Policy readiness** denotes to what extent a climate risk is being recognised and managed in Europe. The analysis is based primarily on adopted legislation and published policies, strategies and plans at the EU level; unpublished or internal documents are not considered. The implementation of policies at European and national levels and its effectiveness have not been systematically analysed, although considerations of implementation have been included where evidence was available.

The methodology for the risk urgency evaluation (see Section 5) has four categories of policy readiness:

- Low: few if any policies, plans or strategies are in place to reduce the risk.
- Medium: policies, plans, strategies or legislation are in place, but their targets and objectives are vague, or only short-term actions are considered.
- Advanced: policies, plans or strategies that manage the risk effectively are partly in place.
- Very advanced: policies, plans or strategies are in place with clear objectives and actions to manage the risk. Policies and actions consider short-term risk management as well as long-term risk reduction where relevant.

Considering the limited evidence available regarding policy readiness, in particular at the national level, only the two central categories were used in practice, with 'medium' being the default choice.

**Risk ownership** describes where the lead responsibility to manage a major climate risk lies between the European level and Member State level. EUCRA distinguishes three types of risk ownership:

- EU: policy areas where the EU predominantly has the legislative remit and responsibility to act.
- Co-owned: policy areas that fall under shared and special competences where the EU could potentially implement policies in accordance with the EU Treaty and

intergovernmental agreements, but also in circumstances where actions in more than one policy area are needed and where the level of risk ownership differs.

- National: policy areas that are largely under the responsibility of Member States.

EUCRA did not include a comprehensive analysis of risk ownership, which would also have to consider the role of various Directorates-General of the European Commission, subnational governance levels and private actors. Risk ownership was not incorporated into the risk urgency evaluation as an independent variable, but it informed the assessment of policy readiness. It was also considered in the formulation of priorities for action (see Chapter 21).

The indicative policy analysis was conducted mainly by the author teams, assisted by experts from the EUCRA policy chapters. Members of the risk review panel were invited to propose changes to the EUCRA authors' assessments, but few adjustments were made in practice.

## 5 Risk urgency evaluation

The risk urgency evaluation determined the urgency and type of policy action ('urgency to act') according to five categories (see Table A2.3).

### Table A2.3 Description of urgency categories used in EUCRA

| Urgency to act | Description |
|---|---|
| **Urgent action needed** | The combination of catastrophic risks and insufficient policy readiness calls for urgent new, stronger or different action in the coming years to reduce climate risks. Such actions include policymaking, implementation, capacity building or enabling the environment for adaptation, over and above those already planned. |
| **More action needed** | The severity of risk and the limited level of policy readiness calls for more action to be implemented. It is crucial to initiate processes that strengthen adaptation action to avoid critical impacts of climate change. |
| **Further investigation** | The available knowledge is insufficient to call for specific new action. Priority should be given to gathering additional evidence regarding the severity of the risk as well as policy readiness, e.g. through dedicated research, monitoring or policy evaluation. |
| **Sustain current action** | Current or planned levels of activity are appropriate, but continued implementation of these policies or plans is needed to ensure that the risk continues to be managed in future. A monitoring and evaluation process should be in place to evaluate policy effectiveness, with a view to continuous improvement. |
| **Watching brief** | The evidence in these areas should be kept under review, with continuous monitoring of risk levels, so that further action can be taken if necessary. |

**Source:** EEA.

The risk urgency evaluation was done algorithmically based on the outputs of the risk analysis and the indicative policy analysis. The key element is a risk urgency matrix that considers risk severity and confidence (for a given time period and warming scenario) as well as policy readiness (see Table A2.4). This matrix builds on experiences from recent national climate risk assessments, which were adapted to the EUCRA framework and objectives.

**Table A2.4 Matrix for determining risk urgency based on risk severity, confidence and policy readiness**

| Risk severity | Confidence | Policy readiness | | |
|---|---|---|---|---|
| | | **Very advanced** | **Advanced** | **Medium/low** |
| **Catastrophic** | High | *More action needed* | *Urgent action needed* | *Urgent action needed* |
| | Medium | *Further investigation* | *More action needed* | *Urgent action needed* |
| | Low | *Further investigation* | *Further investigation* | *More action needed* |
| **Critical** | High | *Sustain current action* | *More action needed* | *Urgent action needed* |
| | Medium | *Sustain current action* | *Further investigation* | *More action needed* |
| | Low | *Sustain current action* | *Further investigation* | *Further investigation* |
| **Substantial** | High | *Sustain current action* | *Sustain current action* | *More action needed* |
| | Medium | *Sustain current action* | *Sustain current action* | *Further investigation* |
| | Low | *Sustain current action* | *Sustain current action* | *Further investigation* |
| **Limited** | High | *Sustain current action* | *Sustain current action* | *Watching brief* |
| | Medium | *Sustain current action* | *Sustain current action* | *Watching brief* |
| | Low | *Sustain current action* | *Sustain current action* | *Watching brief* |

**Source:** EEA.



The rows in Table A2.4 refer to combinations of risk severity and confidence in the assessment, whereas the columns refer to the evaluation of policy readiness. In general, higher risk severity, higher confidence and lower policy readiness increase the urgency and specificity of the recommended policy actions. Risks with low or medium confidence in the risk severity assessment may be assigned to the category 'Further investigation', whereas this category is not used for risks with high confidence. Risks with advanced or very advanced policy readiness can be assigned to the category 'Sustain current action', unless risk severity is critical (for advanced policy readiness) or catastrophic (for very advanced policy readiness); this category is not used for risks with medium or low policy readiness. Risks with low and medium policy readiness are not further distinguished in the risk urgency matrix, because the urgency to act is essentially the same. For catastrophic risks with high confidence, even very advanced policy readiness would result in 'More action needed' to allow for cases where these policies may not be sufficient when risk severity increases substantially over time. However, this combination has not been chosen in this first EUCRA.

The risk urgency matrix determines the urgency score based on the risk severity and confidence for a particular time period (current, mid-century or late century) and warming scenario (low or high warming; only for late century). The overall urgency to act corresponds to the highest urgency score throughout the policy horizon. In other words, the urgency to act for risks with a short policy horizon is determined only by the risk severity and confidence for the current period, whereas the urgency to act for risks with a medium or long policy horizon also takes into account risk severity and confidence for mid-century and late century, respectively. There are two additional considerations for risks with a long time horizon. First, the highest urgency score ('Urgent action needed') is reserved for those risks that reach this score already based on risk severity in the current or mid-century period. Second, if the urgency to act differs between the low and high warming scenarios (in late century), the score according to the high warming scenario is chosen, but a corresponding note is added when presenting the results of the risk urgency evaluation.

# 6 Quantitative benchmarks for the risk severity assessment

### *Introduction*

The description of the four categories for risk severity in Section 3 is rather generic and could lead to quite subjective assessments. To facilitate comparability of key climate risks across storylines and factsheets, authors were provided with quantitative benchmarks for the different severity categories, which have been informed by existing national climate risk assessments. These benchmarks refer to economic impacts, effects on people and other impacts (such as on land, ecosystems and iconic heritage assets). If a climate risk affects different exposure units (e.g. economy and people), the overall severity rating corresponds to the highest rating across exposure units.

EUCRA authors and members of the risk review panel were encouraged to consider these benchmarks as much as possible in their assessment of risk severity. Considering that risk severity classes in EUCRA are very broad and indicate primarily the order of magnitude of a problem, applying the quantitative benchmarks presented here is not contingent on the availability of quantified model-based impact or risk assessments.

### *Benchmarks for annualised impacts*

Table A2.5 shows benchmarks for classifying risks according to the magnitude of annualised impacts on the economy, people and other impact categories. These benchmarks can be applied directly to slow-onset hazards and relatively frequent extreme events for which average annual impacts can be estimated.

The benchmarks for economic impacts can be applied to annual average damage (for slow-onset hazards) or equivalent annualised damage (for impacts of extreme events). They are expressed both in absolute terms (for the EU) and in relative terms, as a fraction of gross domestic product (GDP). The benchmarks for impacts on people consider the numbers of deaths, other health impacts and people affected. Climate risks directly affecting the economy or human health are of key concern to policymakers, but not all relevant risks can be expressed in monetary terms or as impacts on people. For those 'other' risks, it is much more difficult to establish sound quantitative benchmarks, because they are crucially dependent on subjective judgements. The right-most column presents such benchmarks for impacts on land, ecosystems and iconic heritage assets. If a risk assessment is done for one of the four subcontinental regions considered in EUCRA, the absolute thresholds are adjusted for GDP, population or area.

**Table A2.5 Risk severity for different types of impacts – benchmarks based on annualised impacts**

| Risk severity | Economic damage | Impact on people | Other impact categories |
|---|---|---|---|
| **Catastrophic** | At least 1% of GDP (EU: ca EUR 150 billion) | > 100,000 deaths or >1,000,000 health impacts or >10,000,000 people affected | > 40 million hectares of land lost or severely damaged (10% of land area) |
| **Critical** | 0.25-1% of GDP (EU: ca EUR 40-150 billion) | > 10,000 deaths or >100,000 health impacts or >1,000,000 people affected | 4 million to 40 million hectares of land lost or severely damaged;<br>Major impact (10% or more) on valued habitat or landscape types;<br>Major impacts on or loss of species groups; |

| | | | |
|---|---|---|---|
| | | | Major impact (10% or more) on an individual natural capital asset and associated goods and services;<br>Major loss or irreversible damage to iconic heritage assets |
| **Substantial** | 0.05-0.25% of GDP (EU: ca EUR 10-40 billion) | >1,000 deaths or >10,000 health impacts or >100,000 people affected | 400,000 to 4 million hectares of land lost or severely damaged;<br>Intermediate impact (1-10%) on valued habitat or landscape types;<br>Intermediate impacts on or loss of species groups;<br>Intermediate impact (1-10%) on an individual natural capital asset and associated goods and services;<br>Medium loss or irreversible damage of iconic heritage assets |
| **Limited** | <0.05% of GDP (EU: ca EUR 10 billion) | <100 deaths and <1,000 health impacts and <10,000 people affected | Less than 400,000 hectares of land lost or severely damaged;<br>Minor impact (less than 1%) on valued habitat or landscape types;<br>Minor impacts on loss of species groups;<br>Minor impact (less than 1%) on an individual natural capital asset and associated goods and services;<br>Low loss or irreversible damage to iconic heritage assets |

**Notes:** For the EEA-38 (32 EEA member and six cooperating countries), GDP is around 15% higher than stated here for the EU-27. A certain level of risk severity can also be triggered if a threshold is transgressed at the level of one of the four EUCRA regions (adjusted for GDP).

**Source:** EEA.

### *Benchmarks for impacts of one-off events*

For impacts of large one-off events where annualisation is not possible, Table A2.6 adjusts the severity scores from Table A2.4 based on the likelihood of the event within a 5-year period (corresponding to the length of an EU policy cycle). Events that are less likely have a lower risk severity score than events of the same magnitude class that are more likely. Events with an estimated likelihood below 2% in a 5-year period are not considered in the first EUCRA.

**Table A2.6 Risk severity for benchmarks considering the magnitude of the impact and the likelihood of the event**

| **Risk severity** (adjusted) | **High likelihood** (>50% during 5-year period) | **Medium likelihood** (10-50% during 5-year period) | **Low likelihood** (2-10% during 5-year period) |
|---|---|---|---|
| **Catastrophic** | Catastrophic | | |
| **Critical** | Critical | Catastrophic | |
| **Substantial** | Substantial | Critical | Catastrophic |
| **Limited** | Limited | Substantial | Critical |

**Source:** EEA.

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