



CrossEU

D4.3 - Analysis of the climate change impacts and responses in sectoral policies (Version 1)

WP4 - Task 4.2

May 2025 [M17]





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Executive Summary

The CROSSEU deliverable "D4.3 – Analysis of the climate change impacts and responses in sectoral policies" comprehensively analyses the socioeconomic impacts of climate change and extreme events in Europe. The deliverable focuses on assessing the effectiveness of existing mitigation and adaptation (M&A) measures across twelve identified sectors and three selected case study areas (CSAs) of the CROSSEU project. It provides an in-depth examination of policy responses to climate change, including laws, regulations, incentives, and initiatives, while also identifying gaps and opportunities for improvement. The analysis integrates findings from regional data, policy document reviews, and expert interviews conducted in two pilot CSAs, offering a nuanced understanding of how climate change policies intersect with sectoral strategies. It provides a critical foundation for understanding the interplay between climate change policies and sectoral strategies, offering actionable insights to enhance resilience and mitigate risks in the face of extreme weather events connected to climate change.

The analysis starts out by exploring the socioeconomic impacts of climate change, emphasizing the interconnected challenges posed by the four climate hazard categories in focus of the CROSSEU project (i.e. heat, drought, storm and snow). It highlights the need for proactive and adaptive strategies to mitigate risks and enhance resilience, particularly in Climate Change Hotspots (CCHs). The analysis includes structural, institutional, and social measures implemented in response to these hazards, drawing on examples from Southern Denmark, Northern Italy, and the Central Alps. These case studies illustrate both successful practices and persistent gaps, providing valuable insights into regional approaches to climate resilience.

A key focus of the deliverable is the evaluation of existing M&A measures, assessing their success in achieving stated objectives and identifying barriers to implementation. The document underscores the importance of integrating climate science into sectoral policies, leveraging cross-sectoral approaches, and fostering inclusive governance to address the multifaceted impacts of climate change. It also emphasizes the role of innovative technologies, public-private partnerships, and community-based initiatives in enhancing resilience and promoting sustainable development.

The findings of this deliverable underscore the importance of integrated, cross-sectoral approaches to address the complex and interconnected challenges posed by climate change. Conclusions are drawn regarding sectoral impacts and policy responses, cross-sectoral integration of successful climate change responses, lessons learned from good practice



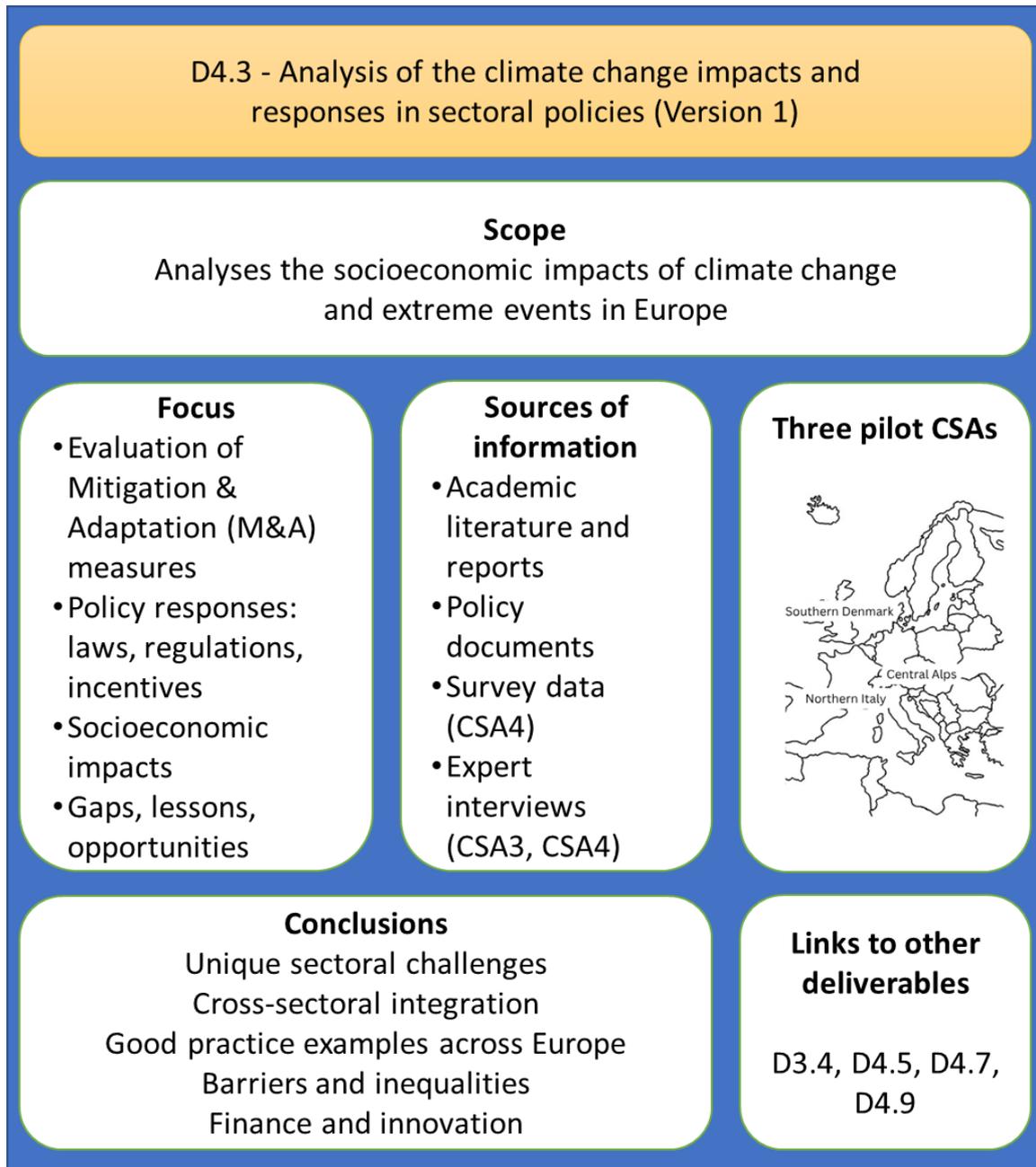
examples as well as regarding barriers, inequalities and the role of financial instruments.

This deliverable is one of three CROSSEU deliverables on governance issues that were developed in parallel under the leads of CROSSEU Work Package 4 task leads BOKU (D4.3), K&I (D4.5) and DTU (D4.7). While this deliverable analyzes climate change impacts and policy responses, D4.5 shifts the focus to disadvantaged populations and examines their vulnerabilities, and D4.7 explores economic, financial, and investment policies in the context of climate change impact, utilizing material collected in all eight CROSSEU CSAs. In their combination, these three deliverables emphasize the significance of climate change impacts on the CROSSEU focus sectors and populations in CCHs, while differing in their geographical scope and research questions.

Looking ahead, this deliverable sets the stage for its successor, CROSSEU deliverable D4.4, which will expand the analysis to additional CSAs and introduce a forward-looking perspective. This future work will explore potential new policy options, considering emerging challenges such as evolving climate dynamics, socioeconomic changes, and technological advancements.



Graphical Abstract





Keywords

Climate Change Impacts, Mitigation and Adaptation (M&A) Measures, Sectoral Policies, Cross-sectoral Integration, Climate Change Hotspots (CCHs), Resilience and Risk Reduction, Policy Evaluation and Governance



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Abbreviations and acronyms

| Acronym | Description |
|----------------|-------------------------------------------------------------------------------------------------------|
| BOKU | BOKU University |
| CCH | Climate change hotspot |
| CEST | European Charter for Sustainable Tourism |
| CO2 | Carbon dioxide |
| CROSSEU | Cross-sectoral Framework for Socio-Economic Resilience to Climate Change and Extreme Events in Europe |
| CSA | Case study area |
| DRR | Disaster risk reduction |
| DSS | Decision-support system |
| DTU | Danish Technical University |
| EEA | European Environment Agency |
| EU FD | European Floods Directive |
| FAO | Food and agriculture organization of the United Nations |
| GFCS | Global framework for climate services |
| GHG | Greenhouse gas |
| HNAP | Health National Adaptation Plan |
| IPLC | Indigenous peoples and local communities |
| IWRM | Integrated water resource management |
| K&I | Conoscenza e Innovazione Societa |
| LDC | Least developed country |
| M&A | Mitigation and adaptation |
| NAP | National Adaptation Plan |
| NBS | Nature-based solution |
| NGFS | Central Banks and Supervisors Network for Greening the Financial System |
| NWRM | Natural water retention measure |



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|---------------|------------------------------------------------------------------|
| OECD | Organization for Economic Cooperation and Development |
| PAI | Hydrological Structure Plan (Italy) |
| PEAP | Provincial Environmental Energy Plan (Italy) |
| PGRA | Flood Risk Management Plan (Italy) |
| RCP | Representative Concentration Pathway |
| SDG | Sustainable Development Goal |
| SIDS | Small island developing state |
| SNAC | National Strategy for Adaptation to Climate Change (Italy) |
| UNDP | United Nations Development Programme |
| UNIPD | Università degli Studi di Padova |
| UNECE | United Nations Economic Commission for Europe |
| UNEP | United Nations Environment Programme |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| WFD | Water Framework Directive |
| WHO | World Health Organization |
| WMO | World Meteorological Organization |
| WP | Work Package |



1. Introduction

This deliverable (D4.3) was created in Task 4.2 of the Horizon Europe project “Cross-sectoral Framework for Socio-Economic Resilience to Climate Change and Extreme Events in Europe (CROSSEU)”. It was developed in close collaboration with project partners DTU and K&I, and builds on information and resources provided by other project partners; first and foremost, DTU, K&I, UNIPD and WMO.

As set out in the Grant Agreement, Task 4.2 analyses interrelations of climate change policies with sectoral policies to assess the effectiveness of existing mitigation and adaptation (M&A) measures and to produce new insights on how coping with climate change hotspots (CCHs) in Europe can be aligned with sectoral policies. To do so, it builds on regional, sector-specific data collected in WP2 of the CROSSEU project as well as on policy document analyses and expert interviews with stakeholders in CROSSEU Case Study Areas (CSAs) and presents the analysis of climate policy responses (e.g. laws, regulations, incentives, or initiatives) in support of climate change mitigation or adaptation in the twelve CROSSEU sectors and in selected CROSSEU CSAs.

The deliverable starts out with an introduction to the socio-economic impact of climate change (chapter 2). This is followed by a discussion of extreme weather events and connected policy responses (chapter 3). Chapter 4 describes climate change impacts and policy responses concerning the twelve CROSSEU sectors. Chapter 5 presents an overview of good practice examples of policy responses to extreme events from across Europe. Chapter 6 provides an ex-post analysis of existing mitigation and adaptation measures in three selected CROSSEU case study areas (CSA3, CSA4, CSA5). Chapter 7 gives an outlook on the contents of the successor deliverable D4.4. The deliverable is rounded off with conclusions (chapter 8).

Approach and methodology

This deliverable examines climate change M&A policies through a comprehensive analysis of policy documents and approved sectoral strategies regarding the twelve CROSSEU sectors and in selected CROSSEU CSAs. Relevant documents for the desk analysis were identified in collaboration between BOKU (as lead author of D4.3) and the CROSSEU consortium partners leading work in the eight Case Study Areas (CSA), and analyzed by BOKU.

To complement the desk analysis, the three WP4 task leads BOKU, K&I and DTU collaboratively developed survey questions (see Annex I) for case study partners to use in their stakeholder interactions, enabling the collection of primary data. The questions were included in a large survey by CROSSEU



partner UNIPD for CSA3. Data collection and analysis of survey data are detailed in Annex II.

In addition, BOKU, K&I and DTU collaboratively developed a guideline for expert interviews (see Annex III). A total of ten expert interviews were conducted to provide further insights and contextual understanding in two pilot CSAs (CSA3 and CSA4) of the CROSSEU project (see Annex IV). The identification of knowledgeable experts for each case study was carried out by the CROSSEU consortium partners during a dedicated session at the second consortium meeting, which took place in Prague in January 2025. The session was organized by BOKU, with the support of K&I and DTU. Following this, online expert interviews were conducted in Danish and English for CSA3, and in Italian for CSA4. Interviews were transcribed and analyzed by BOKU (CSA3) and K&I (CSA4).

This deliverable (D4.3) focuses on ex-post analysis, identifying existing mitigation and adaptation measures, their objectives, and their effectiveness in achieving their goals. The follow-up deliverable (D4.4) will, first, expand the ex-post analysis to further CSAs of the CROSSEU project and, second, shift to an ex-ante analysis, investigating potential options for new policies (see outlook on project deliverable 4.4 in chapter 7).

By assessing alternative policy approaches, both D4.3 and D4.4 aim to contribute to the development of more effective strategies for addressing climate change challenges. Results will feed into the development of the CROSSEU Decision Support System (DSS) as well as into the development of policy recommendations (project deliverable D4.9).



2. Socio-economic impact of climate change

Climate change has emerged as one of the most pressing global challenges of the 21st century, with profound implications for socioeconomic systems worldwide. The increasing frequency and intensity of extreme weather events, such as hurricanes, floods, droughts, and heatwaves, have underscored the urgent need for effective policy responses to mitigate and adapt to these impacts. These events not only cause immediate physical damage but also have long-term socioeconomic consequences, affecting livelihoods, health, and economic stability.

Impact of climate change can be broadly grouped into three categories: ecological, social, and economic impact. Following the overall scope of the CROSSEU project, Task 4.2 is concerned with the socio-economic impacts of climate change (and policy responses to mitigate or adapt to them; see section 3). Socio-economic impacts include impact on social aspects such as equity, risk distribution, human health impacts, and relocations of populations (cf. Lal et al., 2011, Karl et al. 2009) as well as on economic factors including “*increased risk and uncertainty of forest and agricultural production (Smith et al. 2007); alteration in productivity for crops and forest products (Feng and Hu 2007); changes in supply of ecosystem goods and services (Sohngen and Sedjo 2005; Adams et al. 2009); altered cost of utilities and services (Scott and Huang 2007).*” (Lal et al. 2011: 821)

The socioeconomic impacts of climate change are widespread and varied across different regions and sectors. Climate change has already caused substantial damages and increasingly irreversible losses in terrestrial, freshwater, cryospheric, and coastal and open ocean ecosystems, which in turn affect human societies (IPCC, 2023). Vulnerable communities, particularly those who have historically contributed the least to current climate change, are disproportionately affected. This includes regions and people with considerable development constraints, such as those in Africa, Asia, Central and South America, Least Developed Countries (LDCs), Small Island Developing States (SIDS), and the Arctic, as well as Indigenous Peoples, small-scale food producers, and low-income households.

Climate change has reduced food security and affected water security, hindering efforts to meet the United Nation’s Sustainable Development Goals (SDGs). Although overall agricultural productivity has increased, climate change has slowed this growth over the past 50 years globally, with negative impacts mainly in mid- and low-latitude regions but some positive impacts in high-latitude regions (IPCC, 2023). Ocean warming and acidification have adversely affected food production from fisheries and shellfish aquaculture in some oceanic regions. Roughly half of the world’s population currently experiences severe water scarcity for at least part of the year due to a combination of climatic and non-climatic drivers.



In urban areas, climate change has caused adverse impacts on human health, livelihoods, and key infrastructure. Hot extremes have intensified in cities, compromising urban infrastructure, including transportation, water, sanitation, and energy systems, leading to economic losses, service disruptions, and negative impacts on well-being. These adverse impacts are concentrated among economically and socially marginalized urban residents.

Climate change is driving displacement in various regions, including Africa, Asia, North America, and Central and South America, with small island states in the Caribbean and South Pacific being disproportionately affected relative to their small population size. Economic damages from climate change have been detected in climate-exposed sectors such as agriculture, forestry, fishery, energy, and tourism. Individual livelihoods have been affected through the destruction of homes and infrastructure, loss of property and income, human health impacts, and food security issues, with adverse effects on gender and social equity.

Furthermore, socioeconomic impacts of climate change will escalate with every increment of global warming, becoming increasingly complex and more difficult to manage (see also Figure 1). Multiple climatic and non-climatic risk drivers will interact, resulting in compounding overall risk and cascading risks across sectors and regions. For instance, climate-driven food insecurity and supply instability are projected to increase with global warming, interacting with non-climatic risk drivers such as competition for land, pandemics, and conflict. Future exposure to climatic hazards is increasing globally due to socio-economic development trends, including migration, growing inequality, and urbanization. Vulnerability will concentrate in informal settlements and rapidly growing smaller settlements, while in rural areas, vulnerability will be heightened by high reliance on climate-sensitive livelihoods. The loss of ecosystems and their services has cascading and long-term impacts on people globally, especially for Indigenous Peoples and local communities who are directly dependent on ecosystems to meet basic needs.

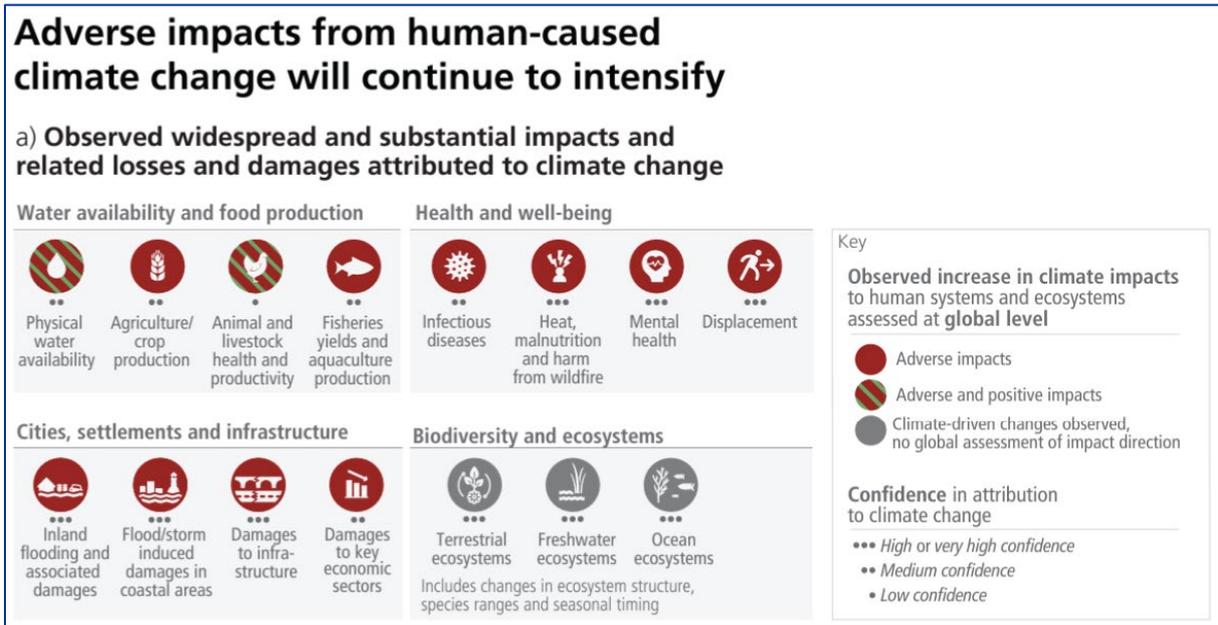


Figure 1 Adverse impacts from climate change; Source: IPCC, 2023, p.7

Impact of extreme weather events

Extreme weather events have significant socioeconomic impacts, which are exacerbated by climate change (IPCC, 2023). Human-caused climate change has already led to widespread adverse impacts and related losses and damages to nature and people, with vulnerable communities disproportionately affected. Extreme weather events, such as heatwaves, heavy precipitation, droughts, and tropical cyclones, have increased in frequency and intensity, leading to substantial damages and increasingly irreversible losses in various ecosystems. These events have caused economic damages in climate-exposed sectors like agriculture, forestry, fishery, energy, and tourism, and have adversely affected individual livelihoods through the destruction of homes and infrastructure, loss of property and income, and negative impacts on human health and food security. Urban areas have also experienced adverse impacts on human health, livelihoods, and key infrastructure, with hot extremes intensifying in cities and compromising urban infrastructure, including transportation, water, sanitation, and energy systems. These impacts are concentrated among economically and socially marginalized urban residents (ibid.).

Additionally, climate-driven food insecurity and supply instability are projected to increase with global warming, interacting with non-climatic risk drivers such as competition for land, pandemics, and conflict. The socioeconomic development trends, including migration, growing inequality, and urbanization, are increasing future exposure to climatic hazards globally, with human vulnerability concentrating in informal settlements and rapidly growing smaller settlements. In rural areas,



vulnerability is heightened by high reliance on climate-sensitive livelihoods. The loss of ecosystems and their services has cascading and long-term impacts on people globally, especially for Indigenous Peoples and local communities who are directly dependent on ecosystems to meet basic needs (ibid.).

Forms of socioeconomic impact differentiate between geographic areas within Europe; such as e.g. coastal areas, landlocked areas, mountain areas or urban areas.

- Coastal areas, such as the coast of southwest Europe, are affected by extreme temperature, precipitation, wind speed, and sea storms that can reach the level of hurricanes (Mateos et al., 2023). Such events can, among other things, lead to coastal flooding, river flooding, coastal erosion, beach retreat, rockfalls and landslides in cliff areas; with devastating effects in terms of human fatalities and injuries as well as, for example, damage to housing, infrastructure, cultivated areas, and natural ecosystems as well as cuts in water and electricity supply (ibid.).
- Alpine forests are primarily influenced by the following climatic factors (cf. European Energy Agency, 2017): a temperature increase exceeding the global average¹; a rise in annual precipitation in the north-west, contrasted with a decline in the south-east of the Alps; and significant variability in precipitation patterns, including reduced summer rainfall, increased winter precipitation in the north-west, and changes in the intensity of extreme weather events. Additionally, extreme weather events – such as heavy rainfall, droughts, heatwaves, and potentially stronger storms – are anticipated to become more frequent and intense across the entire Alpine region. These changes will make forest hydrological systems more vulnerable to extreme conditions. Extreme events, such as intense storms and heavy rainfall, heighten the risk of rockfalls and landslides, especially in degraded soils and stressed forests. This, in turn, reduces the availability of suitable land for settlement, intensifies competition for land use, and directly impacts transport and energy infrastructure. Rockfall hazards necessitate frequent road clearing.

¹ Between the late 19th and 20th centuries, the Alpine region experienced a rise in mean annual temperature of approximately 2 °C, nearly double the northern hemisphere's average (European Energy Agency, 2017).

3. Extreme weather events and policy response

The incident of an extreme weather event has the potential of instigating climate policy change. Disasters such as extreme weather events have been described as “focusing events” (Birkland, 2006, p.97) introducing “windows of opportunity” (Kingdon, 1984; Giordono et al., 2020, p. 610) for policy change. According to the conceptual framework by Giordono et al. (2020), policy change may occur in form of coping with current risks, building risk management capacity, adapting to future risks and/or mitigating to inhibit increase risks in the future (see Figure 2).

Such focusing events occur suddenly, rarely and with actual or projected harm and generating significant attention, mobilization, and policy change. Building on Birkland’s (1997, 1998) concept, these catastrophic events can mobilize communities and influence policy, though not all extreme events lead to change. Factors determining whether an event triggers local policy shifts include event characteristics, post-event debate, and community traits (see Figure 2).

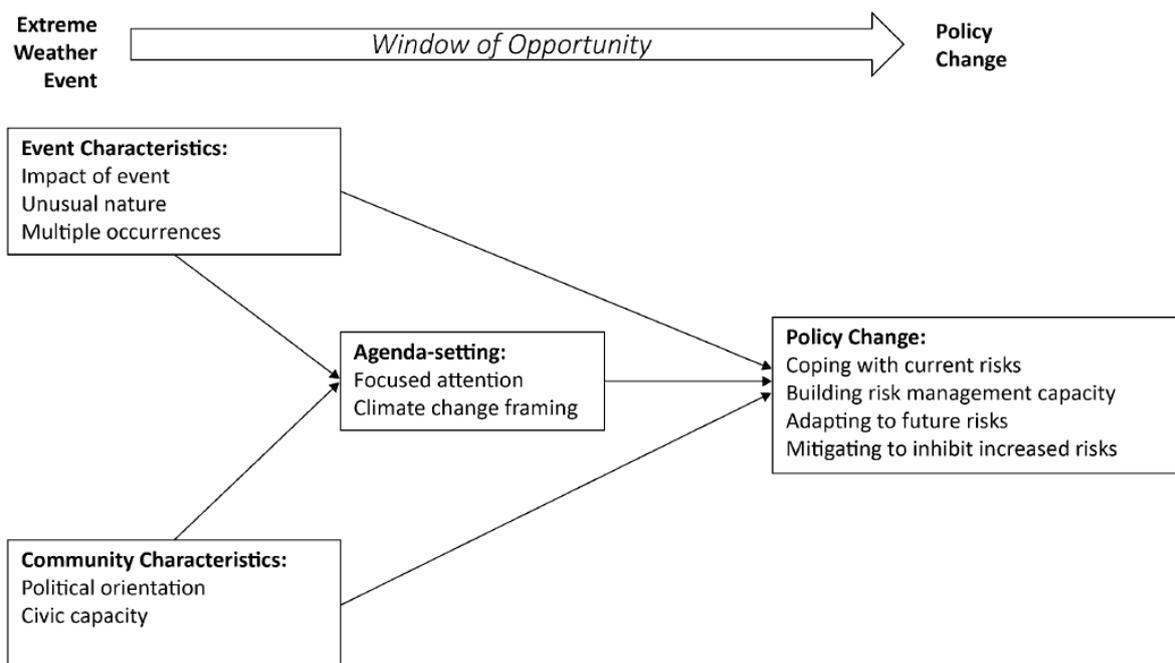


Figure 2 Conceptual framework for policy change in the wake of extreme weather events; Source: Giordono et al., 2020, p.612

Events that are sudden, rare, and cause actual or projected harm are more likely to influence policy. The impact of an event – especially rapid-onset disasters causing significant losses – can mediate policy responses. Additionally, unusual events or a series of contrasting extreme events (e.g., floods followed by wildfires) often spark climate change discussions and policy considerations.



Policy change is, however, dependent on the specific context and event, and scholars have observed that experiencing a disaster does not always result in policy change (Giordono et al., 2020). In fact, disasters can often lead to policy inertia and failure, potentially as frequently as they lead to significant policy changes. Although there are limited studies on local policy responses to extreme weather events, those that exist indicate that extreme events can indeed prompt policy changes, but the specific conditions of the community and the event play a crucial role.

3.1. Typology of responses

Policy responses to extreme weather events encompass a broad range of strategies and measures aimed at mitigating impacts and enhancing resilience. These responses include new or adapted laws, regulations, incentives, and initiatives in support of climate change mitigation or adaptation. Different types are illustrated in Figure 3².

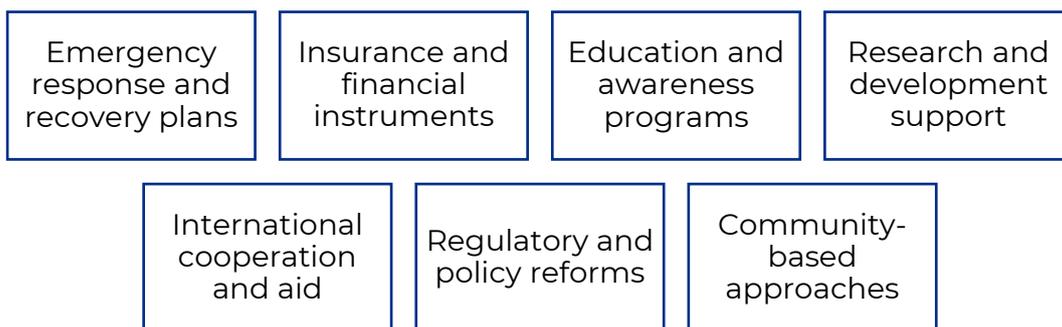


Figure 3 Types of policy responses to extreme weather events

In most cases, a combination of different types and forms of responses will be implemented. Due to the nature of climate change as a cross-cutting issue, integration into sector-based policies is vital, and a cross-sectoral approach is needed.

Policy responses to the socioeconomic impact of climate change encompass a broad range of strategies aimed at mitigating impacts and enhancing resilience across various sectors. These responses can take the form of laws, regulations, incentives, or initiatives. For instance,

² Please refer to CROSSEU deliverable 4.7 (section 2.2) for a more in-depth explanation and examples of each policy instrument.



governments may enact legislation to limit greenhouse gas emissions, establish regulatory frameworks to ensure compliance with environmental standards, provide financial incentives to promote renewable energy adoption, or launch initiatives to enhance community resilience to climate-related disasters.

Policy responses are designed to address the multifaceted challenges posed by climate change, focusing on both mitigation and adaptation strategies to safeguard socioeconomic well-being and environmental sustainability. The IPCC synthesis report for policymakers (IPCC, 2023) emphasizes the need for inclusive governance and coordinated policies to enable climate-resilient development and address the impacts of climate change on human well-being and planetary health.

Policy responses to the socioeconomic impact of climate change include (but are not limited to):

- Provision of climate information and forecasts to inform decision-making in climate-sensitive sectors: This is often a first step and supports adaptation and mitigation efforts. It includes the use of meteorological, hydrological, and oceanographic information to mitigate the impacts of weather and climate variability, climate change, and climate-related disasters, ultimately supporting the net zero emissions transition (World Meteorological Organization, 2023a).
- Improving public policy and management: This is another crucial aspect and includes designing policies that intentionally address climate change impacts, such as policy feedback mechanisms in a changing climate, and employing economics-based approaches to public management that consider environmental accounting and the recovery of meteorological services costs (World Meteorological Organization, 2022b).
- Enhancing urban planning and management: This is essential for adapting to climate change and mitigating societal impacts of, for example, heatwaves and urban heat islands. It includes developing interdisciplinary urban climate services and long-term urban planning for sustainable development, climate change mitigation, and adaptation (World Meteorological Organization, 2021).
- Promoting capacity development: This is vital, especially in developing countries. Initiatives supported by international agencies aim at enhancing resilience to climate variability and change by developing the capacity of scientists, policymakers, technical experts, and local communities (World Meteorological Organization, 2020).
- Effective communication of climate science and services: This is essential for raising awareness among decision-makers and the general public about the local and regional impacts of climate variability and change. This includes focusing communication efforts



on priority areas such as agriculture, health, water, disaster risk reduction, and energy (World Meteorological Organization, 2022a).

Policy responses to the socioeconomic impact of climate change, and to extreme weather events in particular, must be tailored to the specific characteristics of each event, the geography of the affected area, and other relevant factors. Different types of extreme weather events, such as storms, floods, droughts, and heatwaves, present unique challenges that require distinct approaches. For instance, flood-prone regions may prioritize the development of robust flood defense systems and early warning mechanisms, while areas susceptible to drought might focus on water conservation strategies and sustainable agricultural practices. Geographic factors, including topography, climate, and population density, also play a crucial role in shaping policy responses. Coastal regions may need to implement policies that address sea-level rise and coastal erosion, whereas urban areas might concentrate on mitigating the urban heat island effect and enhancing green infrastructure. Additionally, socioeconomic factors such as the level of economic development, community resilience, and access to resources influence the effectiveness and design of policy interventions. By considering these diverse elements, policymakers can develop more targeted and effective strategies to mitigate the impacts of extreme weather events and enhance the resilience of affected communities.

3.2. The cross-cutting issue of climate change

Impacts of climate change generally affect multiple sectors and regions. Effects are wide-ranging, and impact areas such as agriculture, marine ecosystems, energy production, and transportation infrastructure. Addressing the impacts of climate change therefore requires the collaboration of governmental and non-governmental actors, emphasizing the importance of integrated, cross-sectoral approaches. Effective climate responses should incorporate multi-objective policy frameworks that enable synergies while managing trade-offs between sectors, ensuring that climate action supports broader sustainable development efforts.

As detailed by the Intergovernmental Panel on Climate Change (IPCC, 2023), impacts such as glacier retreat, rising sea levels, and more frequent extreme weather events have broad influence on various policy areas, including poverty reduction, health, water and energy systems, transportation, and biodiversity. The combination of climate and non-climatic factors can deepen existing inequalities, creating poverty-environment traps that heighten the risk of prolonged poverty, particularly in vulnerable regions. Responses to climate change impact must therefore aim to promote equitable outcomes across all sectors and populations,



ensuring that no group is disproportionately affected by responses and avoiding maladaptation.

Climate change impacts and responses in sectoral policies are multifaceted and require a comprehensive understanding across various sectors. The World Meteorological Organization (WMO) provides extensive guidance on assessing and addressing these impacts within strategic sectors. It focuses on five key sectors (see Table 1) identified in the Global Framework for Climate Services (GFCS)³.

Table 1 Climate change impacts and responses in key strategic sectors

| Key sector | Impacts & responses |
|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Agriculture and food security | Climate variability and change significantly affect agriculture and food security. Predicting sectoral systems' behavior, such as crop production and plant diseases, allows for forecasting sectoral impacts, thereby informing strategies for food security and agricultural planning (World Meteorological Organization, 2023b). |
| Disaster risk reduction | The integration of climate data and expert advice is crucial for disaster risk reduction, including improved flood forecasting and early warning systems. This is increasingly recognized as an economic and political issue at both national and international levels, prompting investment in enhancing forecasting capabilities (World Meteorological Organization, 2022c). |
| Energy | The energy sector's complexity with climate variability involves both the impact on energy production (e.g., wind, hydropower) and consumption. Seasonal climate forecasts assist energy companies in anticipating demand spikes, crucial for matching production requirements (World Meteorological Organization, 2020b). |
| Health | Developing methods to address slowly responding impacts, particularly in health, such as vector-borne diseases related to climate change, is essential. This involves integrating climate data into public health planning and response strategies (World Meteorological Organization, 2021). |

³ The Global Framework for Climate Services (GFCS) is an international initiative designed to enhance the development, delivery, and effective use of climate services worldwide. Its core purpose is to integrate climate science into decision-making processes at all levels, enabling societies to better manage the risks and opportunities associated with climate variability and change. <https://gfcs.wmo.int/site/global-framework-climate-services-gfcs/about-gfcs>; last accessed May 13th, 2025



| | |
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| Water | Assessing the impacts of climate change on water resources is critical for sustainable water resource management. This includes understanding how climate variability and change affect water availability and quality, informing policies and practices for water use and conservation (World Meteorological Organization, 2008). |
|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

In summary, addressing climate change impacts across these sectors requires a multidisciplinary approach that integrates climate science into sectoral policies and planning. This involves leveraging climate data and forecasts, developing sector-specific adaptation and mitigation strategies, and enhancing resilience through informed decision-making and policy formulation.

The World Meteorological Organization (WMO) further provides a set of diverse good practice examples of cross-sectoral approaches to respond to the socioeconomic impact of climate change. A selection of good practice examples is presented in Figure 4.

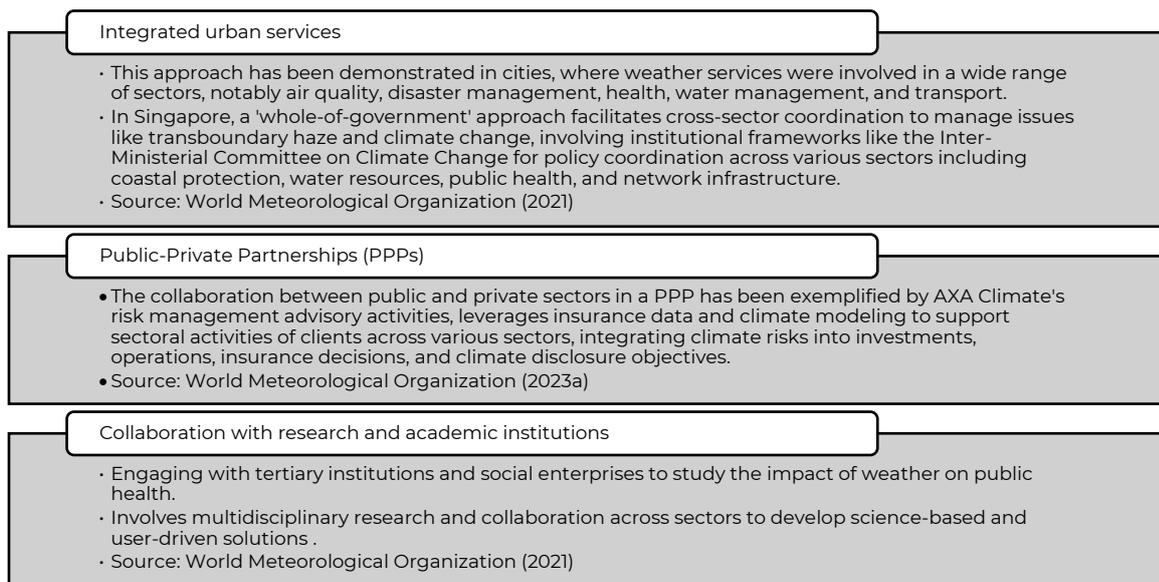


Figure 4 Good practice examples of cross-sectoral approaches in response to socioeconomic impact of climate change

These examples illustrate the importance of cross-sectoral approaches in addressing the complex and interconnected impacts of climate change on socioeconomic systems.

4. Responses in sectoral policy

The CROSSEU project identified twelve sectors for analysing impact of climate change and crosscutting issues. Table 2 summarizes key impact and policy responses identified in the analysis of pertinent reports and academic publications. More details on impact and policy responses per sector are provided in the following sub-sections of the chapter (sub-sections 4.1 to 4.12).

Table 2 Socioeconomic impact of climate change and policy responses per CROSSEU sector

| Sector | Key impacts of climate change | Policy responses |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Agriculture | <ul style="list-style-type: none"> • Reduced crop yields • Impact on livestock and infrastructure | <ul style="list-style-type: none"> • Development of climate-friendly technologies • Resource-saving practices |
| Biodiversity | <ul style="list-style-type: none"> • Disruption of ecosystems • Decline in ecosystem services | <ul style="list-style-type: none"> • Ecosystem-based adaptation • Strong action to reduce greenhouse gas emissions |
| Energy | <ul style="list-style-type: none"> • Damage to infrastructure • Increased energy demand for cooling | <ul style="list-style-type: none"> • Enhancement of resilience • Promotion of clean energy investment |
| Finance | <ul style="list-style-type: none"> • Increased costs from disaster recovery and insurance claims • Financial instability due to extreme weather events | <ul style="list-style-type: none"> • Integration of climate change into risk management frameworks • Investment in climate-resilient infrastructure |
| Forestry | <ul style="list-style-type: none"> • Habitat loss • Decline in biodiversity | <ul style="list-style-type: none"> • Forest conservation and restoration • Sustainable land-use practices |
| Health | <ul style="list-style-type: none"> • Increased incidences of diseases • Mental health impacts from extreme weather events | <ul style="list-style-type: none"> • Health National Adaptation Plans (HNAPs) • Evidence-based adaptation plans for health |
| Insurance | <ul style="list-style-type: none"> • Higher claims and payouts • Strain on insurance companies | <ul style="list-style-type: none"> • Innovative insurance products • Risk reduction measures |
| Migration | <ul style="list-style-type: none"> • Population displacement due to extreme weather events | <ul style="list-style-type: none"> • Policies to support climate migrants • Integration into new communities |
| Social Justice | <ul style="list-style-type: none"> • Disproportionate impact on vulnerable groups • Increased food insecurity | <ul style="list-style-type: none"> • Promotion of equitable treatment • Protection of vulnerable groups |
| Tourism | <ul style="list-style-type: none"> • Changes in tourist numbers and spending | <ul style="list-style-type: none"> • Sustainable mobility investments |



| | | |
|------------------|----------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| | <ul style="list-style-type: none"> • Vulnerability of destinations to extreme weather events | <ul style="list-style-type: none"> • Use of renewable energies for local public transport |
| Transport | <ul style="list-style-type: none"> • Damage to infrastructure from extreme weather events • High socioeconomic costs | <ul style="list-style-type: none"> • Investment in resilient transport infrastructure • Adaptation planning |
| Water Management | <ul style="list-style-type: none"> • Water scarcity • Impact on hydropower generation | <ul style="list-style-type: none"> • Combination of natural, engineered, technological, social, and institutional measures |

4.1. Agriculture and food security

The agricultural sector is extensively and adversely impacted by extreme weather events in form of heavy rainfall, droughts, and rising temperatures. These events can physically damage crops and hinder plant growth, ultimately leading to reduced crop yields (Zampieri et al., 2017; Cogato et al., 2019). Beyond direct crop damage, extreme weather events also have widespread impacts on broader agricultural systems, including livestock, infrastructure, natural resources such as soil and water, and the health of farmers (Escarcha et al., 2018; FAO, 2018; Talukder et al., 2021).

Climate change impacts on agricultural and food security

Drought has been identified as the most limiting factor of global wheat productivity (Cattivelli et al. 2008). The impact of droughts on wheat yields depends on the wheat growing phase during which they occur as well as on their duration and intensity (Rampino et al. 2006).

Climate change is expected to negatively affect crop yields worldwide due to increasing greenhouse gas (GHG) emissions. This impact will vary depending on the overall amount of GHGs emitted in the coming decades. Beyond crop yields, climate change will affect biodiversity, soil quality, animal and plant resilience to diseases, and poverty and inequalities across and within countries. These factors could trigger migration flows and conflicts, with significant negative consequences for billions of people (FAO, 2018).

Agricultural sectors need to adapt to climate change while also contributing to its mitigation. Substantial investments are required to develop and implement resource-saving and climate-friendly technologies. Efforts in agriculture alone are not enough; drastic economy-wide GHG reductions are needed. Climate change will exacerbate poverty and inequalities, disproportionately affecting poor people and worsening food availability and access. Equitable access to resources, improved



information, job creation, decent wages, and diversified earning opportunities for rural people are essential to mitigate these impacts.

The FAO (2018) highlights that climate change impacts go beyond crop yields, affecting soil quality, fish habitats and stocks, the biodiversity of landscapes, and the epidemiology and antimicrobial resistance of pests and diseases. Additionally, climate change will incrementally affect all agricultural sectors, including livestock production and fisheries, particularly in low- and middle-income countries.

Agricultural and food security policy responses

Overall, proactive measures and substantial investments are critical to address the multifaceted impacts of climate change on agricultural production and food security. Agricultural sectors can adapt to climate change and lower their GHG emissions while producing enough food for all (FAO, 2018). However, for this to be possible, substantial investments must be made to develop and implement more resource-saving and climate-friendly technologies.

The FAO (2018) outlines several strategies in agricultural policies aimed at promoting sustainability, improving food security, and addressing poverty and inequality:

- One key strategy is the investment in research and development. This involves stepping up public spending on research and development and enabling a better environment for private research into innovative sustainable agricultural technologies, particularly those suitable for family farmers. Ensuring family farmers' access to innovative technologies is also crucial. This can be achieved through measures such as specific credit lines, incentives, advisory services, and the creation of communities of practice to share information and exploit economies of scale.
- Improving coordination along value chains is another important strategy. Enhancing coordination ensures that the weaker segments in the chain reap the benefits of integrating agricultural sectors into wider markets. Protecting asset ownership and control is also emphasized, with effective measures needed to implement transparent land markets and institutional arrangements to prevent dispossession of essential capital.
- Promoting sustainable agricultural practices is vital for long-term sustainability. This includes encouraging the adoption of practices such as agroforestry, organic agriculture, agroecology, and integrated pest management. The use of information and communication technologies can accelerate the spread and adoption of these innovations. Furthermore, raising consumer awareness about environmentally sustainable diets, regulating and



discouraging food waste, enforcing more efficient food pricing, and limiting the use of biofuels are critical actions to contain the expansion of agricultural sectors.

- Equitable income distribution is essential for improving food security and nutrition. Pursuing a more equitable distribution of income within and across countries involves promoting sustainable technologies, facilitating access to markets for family farmers, building stronger institutions, implementing effective social protection schemes, and reducing illicit financial flows. Climate change mitigation and adaptation require substantial investments to develop and implement resource-saving and climate-friendly technologies. Agricultural sectors can adapt to climate change and lower their GHG emissions while producing enough food for all. However, efforts in agriculture alone are not enough; drastic economy-wide GHG reductions are needed.
- International trade plays a significant role in facilitating the balanced use of natural resources and compensating for domestic food deficits. Strong global and national institutions are needed to coordinate efforts across countries and prevent unfair competition against those adopting more stringent environmental and social regulations. Economic diversification into rural non-farm income-generating activities is also important. This can be promoted by developing industrial policies, protecting infant industries, and implementing measures to favour private businesses, particularly small- and medium-sized enterprises.

4.2. Biodiversity and ecosystem services

Extreme weather events and shifting climate conditions disrupt ecosystems and biodiversity. Habitat loss, species migration, and changes in reproductive cycles can lead to a decline in biodiversity. Ecosystem services, such as pollination, water purification, and carbon sequestration, are compromised, affecting both environmental health and human well-being (Convention on Biological Diversity, 2020).

Climate change impacts on biodiversity and ecosystem services

Climate change is already impacting biodiversity and is projected to have progressively greater impacts, with significantly greater risks to natural and human systems in a world warming to 2 degrees Celsius above pre-industrial temperatures compared to 1.5 degrees Celsius above pre-industrial temperatures. It is likely to become the largest driver of biodiversity loss in the second half of the 21st century (Convention on Biological Diversity, 2020). Climate change impacts undermine ecosystem resilience and weaken the contribution of ecosystems to both mitigation



and adaptation of climate change. Higher sea temperatures have led to an increase in mass coral bleaching, compounded by the impact of ocean acidification. Additionally, climate change has impacted terrestrial and freshwater species and ecosystems in high mountain and polar regions, contributing to shifts in seasonal activities of species and altered abundance and distribution of plant and animal species.

The degradation of ecosystems due to climate change is continuing to threaten the contributions that nature provides to people. The expansion in the production of food, feed, fibre, and bio-energy has occurred at the cost of regulation of air and water quality, climate regulation, pollination, regulation of pests and diseases, and provision of habitat. Poorer groups are most likely to suffer the impacts of declining contributions of nature to people and are least likely to benefit from increasing contributions such as food production. Overall, effective climate action is a prerequisite to slowing and reversing biodiversity loss and ecosystem-based approaches, alongside strong action to reduce greenhouse gas emissions, are essential to mitigate these impacts.

Biodiversity and ecosystem policy responses

Policy responses to mitigate or adapt to the impacts of climate change include employing nature-based solutions alongside a rapid phase-out of fossil fuel use (Convention on Biological Diversity, 2020). These solutions aim to reduce the scale and impacts of climate change while providing positive benefits for biodiversity and other SDGs.

Efforts to conserve and restore biodiversity need to be scaled up at all levels using approaches that depend on local context. This involves combining major increases in the extent and effectiveness of well-connected protected areas and other effective area-based conservation measures, large-scale restoration of degraded habitats, and improvements in the condition of nature across farmed and urban landscapes as well as inland water bodies, coasts, and oceans. Effective steps must be taken to address all remaining pressures driving biodiversity loss, including invasive alien species, pollution, and the unsustainable exploitation of biodiversity, especially in marine and inland water ecosystems.

In close connection to agriculture and food security policies, transformations in food production are necessary. This includes adopting agricultural methods that can meet growing global demand while imposing fewer negative impacts on the environment and reducing the pressure to convert more land to production. Limiting the demand for increased food production by adopting healthier diets and reducing food waste is also crucial. Additionally, limiting the consumption of other material goods and services affecting biodiversity, such as forestry, energy, and provision of fresh water, is important.



Nature-based solutions could provide about one-third of the total net emission reduction effort required to keep climate change close to 1.5 degrees Celsius (ibid.). With appropriate safeguards, such nature-based solutions could enhance a wide range of ecosystem services, including water filtration, flood and coastal protection, and soil health, as well as contributing to the conservation and sustainable use of biodiversity. However, stringent reductions in the use of fossil fuels are necessary to solve the climate problem. Indigenous peoples and local communities must be fully involved in the development and implementation of land-based approaches. Careful assessment of synergies and trade-offs is required, as tree planting is not always appropriate, especially non-native species in monoculture plantations. Conserving and restoring the role of species and genetic diversity in addition to ecosystem extent is important.

4.3. Energy

The energy sector faces challenges from climate change, including damage to infrastructure from extreme weather events like hurricanes and floods. Additionally, changes in water availability can impact hydropower generation, while heatwaves can increase energy demand for cooling (International Energy Agency, 2024). Transitioning to renewable energy sources is crucial to mitigate these impacts and ensure energy security (IPCC, 2023).

Climate change impacts on energy

Climate change and extreme weather events have significant impact on the energy sector; including reducing the effective capacity of power plants, increasing transmission losses, and altering energy demand patterns by increasing the need for cooling and decreasing the need for heating.

Extreme weather events, which are becoming more frequent due to climate change, also have major implications for energy use. For instance, in 2023, approximately 800 terawatt-hours (TWh) of electricity were used for cooling during extreme heat events, a substantial increase from less than 300 TWh in the 1990s (International Energy Agency, 2024). The total cost of meeting cooling demand during these extreme heat events has risen from just over USD 10 billion annually in the 1990s to nearly USD 30 billion annually in the last decade (ibid.). This increase is partly due to the growing number of extreme heat events and partly due to the increasing



uptake and use of air conditioning⁴. Although decreased demand for heating has offset some of the increased demand for cooling, meeting the rise in cooling demand during peak times will likely result in higher system costs in the future.

Hydropower output is declining in many parts of the world, largely due to climate change-induced shifts in precipitation patterns, increased variabilities in runoff, and physical damage to dams caused by extreme weather events (ibid.): These factors have contributed to the decrease in the hydropower capacity factor from 44% in the 1990s to 41% in the 2020s, implying a loss of around 330 TWh of annual power generation today; a loss that is roughly equivalent to the amount of generation from all new solar photovoltaic added worldwide in 2023. Compensating for the loss of generation resulting from the derating of hydropower, including pumped storage, is estimated to have cost around USD 18 billion each year over the last ten years.

Energy policy responses

Policy responses to the impacts of climate change and extreme weather events on the energy sector aim to enhance the resilience of energy systems, ensure energy security, promote clean energy investment, and improve energy efficiency to mitigate the impacts of climate change and extreme weather events on the energy sector. They involve several strategies (cf. International Energy Agency, 2024):

- **Enhancement of resilience:** This includes the development of digital technologies that help operators manage stresses and reduce the risk of potential damage from extreme weather events as well as crisis management and contingency planning for climate-related disruptions. Additionally, longer-term efforts focus on diversifying energy sources and investing in resources that can better withstand extreme weather events.
- **Comprehensive energy security approach:** The International Energy Agency (IEA) advocates for a comprehensive approach to energy security that encompasses traditional risks and new hazards emerging from climate change and clean energy transitions. This approach includes increasing the supply of power and fuels, ensuring adequate and resilient infrastructure and systems, using energy more efficiently, and minimizing CO₂ and methane emissions. The IEA emphasizes that policy makers need to balance energy security and climate action, as failure to act on emissions increases risks to

⁴ These figures only cover energy costs and do not reflect all the costs incurred by electricity grids to expand generation and deliver power.



energy security due to the physical consequences of a changing climate.

- **Coordinated infrastructure planning:** Efforts to reduce unabated fossil fuel use and scale up clean energy need to be carefully designed to avoid mismatches between the rate of expansion of low-emissions electricity generation, networks, and electrified end-user equipment, and the decommissioning of natural gas-fired plants and gas networks. This coordinated planning helps prevent energy security risks and ensures that consumers who cannot afford higher upfront investments for electric end-use equipment are not disproportionately affected. Existing infrastructure can play a role in accelerating the development of low-emissions fuels, such as biomethane, low-emissions hydrogen-based fuels, and some liquid biofuels, which can utilize existing infrastructure and end-use equipment.
- **Public investment in clean energy:** Governments are providing significant support for clean energy investment through licensing regimes, major project approvals, large infrastructure developments, direct support, and tax credit provisions. Specific government support for clean energy investment has been incorporated into recovery plans made in response to the Covid-19 pandemic and the global energy crisis. Announcements of government support for clean energy investment since 2020 cumulatively reached USD 2 trillion in the first half of 2024. This support aims to shield consumers and industries from high energy prices during crises and promote clean energy technologies.
- **Increase energy efficiency:** Energy efficiency measures can significantly reduce peak electricity demand. Minimum energy performance standards for appliances, improved building insulation, and more efficient industrial motors all serve to reduce total and peak electricity demand. Demand-side flexibility measures, such as smart meters, dynamic tariffs, and demand response-enabled appliances, also help manage peak demand and reduce the need for expanding fossil fuel dispatchable power plants. These measures contribute to maintaining system adequacy and reducing the need for new dispatchable capacity.

4.4. Finance

Climate change poses significant risks to the financial sector, including increased costs from disaster recovery and insurance claims. Extreme weather events can disrupt economic activities, leading to financial instability. Investment in climate-resilient infrastructure and sustainable practices is essential to safeguard financial systems and promote long-term economic stability (cf. UNEP, 2015).



Climate change impacts on finance

Climate change has significant impact on the financial sector, particularly through the amplification of risks induced by climate-related natural hazards such as floods (Mandel et al., 2021). Changes in the distribution and frequency of extreme weather events, driven by climate change, pose a threat to global financial stability. This threat is exacerbated by the financial leverage and centrality of high-income countries in the global financial network. High-income countries, which are more financially leveraged, face larger amplification of impacts due to their central role in global financial networks. Consequently, in high-end climate scenarios, systemic risk may emerge as total impacts become commensurate with the capital of the banking sectors of countries that serve as hubs in the global financial network.

The magnitude of global risks is determined by the interplay between the exposure of countries to climate-related natural hazards and their financial leverage. Climate change induces a shift in the distribution of impacts towards high-income countries, leading to larger amplification of impacts. Conversely, high-income countries are more exposed to financial shocks. Adaptation policy plays a crucial role in determining the future exposure of high-income countries, implying that the avoided costs in terms of financial stability should be considered as benefits of adaptation policy.

The management of climate-related financial risks can be approached both at the macro- and micro-level. At the macro-level, insurance plays a major role in limiting the propagation of climate impacts. At the micro-level, climate-induced risks can be a source of systemic risk for the financial sectors of the most leveraged countries, mostly in Western Europe. This highlights the need for financial institutions to integrate climate change into their risk-management frameworks.

Finance policy responses

The impact of climate change on finance and the financial sector is profound, with significant implications for global financial stability. Adaptation policies and risk management frameworks are essential to mitigate these risks and ensure the resilience of financial systems in the face of climate-induced shocks.

Strategic actions and measures to adjust and prepare financial systems and institutions to cope with the adverse effects of climate change play a crucial role in mitigating the impact of climate change on the financial sector (Mandel et al., 2021). Investments in this regard also significantly improve financial stability. A clear adaptation policy is necessary for investors to accurately account for physical risks in their long-term investment decisions, thereby reducing future exposure. However, many coastal countries, for example, lack such clear adaptation policies; partly



due to the large upfront investments required for coastal protection and the deep uncertainty associated with future sea-level rise.

Since impacts of climate change in one country can affect financial stability in another country, global cooperation is needed. Mandel et al. (2021) emphasize the need for a framework to manage financial risks related to climate change. At a macro level, insurance by private actors or the government is useful in reducing the spread of climate impacts. At the micro level, climate-related risks can cause major problems for the financial sectors of countries with a lot of debt, especially in Western Europe. This highlights the need for financial institutions to include climate change in their risk management plans. The "Central Banks and Supervisors Network for Greening the Financial System" (NGFS) has recently emphasized the importance of considering climate change in financial risk management.

4.5. Forestry

Forests are vulnerable to climate change through increased risks of wildfires, pest infestations, and disease outbreaks. These impacts can lead to loss of timber resources, reduced carbon sequestration, and degradation of forest ecosystems (FAO, 2024). Sustainable forest management practices are necessary to enhance resilience and protect forest resources.

Climate change impacts on forestry

Climate change is significantly impacting forestry by making forests more vulnerable to various stressors. These include both abiotic stressors, such as wildfire, drought, and extreme temperatures, and biotic stressors, such as pests, diseases, and invasive species.

One of the major impacts is the increase in the frequency and intensity of wildfires. An estimated 340–370 million hectares of the Earth's land surface are affected by fire annually, with the actual area likely being higher due to measurement limitations (FAO, 2024). Wildfires, driven by climate change and land-use changes, are becoming more frequent and intense, even in areas previously unaffected (ibid.): In 2023, fires emitted 6,687 megatonnes of carbon dioxide globally, which amounts to more than double the carbon-dioxide emissions by the European Union from fossil fuels in that year; in Canada, fires burned 14.6 million hectares, which was more than five times the 20-year average. These increases in wildfire activity accelerate positive feedback loops in the carbon cycle, posing challenges for global climate-change mitigation efforts.





Forestry policy responses

Responses to climate change in forestry policies include approaches aimed at enhancing forest conservation, restoration, and sustainable use. Policies focus on increasing the resilience of forests to climate change and mitigating climate change impacts. Responses include (cf. FAO, 2024):

- Development of integrated landscape approaches for entire ecosystems: These approaches include ecosystem-based adaptation to climate change, climate-smart agriculture that combines sustainable farming practices with forest conservation, and biodiversity offsetting aimed at achieving net gains in biodiversity. Additionally, there is a focus on decoupling agricultural supply chains from deforestation to promote sustainable land-use practices .
- Implementation of financial incentives and support programs to encourage sustainable forest management: This includes, for example, the introduction of financial incentives for forest users to restoration sites or the payment of income support for reforestation to local communities.
- Development of hybrid institutions that combine elements of public, private, and community-based management structures: Such institutions (e.g. collaborative reforestation projects where governments provide incentives for private landowners to participate in reforestation efforts) have greater capacity to integrate diverse stakeholders and foster multistakeholder partnerships, promoting more inclusive decision-making.
- Voluntary, non-governmental certification programs (e.g. Forest Stewardship Council, Programme for the Endorsement of Forest Certification): Promotion of higher forest governance standards via government policies, laws, and enforcement practices.

4.6. Health

Climate change is increasingly contributing to humanitarian emergencies due to undernutrition, malaria, diarrhea, and heat stress. Areas with weak health infrastructure, primarily in developing countries, will struggle the most to cope without assistance to prepare and respond. Reducing greenhouse gas emissions through improved transport, food, and energy use choices can lead to significant health benefits, particularly by reducing air pollution (cf. WHO, 2021b).



Climate change impacts on health

Climate change has been acknowledged as the single biggest health threat facing humanity (cf. WHO, 2021a). The Intergovernmental Panel on Climate Change (IPCC, 2023) has concluded that to avert catastrophic health impacts and prevent millions of climate change-related deaths, the world must limit temperature rise to 1.5°C. Global heating of even 1.5°C is not considered safe; every additional tenth of a degree of warming will take a serious toll on people's lives and health.

Climate change is already impacting health in many ways, including fatalities and illness from increasingly frequent extreme weather events, the disruption of food systems, increases in zoonoses and food-, water-, and vector-borne diseases, and mental health issues (WHO, 2021a). Furthermore, climate change is undermining many of the social determinants for good health, such as livelihoods, equality, and access to health care and social support structures.

Health risks from climate change are disproportionately felt by the most vulnerable and disadvantaged groups of people; including women, children, ethnic minorities, poor communities, migrants or displaced persons, older populations, and those with underlying health conditions.

It remains challenging to accurately estimate the scale and impact of many climate-sensitive health risks. However, scientific advances progressively allow the attribution of increases in morbidity and mortality to human-induced global warming. In the short- to medium-term, the health impacts of climate change will be determined mainly by the vulnerability of populations, their resilience to the current rate of climate change, and the extent and pace of adaptation. In the longer-term, the effects will increasingly depend on the extent to which transformational action is taken now to reduce emissions and avoid the breaching of dangerous temperature thresholds and potential irreversible tipping points (ibid.).

Health policy responses

Responses in health policies to address the impacts of climate change aim at building resilience and sustainability within health systems. They are designed to protect populations from the health risks associated with climate change and to ensure that health systems can adapt and respond effectively. Some of the main responses in health policies include (cf. WHO, 2021a):

- Assessments of health vulnerabilities and adaptation capacities: Regular assessments provide an important foundation for any government's response to climate risks and help identify which populations and geographical areas are most vulnerable and disadvantaged. The evidence gathered through these assessments



should inform the development of comprehensive and ambitious Health National Adaptation Plans (HNAPs).

- Evidence-based adaptation plans for health: National Adaptation Plans (NAPs) allow countries to identify medium- and long-term adaptation needs and develop strategies to address those needs. A Health National Adaptation Plan (HNAP) should offer a strategy to engage other health-determining sectors, ensure necessary finance, and build the capacity to effectively build health systems that are more resilient to future health shocks and climate change impacts.
- Strengthen climate resilience and environmental sustainability of health systems and facilities: The improvement of health systems and facilities facilitates the protection and improvement of the health of all people in an unstable and changing climate. This includes increasing access, affordability, and sustainability of essential health services, enhancing the capacity of the health workforce, and implementing actions around key components such as energy, infrastructure, technologies, water, sanitation, hygiene, and healthcare waste.
- Closing the financing gap for health adaptation and resilience: This includes allocating climate finance to adaptation efforts and removing existing barriers to finance for health adaptation and resilience.
- Protecting health and advancing climate justice: The implementation of health-promoting interventions in other sectors, such as water, energy, food, and agriculture to develop synergies can help protect health and advance climate justice.

4.7. Insurance

The insurance sector faces growing challenges from the increasing frequency and severity of extreme weather events. Higher claims and payouts for damages can strain insurance companies and lead to higher premiums for policyholders (cf. UNEP, 2015). Developing innovative insurance products and promoting risk reduction measures are essential to manage these impacts.

Climate change impacts on insurance

Climate change poses significant risks to the financial system, impacting various sectors and necessitating the integration of environmental considerations into financial decision-making. The financial system must take climate risk into account, anticipate ambitious targets, and integrate these into investment decisions to ensure long-term stability and resilience.



The financial system's alignment with sustainable development is crucial, as environmental deterioration continues to threaten development models and damage vital life support systems. According to data from the year 2015, the global economy was causing environmental damage worth more than \$7 trillion annually; with patterns of economic growth that were set to further erode global natural wealth by over 10% by 2030 (UNEP, 2015).

Environmental risk factors have increasingly been leading to asset stranding, where assets experience unexpected or premature write-downs, devaluations, or conversion to liabilities. These risks arise from both the degradation of natural capital and the transition to more sustainable development models. A key example is the risk that most fossil fuel reserves may not be commercialized if global climate targets are achieved. It has been estimated that in a low-carbon scenario, the value of "unburnable" fossil fuel reserves could exceed \$100 trillion by 2050 (Channell et al., 2015).

Insurance policy responses

Policy responses relevant to the financial sector include measures to manage risk, promote innovation, strengthen resilience, and ensure policy coherence (cf. UNEP, 2015). Innovation can be stimulated by setting common standards, such as those for green bonds, to improve market integrity and investor confidence. Strengthening resilience involves addressing the financial impacts of natural hazards. Ensuring policy coherence involves aligning financial system rules with broader government policies.

Colliers et al. (2021) outline a set of policy responses to address the impact of climate change on insurance:

- Public and private insurance mechanisms to distribute exposure to climate risks and provide new forms of security: This includes public regulation, public backstops for private insurance, and private insurance cover for public functions.
- Collaborations and initiatives between national governments, multilateral organizations, non-profits, foundations, and private insurers: National and regional catastrophe insurance programs, global index insurance facilities, and micro-insurance programs are, for example, being supported by the United Nations and the World Bank.
- Insurance as a governance tool: The role of insurance has shifted from focusing on the health of the insurance industry to governing the



risks associated with climate change. This includes better managing risks through partnerships with global insurers and reinsurers.

- Risk transfer mechanisms: New risk transfer mechanisms, such as catastrophe bonds and other insurance-linked securities, are changing how catastrophic risks are distributed. These mechanisms allow risks to be spread into larger pools of financial capital rather than limited populations of policyholders.
- Public sector involvement: Catastrophe insurance often involves the public sector as a regulator, provider of backstops or reinsurance, or consumer of private insurance products. This dynamic relationship between public and private sectors is crucial for understanding the emerging assemblages of catastrophe insurance and climate change.
- Urban resilience initiatives: In wealthy regions, insurance is used to protect property investments and finance public infrastructure and resilience measures. This involves deploying private insurance as a mechanism of public intervention to advance urban resilience as a public problem.

Overall, it has been concluded that a combination of “(...) *(i) improved risk assessment ability, risk management upgrades in mitigation, adaptation, and transfer, broader public awareness, and public-private partnerships, and finally, innovative and robust market mechanisms must be combined to tackle the climate change challenges in the insurance sector.*” (Gupta and Venkataraman, 2024, p.8).

4.8. Migration

Climate change can drive migration as people move away from areas affected by extreme weather events, sea-level rise, and resource scarcity (cf. McAuliffe and Oucho, 2024). This can lead to social and economic pressures in receiving areas, including increased demand for housing, services, and employment. Policies to support climate migrants and integrate them into new communities are crucial.

Climate change impacts on migration

Climate change impacts migration through both sudden- and slow-onset events, affecting food systems and increasing food insecurity. Sudden-onset disasters like hurricanes and floods destroy infrastructure and agricultural landscapes, while slow-onset events such as drought and rising sea levels alter livelihoods and reduce well-being (ibid.).



These climate events, compounded by social vulnerabilities, can drive migration in non-linear ways.

Migration can serve as an adaptation strategy to climate change, reducing exposure and socioeconomic vulnerability when properly supported. However, involuntary migration due to climate hazards can lead to negative outcomes, including loss of livelihoods and well-being. The success of migration as an adaptation tool depends on the socioeconomic status and agency of the migrants (cf. Vinke et al., 2020).

In some regions, climate impacts combined with reduced access to resources can trigger conflicts and drive migration. Structural vulnerabilities in areas with low resilience also contribute to migration and conflict. Urban centers receiving climate migrants face increased risks without adequate adaptation and planning, including exposure to climatic events and water scarcity.

While remittances from migrants can enhance food security and climate resilience, migration can also be maladaptive, causing labor shortages and worsening food security for vulnerable populations. Carefully crafted policies are needed to address these complexities, prevent forced movements, and leverage positive impacts of mobility for climate adaptation and food security.

Migration policy responses

Responses in migration policy to deal with climate change impacts and risks involve several strategies and frameworks aimed at addressing the complexities of climate-induced migration. McAuliffe and Oucho (2024) detail how the different policies focus on minimizing adverse drivers, enabling safe migration pathways, and ensuring the protection and well-being of migrants:

- Key international frameworks such as the Global Compact for Safe, Orderly and Regular Migration and the Global Compact address the governance of international migration. While the former provides specific recommendations regarding disasters, environmental degradation, and climate change, the latter recommends the adoption of policies and mechanisms to enable safe migration pathways and suggests solutions for migrants compelled to leave their countries of origin due to slow-onset natural disasters, the adverse effects of climate change, and environmental degradation.
- Institutional arrangements for loss and damage compensation (such as the Sharm el-Sheikh Implementation Plan, agreed upon at the



Twenty-seventh Conference of the Parties to the United Nations Framework Convention on Climate Change COP27) aim to manage the impact of climate change on the most vulnerable households and address the losses and damage incurred as a result of climate change and subsequent mobility and immobility.

- Protection of migrant communities and promotion of the fulfillment of human rights during transit and at the new destination: As rural-to-urban migration compounds with international migration to urban centers, the expansion of safe housing and access to public assistance for recently arrived migrant communities are critical. Evidence suggests that non-citizens and children of non-citizens are more likely to be exposed to high levels of food insecurity and require specific attention. Additionally, policies need to consider the mental health impacts of environmental hazards and mobility, including prevailing gender dynamics.
- Forward-looking policy responses acknowledge that human mobility is likely to increase due to environmental change and associated food and water crises. Preparing future migrants and communities can reduce vulnerabilities, increase positive outcomes for origin and destination communities, and ensure the fulfillment of human rights. States must guarantee due process during the procedure leading to the recognition of migratory status and safeguard non-refoulement while the status is determined.

4.9. Social justice

The impacts of climate change are often disproportionately felt by marginalized and low-income communities, exacerbating existing social inequalities. These groups may have limited resources to adapt to extreme weather events and recover from their effects. Ensuring equitable access to resources and support is vital to address social justice issues related to climate change (IPCC, 2022).

Climate change impacts on social justice

Risks and impacts arising from climate change are already leading to a series of human rights violations and situations of injustice from generational (intra and inter) and international perspectives. Disadvantaged and vulnerable groups are hit the hardest by climate change due to their limited means to cope and adapt (cf. United Nations Development Programme, 2022). These groups include children and young people, the elderly, indigenous peoples and local communities (IPLCs),



refugees and those displaced by natural disasters, economically disadvantaged people, and women and girls.

Children and young people are particularly vulnerable to the impacts of climate change. They face heightened risks due to their dependency on adults for protection and resources. Climate change can affect their health, education, and overall development, leading to long-term consequences for their well-being and future opportunities.

Women are recognized to be more severely affected by climate change because they often have limited access to natural resources such as land. This limited access restricts their ability to secure tenure of natural resources, which is crucial for their livelihoods and resilience against climate impacts. Additionally, women often have less ability to access remedies and resources that could help them adapt to changing climatic conditions. According to data by the United Nations Development Programme (2022), there were 118 women aged 25 to 34 living in extreme poverty for every 100 men in 2021; by 2030, this number is expected to increase to 121 women living in extreme poverty for every 100 men. This disparity is further aggravated by the pressure and impact of the triple planetary crisis, which includes climate change, pollution, and nature loss.

The elderly are more susceptible to the adverse effects of climate change due to their physical frailty and often limited mobility. Extreme weather events, such as heatwaves, can pose significant health risks to older individuals, exacerbating existing health conditions and increasing mortality rates.

Indigenous peoples and local communities (IPLCs) often rely heavily on natural resources for their livelihoods and cultural practices. Climate change can disrupt these resources, leading to loss of traditional knowledge, food insecurity, and displacement. Additionally, IPLCs frequently face challenges in having their rights respected and protected, making them more vulnerable to environmental changes.

Economically disadvantaged individuals and communities have fewer resources to adapt to and recover from climate impacts. They may live in areas more prone to environmental hazards, such as floodplains or coastal regions, and lack the financial means to relocate or rebuild after disasters. This economic disparity increases their exposure to climate risks and limits their ability to respond effectively.

Climate change is a significant driver of displacement, forcing millions of people to leave their homes due to extreme weather events, sea-level rise, and other environmental changes. Refugees and displaced persons often face severe challenges in accessing basic services, legal protection, and support, exacerbating their vulnerability.

Overall, disadvantaged and vulnerable groups are hit the hardest by climate change, having less means to cope and adapt to climate change



induced impact such as food insecurity, loss of livelihoods or conflict over access to natural resources. Developing and least developed countries appear to be most affected by climate change, despite contributing the least to its causes.

Social justice policy responses

Policy responses to address the impacts of climate change on social justice aim to promote equitable treatment, protect vulnerable groups, and ensure that environmental benefits and burdens are distributed fairly. The United Nations Development Programme (2022) outlines a set of key social policy responses:

- Legal empowerment approaches focus on enabling people to understand, use, and shape the law to realize their rights, resolve disputes, achieve redress for rights violations, and advance broader changes to laws and governance systems. This approach is particularly important for marginalized and disadvantaged groups, as well as those whose human rights are more severely impacted by climate change, such as women, IPLCs, children and youth, and persons with disabilities. Legal empowerment can help these groups participate in local, national, and global climate and environmental events and negotiations, as well as in policy and decision-making processes.
- Promoting public participation and access to information on environmental matters is fundamental for sustainable development and environmental justice. Ensuring that all segments of society have the opportunity to participate in relevant processes and access information can influence environmental laws and policies. This approach helps to create a bottom-up movement that, when coupled with top-down structural and institutional changes, can effect meaningful change.
- Strong national human rights systems are crucial in order to respect, protect, and fulfil human rights obligations. Independent oversight bodies such as National Human Rights Institutions (NHRIs) play a crucial role in monitoring and supporting rights-based responses to environmental and climate change issues. These institutions can advise the state and other stakeholders on human rights-based approaches to climate action, support communities in decision-making, assist victims in seeking justice and redress, provide education on the human rights impacts of climate change, and engage businesses on their roles and responsibilities.



- Creating coordination mechanisms between relevant sectors and line ministries is important to ensure environmental justice. Connections should be established not only between justice and human rights institutions but also with ministries responsible for agriculture, forestry, environment, water and natural resources, fisheries and marine resources, energy, and health. Strengthening coordination mechanisms across these sectors can help address environmental and climate change challenges more effectively.
- Ensuring gender equality and equal treatment for all individuals, enshrined in law, is essential to guarantee equal access to rights and services related to the environment and natural resources. Special attention should be given to vulnerable and disadvantaged groups, including women, IPLCs, and those displaced by environmental disasters. Legal provisions should guarantee respect and protection of tenure rights of land and natural resources to all legitimate tenure rights holders, leading to more sustainable natural resource management.

4.10. Tourism

Tourism is highly sensitive to climate change, with extreme weather events affecting destinations, infrastructure, and visitor experiences. Coastal areas, ski resorts, and natural attractions are particularly vulnerable (cf. IPCC, 2022). Sustainable tourism practices and climate-resilient infrastructure are necessary to protect the industry and maintain its economic contributions.

Climate change impacts on tourism

The socioeconomic impacts of climate change on tourism are multifaceted and vary across different regions and types of tourism activities. They include changes in tourist numbers and spending, shifts in geographical distribution of tourists, and varying levels of vulnerability across different regions and types of tourism activities (cf. Steiger et al., 2024). These impacts are influenced by socio-political factors, economic conditions, and the effectiveness of adaptation measures. One significant impact is the vulnerability of destinations to climate change, which is influenced by the past evolution of destinations, evolution of tourism policy, occurrence of extreme meteorological events, dependence on tourism activity, and the characteristics of the tourism offering.

Economic impacts from increasing temperatures vary across European regions. Whereas negative net effects on annual overnight stays are expected for southern countries such as Cyprus or Spain, positive net



effects have, for example, been estimated for Norway (Amelung and Moreno, 2012) or Sweden (Jacob et al., 2018).

Deteriorating snow conditions might change the geographical distribution of winter tourists. Despite predominately negative expected impacts on winter tourism, studies for Croatia and Romania also show some potential for increasing tourist numbers due to improving conditions for non-snow activities (Steiger et al., 2024). High returns on investment could be reaped from investing in climate change adaptation measures; Cupac et al. (2020), for example, find that an investment of one euro could lead to a benefit of 14.15 euros for tourism in Bosnia-Herzegovina.

Tourism policy responses

Responses to the impact of climate in tourism policy vary across different levels and regions. On the European level, the European Union's approach to sustainable tourism is outlined through frameworks like the Transition Pathway for Tourism (European Commission, 2022), the European Charter for Sustainable Tourism (CEST) and EU Sustainable Tourism Action Plans. Climate change adaptation and mitigation are included as one of the ten points of action toward sustainable and responsible tourism.

On the national level, there is a broad range of ways in which climate change is addressed across Europe. Climate action in national tourism strategies include demands directed at governments to invest in sustainable mobility, such as improving train connections, increases in the shares of public transport used by tourists, the use of renewable energies for local public transport at tourist destinations, and climate-neutral ski areas (cf. Steiger et al., 2024).

4.11. Transport

Extreme weather events can disrupt transportation networks, causing delays and damage to infrastructure often leading to high socioeconomic costs (cf. Hänsel et al., 2023). Floods, storms, and heatwaves can affect roads, railways, airports, and ports. Investing in resilient transport infrastructure and adaptive planning is essential to ensure reliable and safe transportation systems.



Climate change impacts on transport

The socioeconomic impacts of climate change on transport are significant and multifaceted. Extreme weather events, such as river flooding, flash floods, low flow situations, storms, storm surges, heat waves, fires, thawing permafrost, rising sea levels, and landslides, lead to damages of transport infrastructures and limit the availability of transport services. These disruptions and restrictions are generally connected with high socioeconomic costs because society and the economy greatly depend on a well-functioning and developed transport infrastructure. The resulting disruptions can affect one mode of transport and have short-term as well as long-term impacts on other modes of transport due to modal shifts. This inter-modal perspective is crucial to understand the full extent of the socioeconomic impacts, as traffic disruptions due to extreme weather events and climate change affecting one mode of transport also influence other modes, thereby affecting overall mobility and the transportation of goods (cf. Hänsel et al., 2022).

Transport policy responses

Transport policies in response to climate change focus on both mitigation and adaptation strategies. The European Environment Agency (EEA) has addressed the adaptation of transport to climate change in Europe, highlighting challenges and options across transport modes and stakeholders (European Environment Agency, 2014). The United Nations Economic Commission for Europe (UNECE) has been promoting the adaptation of inland transport to climate change (United Nations Economic Commission for Europe, 2020). The UNECE Group of Experts on Climate Change Impacts and Adaptation for Transport Networks and Nodes was specifically tasked to develop models for evaluating climate change impacts, including changes in extreme events under different climate change Representative Concentration Pathways (RCPs) scenarios. Recommendations focus on raising awareness, building capacity, and integrating knowledge from countries and the scientific community on climate change impact assessment and adaptation for inland transport.

4.12. Water management

Climate change impacts water resources through altered precipitation patterns, increased evaporation rates, and more frequent droughts and floods (UNESCO World Water Assessment Programme, 2020). Effective water management is crucial to ensure water availability for agriculture,



industry, and domestic use. Strategies such as improved water storage, conservation practices, and efficient distribution systems are necessary to address these challenges.

Climate change impacts on water management

Climate change poses significant water-related risks and impacts that affect various aspects of human life, ecosystems, and economic activities (UNESCO World Water Assessment Programme, 2020). Climate change affects the terrestrial water cycle through various processes, which makes quantification and prediction of consequences difficult. Changes in precipitation and temperature directly affect the terrestrial water budget, leading to decreasing streamflow volumes and water availability in different seasons, affecting water availability for agriculture, industry, domestic supplies, and in-stream uses such as power generation, navigation, fisheries, recreation, and the environment.

One of the primary risks connected to climate change is water scarcity, which can halt manufacturing or energy generation due to a lack of water. This scarcity impacts operational aspects, such as the supply of raw materials, disrupting supply chains, and causing damage to facilities and infrastructure. Additionally, water stress can lead to unsafe working conditions, health effects, and lower productivity. Major climate change may also produce fast changes in consumer demand, such as for energy, which usually requires water for generation.

Extreme weather events render societies increasingly vulnerable to water-related disasters. Between 2001 and 2018, around 74% of all natural disasters were water-related, causing over 166,000 deaths and affecting over three billion people, with total economic damage of almost US\$700 billion (ibid.). The impacts of these extreme events demand sustainable solutions for climate change adaptation and disaster risk reduction.

Climate change exacerbates the situation in water-stressed regions and generates water stress in regions where water resources are still abundant today. Physical water scarcity is often seasonal, and climate change is likely to cause shifts in seasonal water availability throughout the year in several places. Water quality will be adversely affected by higher water temperatures, reduced dissolved oxygen, and increased risks of water pollution and pathogenic contamination caused by flooding or higher pollutant concentrations during droughts.

Climate change elevates risks to water infrastructure, with more intense and frequent floods increasing the risks of damage to water treatment and



supply infrastructure, leading to service disruptions. Wastewater treatment plants face increasing incidents of pollution surges caused by floods. Increased variability in rainfall intensity and patterns significantly impacts the performance of urban drainage systems, causing combined wastewater and stormwater overflows during heavy precipitation and flooding. Ageing water infrastructure also poses challenges, with increased operation and maintenance costs, structural changes, and risks of breakage influenced by changing river inflow variability associated with climate change.

Urban settlements are particularly vulnerable to the impacts of climate change on water systems, including extremes in climate change from higher temperatures, reduced precipitation, and drought, as well as increasing heavy precipitation and flooding events. Reduced water availability will mean that by 2050, 3.9 billion people are projected to live under severe water stress (ibid.). The physical impact of flooding and resulting landslides will significantly affect urban settings, causing damage to infrastructure, loss of life, and irreversible land destruction. Access to safe water is affected, leading to contaminated water supplies and discharge of untreated wastewater and stormwater into living environments, exacerbating health risks.

The health risks associated with climate change include physiological effects from exposure to higher temperatures, increasing incidences of respiratory and cardiovascular diseases, injuries, and death due to extreme weather events such as droughts, floods, heatwaves, storms, and wildfires. Indirect effects on health arise from ecological changes, such as food and water insecurity and the spread of climate-sensitive infectious diseases, as well as societal responses to climate change, such as population displacement and reduced access to health services. Mental health impacts after extreme weather events, climate-related displacement, immigration, and loss of culture can be lifelong.

Water management policy responses

Policy responses to impact on water management encompass a combination of natural, engineered, technological, social, and institutional measures aimed at moderating harm or exploiting beneficial opportunities from climate change:

- Adaptation measures include enhancing water efficiency and water-saving strategies, monitoring and data sharing on water quantity and quality, improving coherence of climate change adaptation and



water-related disaster risk reduction (DRR), and attracting funding from multiple sources.

- Mitigation measures include water management interventions such as wetland protection, conservation agriculture, and other nature-based solutions (NBS). These can help sequester carbon in biomass and soils, while improved wastewater treatment can reduce GHG emissions and produce biogas as a renewable energy source.

Climate-smart agriculture practices are recognized for their role in land and water management, soil conservation, and agronomic practices that sequester carbon and reduce GHG emissions. Climate-smart agriculture practices help retain soil structure, organic matter, and moisture under drier conditions and include agronomic techniques such as irrigation and drainage to adjust or extend cropping calendars to adapt to seasonal and interannual climate shifts.

Integrated water resources management (IWRM) practices are essential for addressing climate change impacts. IWRM involves stakeholders across society, the economy, and the environment, promoting public participation, building adaptive capacities, and prioritizing risk reduction for socially vulnerable groups. National policies and strategies informed by water, sanitation, and health vulnerability assessments ensure the sustainability of investments. Financial inclusion activities provide low-income households with credit and insurance to recover from climate events more easily.

In the business sector, water stewardship efforts go beyond conventional corporate social responsibility, addressing water withdrawal and allocation as more important issues than simple replenishment. This requires compromises, trade-offs, or water use reductions in water-stressed areas. Water stewardship is tied to IWRM, which is often led by governments, fostering dialogue with the private sector and integrating human rights into water management practices.



5. Good practice examples from across Europe

The databank of cases provided by the Climate-ADAPT platform⁵ has been systematically searched for good practice examples of adaptation measures addressing climate change and its associated socioeconomic impacts. The selection process focused on identifying relevant cases aligned with the four climate-related hazards and twelve key sectors prioritized within the CROSSEU project.

Each case has been assessed for its relevance, scalability, and potential for transferability to other regional contexts, particularly within the European Union. Emphasis was placed on measures that demonstrate clear outcomes, innovative approaches, and strong stakeholder involvement. The findings from this review are summarized in Table 3.

⁵ The European Climate Adaptation Platform (Climate-ADAPT) is a partnership between the European Commission and the European Environment Agency (EEA). Climate-ADAPT is maintained by the EEA. Website: <https://climate-adapt.eea.europa.eu/en>; last accessed April 16, 2025





Table 3 Adaptation responses to CROSSEU focus hazards across CROSSEU focus sectors

| Sector/Hazard | Heat | Drought | Storm | Snow |
|------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|
| Agriculture / biodiversity / water management | Holistic approach combining removal action and promotion of business opportunities from processing invasive species (lionfish) ⁶ | Enhancement of water availability from large and small reservoirs, micro and drip irrigation, heat-resistant plants, greenhouses, and agrometeorological variable monitoring ⁷ | Storm surge barriers ⁹ Natural Water Retention Measures (NWRMs) to increase the resilience of the territory to flooding ¹⁰ | Creation of man-made snowdrifts to improve the Saimaa seal's breeding habitat in poor snow conditions ¹² |
| | | Agroforestry scheme: cultivation of a mixture of crops and species, especially a mixture of trees and crops ⁸ Multinational agreement to protect and restore wetlands along the river and reconnect it to its natural flooding areas ⁷ | Multinational agreement to protect and restore wetlands along the river and reconnect it to its natural flooding areas ¹¹ | |
| | | Nature-based solutions as re-meandering, creating flood storage areas, buffer strips and wetlands, "Multi-functional water reserves" to store water when it is in excess and recirculate | | |

⁶ <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/preventing-lionfish-invasion-in-cyprus-through-early-response-and-targeted-removal>

⁷ <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/adapting-to-climate-change-by-improving-irrigation-practice-in-vipava-valley-slovenia>

⁸ <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/agroforestry-agriculture-of-the-future-the-case-of-montpellier>

⁹ <https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/storm-surge-gates-flood-barriers>

¹⁰ <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/natural-water-retention-measures-in-the-altovicentino-area-italy>

¹¹ <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/lower-danube-green-corridor-floodplain-restoration-for-flood-protection>

¹² <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/creation-of-man-made-snowdrifts-for-improving-the-breeding-success-of-the-saimaa-ringed-seal>



| | | | |
|-----------------|---------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | | stored water in irrigation systems during periods of water scarcity ¹³ | |
| Energy | / | Novel screw pumps at locks also work as electricity generators ¹⁴ | Replacing overhead lines with underground cabling ¹⁵ |
| Finance | Issuing of climate bonds targeting institutional investors ¹⁶ | / | / |
| Forestry | Green firebreaks (i.e. low flammability strips of vegetation) ¹⁷ | / | / |
| | Forest diversification and ecosystem restoration ¹⁸ | | |
| Health | Mandatory installation of green roofs for new or renovated buildings with a suitable roof ¹⁹ | / | Installation of an online bacterial enzyme monitoring system to monitor the water quality in public, surface waters and diminish the risk for disease outbreaks and |

¹³ <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/adapting-agriculture-to-wetter-and-drier-climates-the-tullstorp-stream-project-sweden>
¹⁴ https://climate-adapt.eea.europa.eu/en/metadata/case-studies/new-locks-in-albertkanaal-in-flanders-belgium/#solutions_anchor
¹⁵ <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/replacing-overhead-lines-with-underground-cables-in-finland>
¹⁶ <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/climate-bond-financing-adaptation-actions-in-paris>
¹⁷ <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/building-fire-resilience-using-recycled-water-in-riba-roja-de-turia-spain>
¹⁸ <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/large-scale-forest-restoration-solutions-for-resilience-to-multiple-climate-stressors-n-north-rhine-westphalia-germany-2>
¹⁹ <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/adapting-to-heat-stress-in-antwerp-belgium-based-on-detailed-thermal-mapping>





| | | | | |
|-----------------------|----------------------------------------------------------------------------------------------------------------------------|---|--------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| | | | adverse health effects among recreants ²⁰ | |
| Insurance | / | / | / | / |
| Migration | / | / | / | / |
| Social justice | Building and restoration of water elements (blue infrastructure) and fountains in most vulnerable places ²¹ | / | / | / |
| Tourism | / | / | People-centred early warning system ²² | Shift to year-round tourism, developing new trails, removing ski lifts, emphasizing hiking, biking, wellness, and culture ²³ |
| | Conservation of historical ruin to make it durable in face of increasing precipitation and frost-thaw cycles ²⁴ | | | |
| Transport | / | / | Combination of structural protection measures and a railway-specific weather monitoring and early warning system ²⁵ | |

²⁰ <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/online-monitoring-and-early-warning-system-for-bacterial-contamination-in-public-surface-waters-in-breda-the-netherlands>

²¹ <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/social-vulnerability-to-heatwaves-2013-from-assessment-to-implementation-of-adaptation-measures-in-kosice-and-trnava-slovakia>

²² https://climate-adapt.eea.europa.eu/en/metadata/case-studies/multi-hazard-approach-to-early-warning-system-in-sogn-og-fjordane-norway/#challenges_anchor

²³ <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/adaptation-in-winter-tourism-in-spessart-germany>

²⁴ <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/restoration-and-climate-adaptation-of-church-ruins-holla-norway>

²⁵ <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/building-railway-transport-resilience-to-alpine-hazards-in-austria>





Learnings from good practice examples across Europe

Good practice cases across Europe demonstrate a broad range of policy responses to extreme weather events, spanning from multinational, national, and regional strategies and agreements to specific projects—such as infrastructure development or research initiatives—and targeted interventions, including the implementation of particular measures. These policy responses are often versatile, addressing multiple types of hazards simultaneously and combining different approaches, such as integrating structural protection measures with early warning systems. Additionally, successful responses tend to be cross-sectoral, involving diverse areas like agriculture, biodiversity, and water management. The strength of connections between individual hazards and the twelve relevant sectors can vary, with strong linkages often observed between specific hazards and sectors—for example, droughts and floods with agriculture or snow-related events with tourism.

Table 4 Two examples for structural measures to flood risk management

Example A for a structural measure: Planned relocation as flood risk management in Bavaria, Germany

Mayr et al. (2020) analyze the small-scale relocation of households following an extreme flood event in Simbach, Germany, on June 1, 2016. Continuous heavy rainfall and the failure of structural measures led to severe flooding, resulting in five fatalities and the evacuation of thousands of people. Some residents were relocated due to the need for an adapted structural alleviation scheme. The relocation process involved early dialogue with affected homeowners, financial compensation based on independent appraisals, and voluntary relocation by law.

The paper discusses the increasing importance of planned relocation as a policy response to the socioeconomic impacts of extreme weather events, particularly in the context of flood and coastal risk management. It highlights that more than 140 million people may need to relocate by 2050 due to flooding, food or water shortages, and economic reasons. Successful implementation of planned relocation requires extensive engagement with citizens; an aspect that is also emphasized by European directives such as the European Floods Directive (EU FD) and the Water Framework Directive (WFD).

Mayr et al. (2020) argue that “collaborative governance” (p.2) was important for the success and acceptance of the relocation decision. This involved the engagement of public agencies and non-state stakeholders in a collective decision-making process, which enhanced the acceptance of top-down decisions and their outcomes among the affected community. The involvement of various stakeholders, including local administrative and governmental actors, planners, and experts, was





crucial for the success of the flood risk mitigation strategy and relocation process.

Mayr et al. (2020) also addresses the challenges and benefits of relocation. While relocation can have significant social and economic impacts on individual well-being and socioeconomic performance, it is often seen as an alternative to expensive structural measures, especially when the renovation of damaged properties is not feasible. Long-term benefits of relocation include reduced risk of loss and cost savings, but challenges such as financial issues, project management, communication, and keeping relocated areas free from development must be addressed. It is emphasized that early involvement of residents and transparent communication are essential for the acceptance and success of relocation processes. Personal communication, trust in local actors, and financial compensation contribute to a positive outcome.

The case study of Simbach highlights the significance of preliminary planning activities and precautionary measures, such as natural hazard insurance, for effective integrated flood risk management (IFRM). It illustrates that planned relocation, when implemented with collaborative governance and early community involvement, can be an effective policy response to the socioeconomic impacts of extreme weather events.

Example B for a structural measure: The Santa Giustina Dam on the Noce River in the Autonomous Province of Trento (Northern Italy)

The Santa Giustina Dam creates the largest artificial lake in the Trentino-Alto Adige region, with a storage capacity of 172 million cubic meters (Terzi et al., 2021). The dam was built in the 1940s and 1950s primarily for hydropower purposes. Its functions include producing a large amount of energy, regulating water flow for downstream users and providing water for irrigation. Several positive and negative effects of the dam on local landscape, socioeconomic activity and the environment have been noted (Maran et al., 2023; Terzi et al., 2021): The dam regulates the water flow of the Noce River, affecting downstream water availability. Because of the dam affecting the river's ecology, a minimum ecological flow threshold was established in 2009, to maintain river ecosystem health. The dam has created Lake Santa Giustina, transforming the local landscape and submerging approximately 406 hectares of land, including houses, roads and bridges (Maran et al., 2023). Other environmental concerns include altered unfavourable impacts on fish behavior and mortality as well as on the river's ability to absorb pollutants from anthropogenic pressures, such as agriculture (ibid.). Such concerns highlight the complex interplay between hydropower production, water resource management, and ecosystem preservation in the Santa Giustina Dam area.



6. Evidence from CROSSEU case study areas (CSAs)

Storms, flooding, and avalanche events represent some of the most disruptive natural hazards in Europe, with wide-ranging socioeconomic consequences. Beyond immediate threats to human life, such events frequently result in extensive damage to homes, transportation networks, and public infrastructure, while also disrupting local economies and public services. The financial burden of recovery, coupled with longer-term social impacts such as displacement, loss of livelihoods, and heightened vulnerability among at-risk groups, underscores the urgency of effective policy responses. As climate change increases both the frequency and intensity of extreme weather events, proactive and adaptive strategies are becoming essential for reducing risk and enhancing resilience.

This section analyzes policy responses to storms and flooding in Southern Denmark (CROSSEU CSA3) and Northern Italy (CROSSEU CSA4), as well as to snow and avalanche hazards in the Central Alps (CROSSEU CSA5). Each of these regions faces distinct challenges shaped by their geographic, climatic, and socioeconomic contexts. The review focuses on a range of policy responses implemented in the aftermath of major events, as well as those designed as part of longer-term adaptation strategies. These responses are grouped into key categories: structural measures such as flood defenses and avalanche barriers; institutional and regulatory tools including land-use planning, hazard zoning, and early warning systems; and social measures aimed at public awareness, capacity-building, and community-based preparedness. By examining these case studies, the analysis seeks to highlight both successful practices and persistent gaps, offering insights into how different regional approaches contribute to broader climate resilience goals.

More details on the economic and financial policy instruments in the case study areas are provided in CROSSEU deliverable D4.7.

6.1. Storms and floods in Southern Denmark (CSA3)

Denmark faces increasing risks from storms and flooding due to climate change, with projections of rising sea levels and more intense rainfall events. The socioeconomic impacts are substantial, with potential flood damages estimated at DKK 406 billion over the next 100 years if no



adaptation measures are taken²⁶. The Danish government and municipalities are actively implementing climate adaptation plans, including risk management and urban resilience projects²⁷, to reduce these impacts.

The municipalities of Åbenrå and Sønderborg in the region Syddanmark (Southern Denmark) were identified as Climate Change Hotspot in case study area 3 (CSA3) of the CROSSEU project. The region of Southern Denmark is one of Denmark's administrative regions, covering an area of 12,191 km². It is bordered by the North Sea to the west, the Baltic Sea to the east, and the German border to the south. The region has a temperate maritime climate, with mild summers averaging 20–25°C and winters around 0–5°C. It is characterized by relatively stable precipitation throughout the year. Its natural features include the Wadden Sea, a UNESCO World Heritage Site known for its unique tidal ecosystem, and rolling landscapes with fertile farmland.

The region is highly exposed and vulnerable towards the occurrences and impacts of storm surge from the Baltic Sea (see CROSSEU project deliverable D2.1). It has low-lying coastlines, and cities in this region are



Figure 5 Landscape Aabenraa, Credits: Aabenraa Kommune

often positioned at the bottom of fjords, next to the sea (see Figure 5²⁸). The combination of a low-lying coastline with a high degree of human and economic activities next to the sea makes this region particularly exposed and vulnerable to the occurrences and consequences of flooding during storm surges. The region has experienced serious flooding events in the last decades.

On October 20th and 21st, 2023, the region was severely affected by a major storm surge. The event was part of Storm Babet, an intense extratropical cyclone that impacted large parts of northern and western Europe. It was one of the worst floods for the Baltic Sea coast in 150 years, with water levels over

²⁶ <https://www.dtu.dk/english/newsarchive/2024/11/the-cost-of-flooding-from-torrential-rain-and-storm-surges-could-reach-dkk-406-billion>; last accessed May 2nd, 2025

²⁷ E.g. in Copenhagen: <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/the-economics-of-managing-heavy-rains-and-stormwater-in-copenhagen-2013-the-cloudburst-management-plan>; last accessed May 2nd, 2025

²⁸ <http://www.bsr-secure.eu/wp-content/uploads/2019/12/Coping-with-increased-flooding-in-Aabenraa.pdf>; last accessed April 16, 2025



two meters higher than usual in some areas: In Aabenraa water levels rose to 2.16 meters above normal; in Sønderborg to 2.10 meters above normal, which amounted to the highest level since the year 1904.

Relevant policies for storm and flood mitigation and adaptation in Southern Denmark

National level²⁹

In Denmark, climate adaptation efforts are closely tied to water management, as municipal responsibilities for adaptation planning and implementation are largely governed by water-related regulations. However, flood management remains regulated by a fragmented set of rules rather than a unified legal framework. This regulatory landscape is highly intricate, as water-related climate adaptation spans multiple legal domains—including the EU Water Framework Directive, the EU Habitats Directive, Danish construction laws, and the Danish Water Sector Reform Act. Despite the significance of water in climate resilience, current legislation lacks a coordinated and comprehensive strategy (Lind and Hansen, 2024).

The updated “Danish Planning Act” of 2018 (Ministry of the Interior and Health of Denmark, 2020) is a crucial document for adaptation efforts in Denmark³⁰. Municipalities must consider climate adaptation action in spatial planning of new and existing land areas and are legally required to address flooding and coastal erosion in their physical planning processes. Previously, coastal erosion had not been included in municipal adaptation plans. According to the “Danish Planning Act” of 2018, it is now mandatory to implement mitigation or remedial measures if planned areas are identified as being at risk of flooding or erosion (Lind and Hansen, 2024). Over the next three years, the Danish Housing and Planning Authority introduced and periodically updated official guidelines to ensure compliance with these changes. These guidelines provide instructions on planning and adapting to flood and erosion risks in line with the Planning Act, incorporating improved data, with the latest version released in 2022 (Danish Housing and Planning Authority, 2022).

Denmark has implemented the EU Floods Directive³¹ through the “Danish Flood Risk Act”³², which features a flood risk assessment and “includes

²⁹ Relevant policies were identified by CROSSEU partner Technical University of Denmark (DTU), local partner and case study area lead in the region of Southern Denmark.

³⁰ <https://pub.norden.org/temanord2023-525/2-denmark.html>; last accessed December 12, 2024

³¹ <https://eur-lex.europa.eu/eli/dir/2007/60/oj/eng>; last accessed May 13th, 2025

³² <https://pub.norden.org/temanord2023-525/2-denmark.html>; last accessed May 13th, 2025



requirements for evaluation and management of risks of flooding from the sea, inlets, lakes and watercourses” (Lind and Hansen, 2024, p 16). Based on flood risk areas identified, and flood hazard maps developed, by central government, the relevant municipalities prepare risk management plans for the identified risk areas (Danish Coastal Authority, 2023). By 2024, a total of 14 high risk areas covering 27 municipalities had been identified (Lind and Hansen, 2024). These municipalities are now required to prepare flood risk management plans to reduce flood risk through mitigation and adaptation measures, considering flood-related climate impacts.³³

The “Danish Strategy for Adaptation to a Changing Climate” (The Danish Government, 2008) describes several policies and strategies to mitigate and adapt to storms and flooding. This includes municipal rescue preparedness based on local risk evaluations as well as adaptation of municipal planning to expected climate changes. National planning legislation aims to limit building and construction in high-risk areas, to avoid significant extra expenses for remedies like coastal protection and dike construction. As required by the EU Directive on the Assessment and Management of Flood Risks, the strategy sets out to identify areas at risk of flooding and create maps and risk management plans. Insurance companies are to potentially increase premiums and develop new financial instruments for risk transfer, to ensure that insurance policies reflect the increased risks due to climate change. Coastal management adaptation measures include reinforcing dikes, dunes, and adapting harbor installations, with a focus on beach nourishment and channel dredging to counter coastal erosion.

The “Action Plan for a Climate-Proof Denmark” (Danish Nature Agency, 2012) highlights the significant socioeconomic impact of extreme weather events in Denmark, particularly focusing on the heavy cloudburst that struck Copenhagen in the summer of 2011. This event had severe consequences for infrastructure and homes, leading to total insurance payments amounting to DKK 6 billion for cloudbursts across Denmark in 2011. The plan also mentioned that climate change was expected to bring increased precipitation, more frequent and intense extreme weather events, and changes in precipitation patterns, which would likely result in more frequent and longer-lasting warm spells, heatwaves, and heavier cloudbursts.

The Climate Act of 2019 is Denmark's first comprehensive and legally binding document addressing climate change. It sets a legally binding goal for the country to reduce its greenhouse gas emissions by 70% by 2030 compared to 1990 levels and to achieve net-zero emissions by 2050 (Danish

³³ https://climate.ec.europa.eu/document/download/b93c433f-e2cb-4fee-a822-9a00ffd7395c_en?filename=countr_y_fiche_dk_en.pdf; last accessed December 10, 2024



Government, 2019). The Climate Act further establishes an independent Climate Council to provide expert advice and monitor progress towards these targets, and it requires the Danish government to develop regular climate action plans. Neither the Climate Act nor the Climate Council deal with adaptation.

The Service Level Act of 2020, which came into effect in 2021, mandates that wastewater utilities are responsible for implementing necessary adaptation measures to mitigate flood risks from heavy rains, such as roof and surface water runoff (Serviceniveaubekendtgørelsen, 2020). It further introduces measures to ensure that public and private utility companies only finance economically viable adaptation measures to prevent "overinvestment." (Ministry of the Environment Denmark, 2022).

In October 2023, launched the country's "Climate Adaptation Action Plan 1"³⁴ marking a renewed national effort to address climate risks, particularly those related to water management, nature, and infrastructure resilience. The plan includes several national initiatives concerning the management of groundwater levels, coastal protection and guidance for municipalities regarding the integration of nature and environmental considerations into local adaptation strategies. Responsibilities for climate adaptation are split across several Danish ministries, which means that different ministries are responsible for, for example, watercourse legislation, urban planning, emergency preparedness, and storm surge protection. A revised "Climate Adaptation Action Plan 2" is in the making, but has not been released at the time this report is being developed.

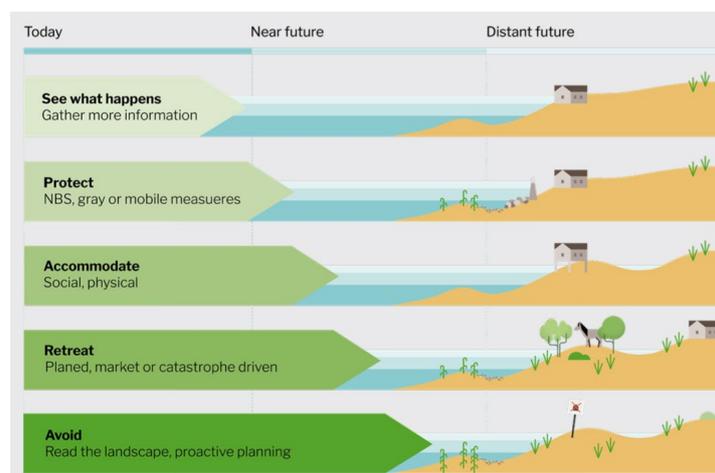


Figure 6 Different approaches to flood risk management (Source: Lind and Hansen, 2024, p. 31)

³⁴ <https://eng.klimatilpasning.dk/national-adaptation/climate-adaptation-in-denmark>; last accessed May 13, 2025



Local level

Both Åbenrå and Sønderborg municipalities in Southern Denmark have emergency plans to address storm surges and flooding, reflecting their proactive approach to climate-related risks:

- Åbenrå has a well-defined emergency management system for storm surges and flooding. The municipality convenes crisis management teams when serious flooding is forecasted, as seen during the October 2023 storm surge³⁵. Measures include distributing sandbags, advising residents on protecting their properties, and coordinating evacuation efforts when necessary. Additionally, municipal planners use web-based platforms to identify vulnerable areas and implement protective measures, integrating surface water management into urban planning to mitigate future risks³⁶. The municipality of Åbenrå follows a climate adaptation approach that includes risk reduction and risk management measures (Åbenrå Kommune, n.d.). Risk reduction includes infrastructure projects, permanent solutions and urban development; while risk management includes mobile solutions and warning systems.
- Sønderborg faces increasing flood risks due to its low-lying coastal areas and rising sea levels. The municipality actively engages in adaptive strategies to enhance infrastructure resilience against storm surges and climate change impacts. Research highlights the vulnerability of Sønderborg's coastal areas, with up to 42.65% of the municipality potentially inundated under extreme scenarios (Jordan, 2024). Local government efforts focus on disaster response planning and infrastructure adaptation, ensuring preparedness for future events.

Both municipalities benefit from Denmark's national storm surge warning system managed by the Danish Coastal Authority³⁷. This system monitors weather forecasts, assesses risks, and coordinates evacuation efforts when necessary.

³⁵ <https://aabenraa.dk/om-kommunen/english/information-about-the-flooding-in-aabenraa/information-about-the-flooding-in-aabenraa/expect-serious-flooding-in-aabenraa-loddenhoej-and-skarrev>; last accessed April 4, 2025

³⁶ <https://aabenraa.dk/om-kommunen/english/information-about-the-flooding-in-aabenraa/information-about-the-flooding-in-aabenraa/update-after-the-storm-surge-in-aabenraa-kommune>; last accessed April 4, 2025

³⁷ <https://kyst.dk/english/storm-surge-warning-management>; last accessed April 9th, 2025



Responses in (cross-)sectoral strategies

Southern Denmark faces growing climate-related challenges, particularly from increased precipitation, sea level rise, and extreme weather events. Sector-specific adaptation strategies have emerged as essential components of regional climate resilience. In wake of the extreme event in October 2023, the Danish government invested EUR 20 million in coastal protection projects³⁸. In addition, a set of key (cross-)sectoral policy responses to increasing impact from storms and flooding can be identified as follows:

- **Agriculture/land use planning:** The agricultural sector is a dominant player in environmental protection in Denmark, projected to contribute significantly to Southern Denmark's GHG emissions towards 2030.
 - Increased precipitation and higher sea levels will affect drainage in low-lying areas, necessitating conscientious land use planning to exempt certain areas from residences and other installations (The Danish Government, 2008).
 - The Multifunctional Land Redistribution Fund helps convert farmland into natural sites to mitigate the downside effects of agriculture on the environment (OECD, 2020).
- **Tourism:** There is a focus on ensuring that buildings, especially in coastal areas, are adapted to withstand higher sea levels and more frequent storms. This includes potentially raising houses on columns in coastal areas (The Danish Government, 2008).
- **Transport and infrastructure:** Regulations and standards for roads and railways are being revised to account for expected climate changes, including higher groundwater levels and increased risk of landslides and erosion. There is an emphasis on ensuring that buildings meet safety requirements for extreme weather conditions, including stronger storms and increased snow loads (The Danish Government, 2008).
- **Water management:** Adaptation includes reorganizing water extraction to account for future groundwater resources and water flow/quality of watercourses and wetlands. In addition, public sewer systems are being adapted to handle more and heavier precipitation, with recommendations for sewer size to manage increased rainfall intensity. Finally, water extraction is moved to areas with more abundant water resources or less impact on watercourses and

³⁸ <https://www.waternewseurope.com/denmark-invests-in-coastal-protection-after-2023-floods/>; last accessed December 10, 2024



wetlands. This is part of a broader strategy to ensure sustainable water supply amidst changing precipitation patterns (The Danish Government, 2008).

In their DK2020 plans, all of Denmark’s municipalities have actions concerning rainfall and/or general water management (see Figure 7). While 76% of municipalities have action regarding risk management of sea level rise, the same is true for 97% of coastal municipalities (Lind and Hansen, 2024). Three-fourths of municipalities have actions concerning watercourses, and two-thirds regrading near-surface groundwater.

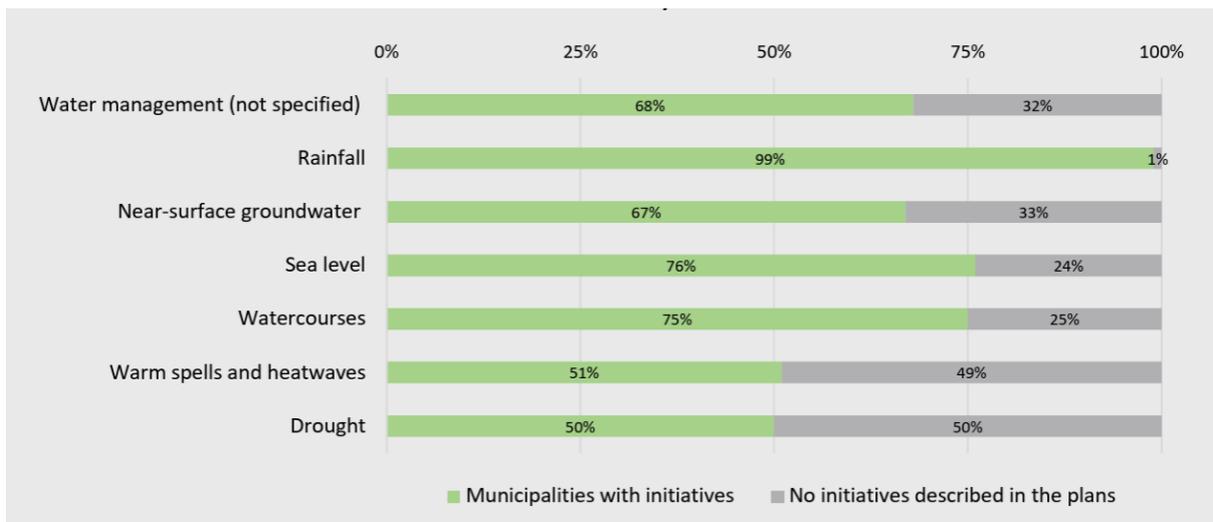


Figure 7 Actions taken by Denmark’s municipalities (Source: Lind and Hansen, 2024, p. 33)

Effectiveness of current policies and policy gaps

Local experts (see Annex IV) highlight several policies and measures as particularly effective in managing the socioeconomic impacts of storms and flooding. Among these are construction projects, such as the establishment of a pump sluice station in Åbenrå (Interview CSA3_1), the development of emergency plans (Interview CSA3_1), and the implementation of zoning policies (Interview CSA3_4).

The extreme weather event of October 2023 had significant repercussions, both in terms of public awareness and policy responses. One expert noted that the event created “a lot of awareness” (Interview CSA3_3, p.6). It also led municipalities to realize that their existing risk mapping did not adequately account for the scale of such events, exposing the limitations of their capacity to manage the impacts (Interview CSA3_4). According to the interviewed expert, this realization triggered a revision of climate adaptation plans to address damages beyond property losses, including impacts on cultural heritage, farmland, and tourist attractions (Interview CSA3_4).



According to one interviewed expert (Interview CSA3_5), the event also prompted the release of the Danish "Climate Adaptation Action Plan 1," which was published in October 2023. Furthermore, the event increased the willingness of Danish residents to co-finance climate adaptation measures (Interview CSA3_5). As another expert observed, "*it was probably one of those events that make people remember*" Interview (CSA3_5). These developments underscore the transformative impact of the October 2023 event on both public perception and policy-making in Denmark.

Despite the progress made, several policy gaps remain. According to the experts interviewed, one significant issue is the absence of a dedicated climate adaptation law. Instead, a multitude of laws address storms, flooding, and their impacts, creating challenges in establishing clear responsibilities for action and cost allocation (Interview CSA3_3). This fragmented legal framework is further complicated by the allocation of coastal protection budgets at the national level, where there is often a lack of awareness or understanding of the challenges faced at the local level, particularly in non-urban areas (Interview CSA3_3). Another concern is the potential for a divided society, where those with the financial means and political connections can secure protection, while others cannot (Interview CSA3_3). Additionally, exceptions to zoning rules, such as allowing people to live year-round in summer houses, exacerbate the challenges of effective land-use planning (Interview CSA3_4).

To address these gaps, experts have proposed several additional policies and governance measures. Broad, institutionalized citizen engagement in coastal adaptation plans is essential to prevent interference from single, influential actors (Interview CSA3_3). There is also a need to create awareness among policymakers and citizens about the collective responsibility for coastal protection (Interview CSA3_3). Zoning policies should be made adaptive to account for changes in what is considered a flood-prone area (Interview CSA3_5). A combination of nature-based solutions, such as those implemented along open coastlines, and hard protection measures in areas with a "zero tolerance policy," like Copenhagen, is recommended (Interview CSA3_4). Experts also suggest integrating zoning policies with investment policies to ensure a cohesive approach (Interview CSA3_4).

Finally, a reconsideration of the concept of utility is necessary. Policymakers must address questions such as: Who benefits from adaptation measures? Is it only landowners, or does the entire Danish population benefit? What role do insurance companies, which insure properties in flood-prone areas, play in this equation? (Interview CSA3_4). These considerations are critical for developing equitable and effective climate adaptation strategies.



6.2. Storms and floods in Northern Italy (CSA4)

The autonomous region Trentino-Alto Adige was identified as Climate Change Hotspot in case study area 4 (Interview CSA4). It is the northernmost political entity in Italy. It has an area of 13,607 km² and is bordered by Austria to the north-east and north respectively, by Switzerland to the north-west, and by the Italian regions of Lombardy to the west and Veneto to the south and southeast. The region is mountainous, covering a large part of the Dolomites and the southern Alps. The climate varies from alpine to continental and subcontinental. The area is characterised by subdaily precipitation extremes and flash floods.

Floods rank among the most severe natural hazards in Italy (Zabini et al., 2021), with future projections suggesting a general rise in flood risk throughout the country (Ojeda et al., 2022). Similar to the broader Mediterranean region, floods in Italy primarily occur as flash floods caused by intense and localized rainfall, posing substantial challenges for forecasting and risk management (Francipane et al., 2021). The growing frequency and intensity of extreme weather events, intensified by climate change, highlight the urgent need for effective policy measures to mitigate their socio-economic impacts and support affected communities.

According to data from a survey of 2,000 residents of North-Eastern Italy between January and March 2025 (see Annex II), about a third (31%) of residents have experienced a flood event, and about a third (38%) have received advance warning information before a flood event. Forms of damage from experiencing a flood event included psychological stress, damage to home/personal property, damage to agricultural or forestry property, interruption of professional activities, and health problems (see Figure 8). About 27% of respondents claimed that they had not suffered any damage.

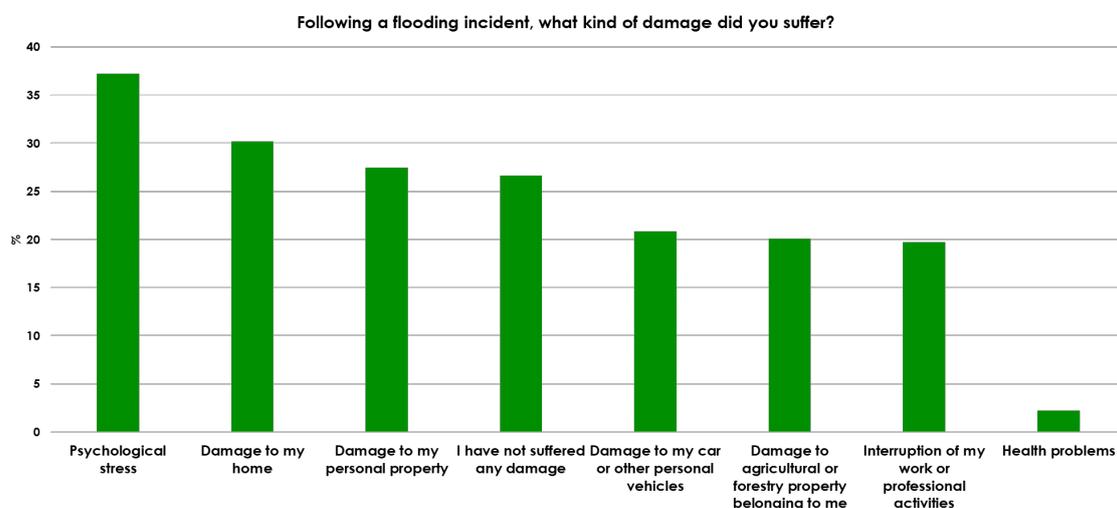


Figure 8 Damage from flood events (Illustration: UNIPD)



In October 2018, the region of Trentino-Alto Adige was impacted by the storm “Vaia”, which, after a climatic anomaly of a prolonged drought, dropped large precipitation amounts ranging from 200mm to 500mm over the mountains of the Eastern Italian Alps. In many places, the total accumulated precipitation was the highest ever recorded for a flood event lasting three days, with a rainstorm severity exceeding 300 years return time for the event cumulated precipitation. The event triggered debris flows and flash floods and led to eleven casualties (Halsnæs et al., 2024). *“The worst effects were caused by the wind, which reached extraordinary speeds: This windthrow, which is normally limited to individual slopes, has reached unprecedented dimensions. The entire timber industry was severely shaken, with repercussions for decades to come. The damages caused by this storm have exceeded the sum of € 100 million.”* (Pollinger et al., 2018, p.4; translated from German).

Actions taken in wake of the event

Immediate actions taken to address the event included prioritization of debris removal coordinated by the Civil Protection Department. Recovery efforts started with first responders directing activities to protect lives, public health, and safety; such as evacuations, sheltering, utility restoration and clearing roads of hazards. Further immediate action was taken in form of restoration of forestry development by forestry inspectorates, in order to make affected windthrow areas accessible and safely reachable in order to create the conditions for the processing of damaged timber (Autonome Provinz Bozen, 2020).

Short-term adaptation strategies included retrofitting of a number of debris flows and flood protection infrastructures. In terms of long-term adaptation strategy, a local forestry school started organizing free training days for windthrow processing in January 2019. In these courses, people with basic training learn to, on the one hand, recognize and correctly assess the sources of danger after a windthrow, and, on the other hand, the basic rules for safe working as well as suitable cutting techniques. By November 2020, a total of 34 damaged wood courses with 170 participants had been organized (Autonome Provinz Bozen, 2020).



Relevant policies for storm and flood mitigation and adaptation in the region³⁹

Trentino and Alto Adige (South Tyrol) are both autonomous provinces, which each hold a wide range of primary competences and have implemented environmental policies closely linked to the territory. At the same time, they are embedded in the larger context of national Italian policies. To do justice to this situation, relevant policies at the national, regional (Trentino-AltoAdige) as well as at the provincial level (for both provinces) are detailed below.

National level (Italy)

The Italian Flood Risk Management Plans (PGRA)⁴⁰ implement European Directive 2007/60/EC, "Floods Directive") and are the main operational flood risk management tool in Italian law. The PGRA aims to reduce the negative consequences of floods on human health, the environment, cultural heritage, and economic activities. They are prepared at river basin district level and updated every six years; the current period being 2021 to 2027.

The Italian National Strategy for Adaptation to Climate Change (SNAC)⁴¹ aims to provide a national vision regarding climate change adaptation, outlining necessary actions, guidelines for improving the resilience of various territories, and proposing specific adaptation priorities and measures. It describes the socioeconomic impacts of climate change and the policy responses aimed at mitigating and adapting to these impacts at national level.

Regional level (Trentino-Alto Adige)

The Flood Risk Management Plans (PGRA) for Trentino-Alto Adige (2021-2027) highlights significant historic flood events in the Trentino-Alto Adige region, such as the floods in November 1966 and July 1981, as well as the Storm Vaia in 2018. Substantial damage caused by these events include the overtopping and breaching of levees, leading to extensive flooding and economic losses. The Storm Vaia in 2018 resulted in the destruction of 41,000 hectares of forest and the felling of 8.6 million cubic meters of

³⁹ The strategies described in this section were either identified by CROSSEU partner UNIPD, case study area lead in the region of Trentino-Alto Adige, or in expert interviews conducted by CROSSEU partner K&I (see Annex IV).

⁴⁰ <https://sigma.distrettoalpiorientali.it/portal/index.php/direttiva-alluvioni/>; last accessed October 29th, 2024

⁴¹ <https://www.mase.gov.it/notizie/strategia-nazionale-di-adattamento-ai-cambiamenti-climatici-0>; last accessed November 5th, 2024



timber; making the event far more devastating than the flood of November 1966, which felled 700,000 cubic meters of timber in Trentino.

The Hydrogeological Structure Plan (PAI) focuses on the development, adoption, and updates of various plans and projects related to hydrogeological risk management in the Adige river basin area, including geological hazard assessments, flood risk management, and related legislative measures.

Trentino

The Province of Trento adaptation work program "Trentino Clima 2021-2023" (Provincia Autonoma di Trento, 2021) outlines the strategy and actions for climate mitigation and adaptation in the Trentino region. It highlights the roles of various stakeholders, the methodology for risk analysis, and the identification of adaptation measures. It was published in August 2023, and is coordinated by Trentino's Provincial Agency for Environmental Protection (APPA). The program entails mitigation and adaptation measures:

- Mitigation measures are in line with Trentino's "Provincial Environmental Energy Plan 2021-2030" (PEAP), which is the main mitigation instrument, targeting a 55% reduction in greenhouse gas emissions by 2030 compared to 1990 levels and aiming for energy autonomy by 2050 (Cittadino and Meier, 2022).
- Adaptation actions include a series of activities to identify measures across various environmental systems and socio-economic sectors. These measures will be integrated into sector-specific plans and programs, as has already been done with the "Water Protection Plan 2022-2027", which includes potential adaptation measures for managing climate risks related to water resources (Provincia Autonoma di Trento, 2021).

The work program "Trentino Clima 2021-2023" further describes a process aimed at adopting Trentino's "Provincial Climate Change Mitigation and Adaptation Strategy", which shall serve as the reference tool to guide actions to contain ongoing warming and counteract the negative impacts of climate change. The process is interdisciplinary, dynamic, and implemented in connection with society: Between March and June 2023, approximately 900 Trentino citizens participated in a survey, identifying priority areas for urgent adaptation action. These areas include water and water resource management, agriculture and animal husbandry, disaster risk reduction, biodiversity and ecosystems, and health.

According to some of the interviewed experts (Interview CSA4_1, Interview CS4_4, Interview CSA_5), current policies are designed with the present effects of climate change in mind, particularly on the adaptation side. For instance, it is being considered that the return periods of natural hazards



are now shorter than in the past. However, according to the interviewed experts, current policies often do not account for further, even short-term, effects of climate change. As a result, many measures could soon become inadequate. A riverbank built to withstand current (increased) flood levels may become too small in the future. Additionally, it would be important to consider the increased frequency of mountain visits due to increasing leisure time: According to our interview partner, an increasing number of non-native people are being exposed to natural dangers; including tourists who may engage in risky activities and largely lack awareness of potential hazards.

Alto Adige (“South Tyrol”)

A crucial local strategy in the province of Alto Adige is the “South Tyrol Climate Plan 2040”, which was adopted by the Provincial Council of Bolzano, the capital of the province, in 2023. This plan has the goal of achieving climate neutrality by 2040 (Interview CSA4_2; Autonome Provinz Bozen Südtirol, 2023) and details an interdisciplinary and dynamic program to this end.

According to the “South Tyrol Climate Plan 2040”, the energy, mobility and agricultural sector are three major areas that require profound transformation. The plan is dynamic, with mechanisms for monitoring progress, updating measures based on scientific data and new developments and public participation, enhancing legitimacy and community involvement. The first step in implementing public participation came in form of the establishment of a “Citizens' Council for Climate”. It is composed of 50 randomly selected citizens and intended to contribute to a transparent and comprehensible implementation of the climate plan. The members of this citizen’s council will follow and evaluate the monitoring operations, debate new proposals and report directly to the Provincial Council of Bolzano. A second step came in form of the establishment of a “Stakeholders' Forum”; a body that brings together representatives of organizations and interest groups with a key role in the path towards climate neutrality. Discussion with the stakeholders’ forum is expected to further shape objectives and measures of the climate plan.

Interviewed experts emphasized the relevance of the “South Tyrol Climate Plan 2040” as guiding document in the region (Interview CSA4_3, Interview CSA4_4, Interview CSA4_4). They explained that, while some measures were already being implemented or had been clearly elaborated, others were still to be concretized and elaborated. Because of the actions implemented so far, according to the interview partners, the preparedness level for extreme weather events has increased substantially.

One interviewed expert expressed the opinion that preparedness among citizens had not risen enough and that there was a “*residual danger*”



(Interview CSA4_2; translated from Italian) for individuals' residences. Ideally, citizens' preparedness level should enable them to deal with flooding for the first 72 hours after a disaster occurs, since relief efforts may be delayed. The interview partner explained that, while structural and non-structural measures (including early-warning systems) implemented by the government had yielded positive results, there was a residual risk of water reaching citizen housing; and that individuals needed to carry out small adaptations to their own buildings (e.g. garages or basement rooms) themselves in order to deal with the remaining risk of preventing water from reaching them in the event of a flood. According to the interviewed expert, this issue was currently being approached in a pilot project within one of the local municipalities. In this pilot project, technicians from the provincial authority support the municipality in identifying regions with residual risk for private homes. If successful, actions tested in the pilot project will be extended to the other municipalities of the province; with the aim of increasing resilience.

In terms of economic instruments, the Provincial Administration of Bolzano has introduced two financial schemes: the "Emergency Interventions in Case of Natural Disasters Fund" and "Disaster Relief Grants for Agricultural and Forest Properties". These two measures are aligned with the National Flood Risk Management Plan (PGR), and are detailed in section 3.2.4 of CROSSEU deliverable D4.7.

Existing storm/flood mitigation and adaptation measures and their objectives

Trentino-Alto Adige employs a comprehensive approach to flood mitigation and adaptation, combining structural measures like dams and flood control channels with non-structural measures such as community engagement and early warning systems. Table 5 lists planned and existing mitigation and adaptation measures in Trentino-Alto Adige. These efforts aim to protect residents, infrastructure, and the environment from the impacts of flooding while also adapting to the challenges posed by climate change. They can be distinguished into structural and non-structural measures:

- Structural measures include:
 - Construction of dams: Several dams have been built in the region to regulate river flow, store excess rainwater, and mitigate the risk of downstream flooding. For example, the Santa Giustina Dam on the Noce River helps manage floodwaters.
 - Reservoirs: These are used to temporarily hold excess water during heavy rain events, thereby reducing flood peaks downstream.



- Flood control channels: The construction of flood control channels allows for the diversion of excess water away from populated areas. These channels are designed to carry floodwaters safely to less vulnerable areas.
- Reinforcement of riverbanks: Riverbanks along critical waterways have been reinforced with levees and embankments to prevent overflow during floods.
- Retaining walls: These structures are built in vulnerable areas to prevent soil erosion and protect infrastructure from floodwaters.
- Land use planning: The region employs land use planning and zoning regulations to restrict construction in high-risk flood zones, minimizing potential damage.
- Non-structural measures include:
 - Early warning systems: The region has implemented sophisticated monitoring and early warning systems that use meteorological and hydrological data to predict flooding events. These systems are crucial for timely alerts to residents and emergency services.
 - Flood Risk Management Plans (FRMP): These plans are developed to assess flood risks, prioritize mitigation strategies, and engage local communities in preparedness efforts.
 - Public awareness campaigns: Programs aimed at educating residents about flood risks and preparedness measures help enhance community resilience.
 - Restoration of wetlands and riverbanks: Efforts to restore natural landscapes can improve flood resilience by enhancing water absorption and slowing runoff.
 - Climate change adaptation strategies: The region is also focusing on broader climate adaptation strategies that integrate flood management with other environmental and social factors, promoting sustainability.

Table 5 Planned and existing mitigation and adaptation measures in Trentino-Alto Adige

| Measure | Objective | State of implementation | Source |
|----------------------------|-------------------------------------------------------------------------------------------------|-------------------------|---------------------|
| Construction of dams | Regulate river flow, store excess rainwater, mitigate the risk of downstream flooding | Implemented | Maran et al. (2023) |
| Construction of reservoirs | Temporarily hold excess water during heavy rain events, thereby reducing flood peaks downstream | Implemented | Maran et al. (2023) |



Deliverable 4.3 – Analysis of the climate change impacts and responses in sectoral policies (Version 1)

| | | | |
|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|--------------------------|
| Drafting of guidelines for maintenance and integrated management of watercourses | Define criteria for the construction of watercourse defense and maintenance works | Included in the Water Management Plan and Flood Risk Management Plan | PGRA |
| Survey of reference morphological sections on watercourses | Support the drafting of river maintenance guidelines | Included in the Water Management Plan and Flood Risk Management Plan | PGRA |
| Environmental redevelopment of the terminal section of the Piave River | Evaluate safety conditions of the terminal section of the Piave River | Initiated | PGRA |
| Morphological redevelopment of the Tegnàs stream | Restore area safety conditions, improve hydromorphological conditions | Initiated | PGRA |
| Activation and development of a Citizens' Water Observatory | Increase databases and communication channels during flood events | Initiated | PGRA |
| Provincial strategy for climate change mitigation and adaptation | To guide administrative actions to contain ongoing warming and counteract the negative impacts of climate change | In progress, with the first version expected by the end of 2023 and implementation starting in 2024 | Trentino Clima 2021-2023 |
| Provincial Energy and Environmental Plan (PEAP 2021-2030) | To reduce greenhouse gas emissions | Integrated into the provincial strategy | Trentino Clima 2021-2023 |
| Horizon Europe project NEVERMORE | To address climate risks in tourism | Ongoing, with collaboration from local stakeholders | Trentino Clima 2021-2023 |
| Interreg project Alpine Space X-RISK CC | To manage natural hazards and risks | Ongoing, technical and participatory activities | Trentino Clima 2021-2023 |
| Irrigation plan, IRRITRE project | To plan irrigation needs and necessary interventions for the agricultural sector | Ongoing | Trentino Clima 2021-2023 |
| Assessment of the financial needs of the Integrated Water Service (IWS) 2021-2027 | To plan interventions for the modernization of water supply networks | Ongoing | Trentino Clima 2021-2023 |
| Information and awareness campaigns | To raise awareness and educate the public on climate change impacts and adaptation | Ongoing, with various initiatives like "Microfoni Fusi" podcast and "Escape Park sui cambiamenti climatici" | Trentino Clima 2021-2023 |



| | | | |
|-------------------------------------------------|------------------------------------------------------------------|------------------------------------------------------------------|--------------------------|
| Diversification of the tourism offer | To adapt tourism offerings to changing climate conditions | Ongoing, part of the Triennale Trentino Marketing Plan 2022-2024 | Trentino Clima 2021-2023 |
| Adaptation of artificial snowmaking practices | To ensure ski tourism viability despite reduced natural snowfall | Ongoing, part of the PTA 2022-2027 | Trentino Clima 2021-2023 |
| Redevelopment and restoration of riparian areas | To enhance natural water purification and groundwater recharge | Ongoing, part of the Piano Tutela delle Acque 2022-27 | Trentino Clima 2021-2023 |

Responses in (cross-)sectoral strategies

Effective responses to complex societal and environmental challenges increasingly require coordinated efforts that transcend individual sectors. In Trentino-Alto Adige, a set of cross-sectoral measures has been implemented to address interconnected challenges in an integrated manner:

- Agriculture and food security:
 - The Fondazione Edmund Mach (FEM)⁴² has been conducting experimental projects to test technologies and refine models to provide farmers with data and tools for better irrigation management. This includes the IRRITRE project⁴³ (2023-2025), funded by the Provincia Autonoma di Trento, which aims to promote sustainable water use through precision irrigation practices by adopting protocols and guidelines that interact with existing and future irrigation control and distribution systems.
 - Additionally, there is a plan to create a provincial irrigation plan involving multiple institutions, including UniTrento and Comifo, to improve water management and address climate change challenges. Widespread use of drip irrigation systems has significantly reduced water consumption⁴⁴.
 - Furthermore, the Senate's Agriculture Commission approved an amendment that will allow field experimentation with plants selected for their resistance to pathogens and reduced chemical input needs, which can help mitigate the effects of climate change and save water. These measures are part of a collaborative effort involving the Province, Fondazione Mach, Fondazione

⁴² <https://fmach.it/en/The-Foundation/Who-we-are>; last accessed November 5th, 2024

⁴³ <https://cri.fmach.it/en/Ricerca/Progetti/IRRITRE-Sistema-informativo-territoriale-per-un-irrigazione-di-precisione-in-Trentino#page-content>; last accessed November 5th, 2024

⁴⁴ <https://www.ufficiostampa.provincia.tn.it/Comunicati/Irrigazione-Trentino-virtuoso-tra-efficienza-e-risparmio-ma-si-puo-fare-ancora-meglio>; last accessed November 5th, 2024



Bruno Kessler, Trentino Digitale, and the Department of Agriculture of the Autonomous Province of Trento.

- Tourism:
 - The Horizon Europe project “NEVERMORE”⁴⁵ (2022-2026) addresses climate risks in tourism in Trentino. The project aims to create models and tools for simulating and evaluating the impacts and risks of climate change. It also aims to develop new interactive digital platforms that help citizens and policymakers understand future scenarios and enhance the effectiveness of mitigation and adaptation strategies.
 - The “Triennale Trentino Marketing Plan 2022-2024”⁴⁶ includes ongoing efforts to diversify the region’s tourism offer in order to adapt it to changing climate conditions. It seeks to move beyond traditional growth models, focusing instead on sustainability, authenticity, and the enhancement of local identity. Key initiatives include the implementation of advanced digital marketing, the enhancement of the Trentino brand through storytelling focused on local communities and authentic experiences as well as special projects dedicated to sustainability and the promotion of local products and events.
 - The adaptation of artificial snowmaking practices is a central component of the PTA (Piano Territoriale di Adattamento) 2022-2027 in Trentino-Alto Adige, reflecting the region's response to declining natural snowfall due to climate change.
- Transport:
 - A monitoring system for greenhouse gas emissions in four major sectors (transport, heating, industry and agriculture) and total emissions has also been established in Alto Adige. The latest available data (2022) shows that emissions over the past few years have increased (Provincia Autonoma di Trento, 2021).

⁴⁵ <https://www.nevermore-horizon.eu/about-us/>; last accessed May 13th, 2025

⁴⁶ The “Triennale Trentino Marketing Plan 2022-2024” is the strategic framework developed by Trentino Marketing to guide the promotion and development of tourism and territorial branding in the Trentino region for the three-year period 2022–2024. The plan was formally approved by the Provincial Government of Trento and is structured around several key pillars and objectives. (<https://www.trentinomarketing.org/media/w3adxyle/pm-2022-2024.pdf>; last accessed May 13th, 2025)



6.3. Snow and avalanches in the Central Alps (CSA5)

The Paznaun Valley was identified as Climate Change Hotspot in case study area 5. It is a region located in the Western part of Tyrol, Austria, covering an area of approximately 40 km in length and bordered by the Silvretta and Verwall mountain ranges. The valley is renowned for its alpine climate, characterized by cold winters with temperatures often dropping below freezing and mild summers averaging 15–20°C. Precipitation is relatively high throughout the year, with snowfall being significant during the winter months.

In the Alps, these regions are subject mainly to the "landlocked and elevated" climate risk category, which is associated with the Alpine and central European mountains and uplands (Fig. 1). These regions show a particularly high exposure of people, settlements and transport infrastructure to landslides (the key hazard) and fluvial flooding (the secondary hazard). The complex topography and projected increase in heavy precipitation are the main drivers explaining the large spatial distribution and exposure to these hazards across the Alps. These NUTS3 regions are projected to experience increasing migration in the future, although they have relatively high levels of adaptive capacity and GDP.

In February 1999, two towns in the Paznaun Valley in Tyrol were severely affected by massive volumes of snow that had accumulated in the mountains above the village. The large snow volumes of the snow avalanche penetrated the safe areas in the local snow avalanche hazard zonation. The powder avalanche hit the village with great force, overturning cars, destroying buildings and burying 57 people. By the time rescue crews managed to arrive, 31 people had died. The next day, an avalanche struck the hamlet of Valzur, further to the east, and claimed another seven lives. The Galtur and Valzur snow avalanches were the worst Alpine avalanches in the last four decades (Prevention web, 2019).

The event claimed 31 lives in Galtur and seven lives in Valzur, and caused extensive damage to property, with small and close-knit community structure destroyed (National Geographic, 2013). The event is recognized as "the most lethal snowstorms recorded" (Traynor, 1999) and determined the rezoning of the former "green snow avalanche risk zone" that is today of a higher risk zone.

Actions taken in wake of the event

The 1999 Galtür and Valzur avalanches in the Paznaun Valley were devastating events that prompted significant policy changes and



improvements in avalanche safety measures⁴⁷. The following policy responses were implemented in the wake of the disaster:

- Revision of hazard zoning: The avalanche exposed flaws in the existing hazard zoning system. As a result, revised standards for defining hazard zone boundaries were issued in July 1999 and “red zones”, where construction is prohibited due to high avalanche risk, were greatly expanded⁴⁸.
- Infrastructure improvements: To enhance protection against future avalanches, a 300-meter avalanche dam was constructed to directly protect the village of Galtür and steel fences were installed on mountainsides above the village to break up areas where unstable snow packs can form; in Valzur, buildings and homes were rebuilt in a safer location up the valley.

The tragic incidents of 1999 prompted public scrutiny regarding the dependability of avalanche-risk forecasts and the mitigation strategies implemented by local authorities: First, there has been a heightened focus on snow research across Europe, leading to significant advancements in estimating avalanche hazards, particularly through the mapping of high-risk zones and the development of numerical models; Second, there has been an increase in understanding low-frequency events (Rousselot et al, 2010).

Austria and other Alpine countries have been refining and improving their avalanche safety policies and practices. Policy responses implemented in the years since the events in 1999 include the introduction or upgrade of early warning systems⁴⁹, the development of more sophisticated avalanche forecasting models, improved risk communication through mobile phone applications and social media platforms, enforcement of stricter zoning regulations in avalanche-prone areas and regular reassessments of hazard zones based on new data and climate change projections. Some communities have implemented relocation programs for buildings in high-risk areas.

Many communities have invested in avalanche protection structures, such as snow nets, deflection dams or snow sheds along transportation routes. Constructive preventive measures of potentially affected buildings, such as

⁴⁷ <https://galtuer.gv.at/unser-galtuer/lawine-1999/96-die-lawine-von-galtuer>; last accessed December 12, 2024

⁴⁸ <https://www.earthmagazine.org/article/benchmarks-february-23-24-1999-alpine-avalanches-sweep-through-austrian-towns-killing/>; last accessed December 12, 2024

⁴⁹ The Intercantonal Early Warning and Crisis Information System (IFKIS) introduced in Switzerland in 2002 in wake of the avalanche winter in 1999 has been continuously upgraded with new technologies and data integration methods.



allocating rooms with short occupancy time in the direction of potential hazard, reinforcing window shutters or removing any window openings at the exposed building side (cf. Holub et al., 2012), have been used complementarily with protection structures.

In the years following the 1999 avalanches, education and training have become integral components of avalanche risk mitigation strategies. Mandatory avalanche awareness training has been instituted for ski resort staff and mountain guides to ensure that individuals working in high-risk environments possess the necessary knowledge and skills to respond appropriately. In addition, schools located in Alpine regions have incorporated avalanche safety education into their curricula, fostering early awareness among children growing up in vulnerable areas. Public awareness campaigns are conducted regularly to inform residents and visitors about avalanche risks and promote best practices for staying safe in mountainous terrain.

Efforts to enhance avalanche safety have also included strengthened cross-border cooperation among Alpine countries. This includes the sharing of data, exchange of best practices, and coordination of rescue efforts in border regions, where joint action is often critical. Collaborative research initiatives have been launched to study the impacts of climate change on avalanche behavior and to develop adaptive strategies that can be implemented across national boundaries.

These ongoing policy responses reflect a continued commitment to improving avalanche safety and risk management in Alpine regions, building upon the lessons learned from the Galtür tragedy and adapting to new challenges posed by changing environmental conditions.



7. Outlook on Deliverable 4.4

The follow-up deliverable (D4.4), due in Month 30 of the CROSSEU project, will build upon the findings of the current analysis by further deepening the ex-post evaluation and introducing a forward-looking, ex-ante perspective. In the first part of D4.4, the ex-post analysis will be broadened to include additional Case Study Areas (CSAs) within the CROSSEU project. This extended analysis will systematically review the existing mitigation and adaptation measures implemented in each CSA, taking into account the local context, governance structures, and hazard profiles. Particular attention will be given to the specific objectives of each measure—whether they aim to reduce exposure, enhance preparedness, strengthen infrastructure, or improve response capacities.

A critical component of this analysis will be the evaluation of the actual effectiveness of these measures in meeting their stated objectives. This will involve identifying which interventions have demonstrated success in practice and which have fallen short, supported by explanations that consider technical, institutional, socio-economic, or environmental factors. Lessons learned from both successful and unsuccessful measures will be synthesized to highlight key enablers and barriers to effective risk reduction and adaptation. The effectiveness of existing M&A measures will be measured in terms of goal achievement (see Table 6).

The second part of D4.4 will introduce an ex-ante analysis that aims to explore the landscape of potential new policy options. This forward-looking section will consider emerging challenges such as climate change impacts, evolving socio-economic dynamics, and technological innovations. It will identify promising strategies and instruments that could complement or replace existing measures, drawing on both theoretical frameworks and practical experiences from within and beyond the Alpine region. Scenarios may be used to assess the feasibility, expected impact, and implementation requirements of these options. Overall, Deliverable 4.4 seeks to inform future policy development by integrating retrospective insights with proactive planning, thereby supporting evidence-based decision-making in disaster risk management and climate adaptation. It will inform CROSSEU Deliverable 4.9 and feed into the development of the Decision-Support System (WP3).

Table 6 Categories of policy success; adapted from McConnell (2010, p. 354)

| | Success | Conflicted success | Precarious success or failure |
|-----------------------------------|--------------------------------------------------|------------------------------------------------------------------|-----------------------------------------------------------|
| Achievement of desired outcome(s) | Achievement of (large part of) desired outcomes. | Some successes, but the partial achievement of intended outcomes | Failure to achieve desired outcomes / successful outcomes |



| | | | |
|-----------------------------|---------------------------------------------|-----------------------------------------------------------------------------|------------------------------------------------------------|
| | | is counterbalanced by unwanted results, generating substantial controversy. | overshadowed by failure |
| Benefits to target group(s) | Intended target group(s) broadly benefit(s) | Partial benefits realised, but not as widespread or deep as intended | Damage to the very group(s) that was/were meant to benefit |



8. Conclusions

The analysis presented in this deliverable D4.3 produces new insights on how coping with climate change hotspots in Europe can be aligned with sectoral policies. It highlights the multifaceted impacts of climate change across various sectors and the corresponding policy responses aimed at mitigation and adaptation. The findings underscore the importance of integrated, cross-sectoral approaches to address the complex and interconnected challenges posed by climate change. The following conclusions regarding climate change impacts and responses in sectoral policies can be drawn at this point:

- **Sectoral impacts and policy responses:** Climate change has profound implications for strategic sectors such as agriculture, health, water management, transport, and energy. Each sector faces unique challenges, including reduced crop yields, increased disease incidence, infrastructure damage, and water scarcity. Effective policy responses, such as the development of climate-friendly technologies, Health National Adaptation Plans (HNAPs), and resilient infrastructure investments, are critical to mitigating these impacts and enhancing adaptive capacities.
- **Cross-sectoral integration:** Successful climate change responses often involve cross-sectoral strategies that integrate structural, institutional, and social measures. Examples include combining flood defenses with early warning systems and promoting ecosystem-based adaptation in biodiversity management. These approaches demonstrate the value of addressing interconnected challenges through coordinated efforts across sectors.
- **Lessons learned from good practice examples:** Case studies and examples from across Europe reveal a range of good practices, such as precision irrigation in agriculture, sustainable tourism initiatives, and collaborative avalanche safety measures. These examples highlight the importance of stakeholder involvement, innovative technologies, and adaptive planning in achieving effective outcomes. However, persistent gaps, such as inadequate consideration of future climate scenarios, remain a challenge.
- **Barriers and inequalities:** Despite progress, barriers to effective mitigation and adaptation persist. These include financial constraints, institutional limitations, and unintended consequences of policies that exacerbate inequalities. Vulnerable groups, such as low-income communities, migrants, and those in climate hotspots, are disproportionately affected, emphasizing the need for equitable and



inclusive policy design. These aspects are analyzed in more detail in CROSSEU deliverable D4.5.

- The role of finance and innovation: Closing the financing gap for climate adaptation and resilience is essential. Investments in research and development, innovative insurance products, and climate-resilient infrastructure are critical to addressing both immediate and long-term challenges. Financial institutions must integrate climate risks into their frameworks to ensure global financial stability. For a detailed analysis of financial instruments used in climate policy, see CROSSEU deliverable D4.7, section 2.2.

In conclusion, addressing the impacts of climate change requires a multidisciplinary, inclusive, and forward-thinking approach. By leveraging lessons learned, fostering cross-sectoral collaboration, and prioritizing equity, policymakers can develop more effective strategies to mitigate risks and build resilience in the face of an uncertain climate future. The findings of this deliverable provide a foundation for future work, in the CROSSEU project and beyond.



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Annex I: Questionnaire for application in case study areas

Part A: Experience with flood events

1. Have you experienced any recent flooding events in the last five years? Yes/No
 - a. If yes, in what year/what event?

 - b. If yes, please indicate if and how the flooding affected you/your family/your business? (e.g. your house, the location of your business, road network, other infrastructure): _____
2. Are you aware of any flood insurance programs? Yes/No
3. Have you ever used any flood insurance? Yes/No
4. How long did the most memorable flood event last? (days)
5. Have you ever received any early warning information before a flood event? Yes/No
6. If yes, through what medium did you receive the early warning information? a) Community Information Centre b) Radio/television c) whatsapp d) SMS or calls e) Face-to-face f) Other:

7. As far as you know, does the early warning system prioritize needs of gender and the vulnerable in society? Yes/No/I don't know

Part B: Flood management policies and activities

8. How well do you know the following policies/activities regarding the management of flood events in the region of Trentino Alto Adige?

| <i>Policy/activity</i> | <i>I know it very well</i> | <i>I have heard about it</i> | <i>I had not heard about it</i> |
|-------------------------------------------------------------------------------------|----------------------------|------------------------------|---------------------------------|
| The European Directive on the Assessment and Management of Flood Risks (2007/60/EC) | | | |
| The European Water Framework Directive (2000/60/EC) | | | |
| The Italian Flood Risk Management Plan (PGRA) | | | |
| The Hydrogeological Structure Plan (PAI) | | | |



| | | | |
|--------------------------------------------------------------------------|--|--|--|
| The Province of Trento Adaptation strategy “Trentino Clima 2021-2023” | | | |
| The local “Gemeindezivilschutzplan” of 2022 | | | |
| The local “Zivilschutzbrowser” / “Browser di protezione civile” | | | |
| Revitalization / renaturation activities | | | |
| Support of (public or private) research and innovation activities | | | |
| Support for social innovation and community action | | | |
| Formation of alliances or other bottom-up initiatives | | | |
| Other: _____ | | | |

9. Do you agree or disagree with the following statements?

| <i>Statement</i> | <i>Strongly agree</i> | <i>Somewhat agree</i> | <i>Somewhat disagree</i> | <i>Strongly disagree</i> | <i>I don't know</i> |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|-----------------------|--------------------------|--------------------------|---------------------|
| “Public policies have achieved to reduce the risks of flooding in the area.” | | | | | |
| “Public policies have reduced the risk of flooding but have also had a negative effect on other areas, such as biodiversity, cost of living, or other aspects.” | | | | | |
| “Public policies to decrease the risk of flooding have had negative effects on disadvantaged groups of people (e.g. people living in areas prone to flood that have to abandon their homes and that are not assisted for being relocated)” | | | | | |
| “Public policies to decrease the risk of flooding are tailored to the specific needs of disadvantaged groups of people (e.g. disabled people, the elderly, children, people with a migration background ...).” | | | | | |
| “Public policies related to flood management are gendered- | | | | | |



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| sensitive ¹ (e.g. consider and valorize gender differences)." | | | | | |
| "Bottom-up initiatives in the local community are at least as important as public policy in decreasing risks of flooding." | | | | | |
| "Communication activities by the local government are effective in reducing the impact of flooding in the area." | | | | | |
| "Quality of life in the area has increased because of policies and activities to reduce the risk of flooding." | | | | | |

10. What (current or anticipated) problems are not addressed by any policy or measure in the area? _____

11. What additional measures should be taken to improve flood management and climate resilience in your area?

12. Do you agree or disagree with the following statements?

| <i>Statement</i> | <i>Strongly agree</i> | <i>Somewhat agree</i> | <i>Somewhat disagree</i> | <i>Strongly disagree</i> | <i>I don't know</i> |
|------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|-----------------------|--------------------------|--------------------------|---------------------|
| "I understand the role of the local government in managing flood risks and implementing flood prevention measures." | | | | | |
| "I am well informed about the flood risk zoning and land use planning regulations in my area." | | | | | |
| "Insurance programs help people to recover from flood events." | | | | | |
| "It is important for governments to invest in green infrastructure (e.g. parks, wetlands) as part of their flood management strategies." | | | | | |
| "The government's flood warnings and emergency information are easy to understand." | | | | | |



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| “Local community infrastructure (dikes, drainage systems, etc.) are well maintained to prevent flood events.” | | | | | |
| “I feel that I am involved in local decision-making related to flood management and climate adaptation planning.” | | | | | |



Annex II: Data collection and analysis via large survey in CSA3

The survey questions (see Annex I) were included in an online questionnaire administered to a representative sample of 2,000 residents of North-Eastern Italy between January and March 2025. Quota sampling was applied to ensure representativeness in terms of age, gender, education, and income level. The questionnaire was distributed through a professional survey agency.

The questionnaire had been developed by CROSSEU partner UNIPD, who also organized data collection and conducted the analysis of the collected data. For data analysis, the project team at UNIPD calculated basic frequencies for multiple choice questions and means (with standard deviations) for Likert scale questions. Answers were crossed with the socio-demographic information collected in the survey, using the appropriate statistical tests (chi-square test for frequencies and ANOVA for means).



Annex III: Interview guideline for expert interviews

Interview guideline about policy responses to climate change for use in CROSSEU Tasks 4.2 and 4.3.

I. Policy response to cope with climate change

Topic A: Identification of relevant policies and measures

1. What policies or measures do you consider particularly effective in mitigating and/or adapting to climate change in [insert geographic region]? (This may include policies that are already implemented as well as policies that have been agreed upon, but have not yet been implemented)

(for each mentioned policy/measure and overall)

- a. What are the goals of these policies/measures?
 - b. What are the most important effects of these policies/measures? (both effects that have already occurred and effects expected in the near future)
 - c. What would not have happened / be happening without these policies/measures?
2. Are there any policies or measures that address impacts of climate change that you consider ineffective or even counterproductive (in general or under specific circumstances)? *(If so, please elaborate!)*

Topic B: Further present and future needs

1. In respect of CC M&A, what current or future problems are currently not addressed by any policy or measure?
2. What (additional) support via policies or other governance measures is needed to deal with climate change impact in [insert geographic region]?

Topic C: Barriers and undesired effects

1. Are there barriers that hinder mitigation efforts of the above-mentioned mitigation policies? *(please answer considering each mentioned mitigation policy/measure and overall)*



2. Are there barriers that hinder adaptation efforts of the above-mentioned adaptation policies? *(please answer considering each mentioned adaptation policy/measure and overall)*
3. Are there unexpected or undesired effects of the above-mentioned mitigation and/or adaptation policies that hit disadvantaged people and/or increase inequality? Who are the affected people? How is this managed? Conversely, are there positive effects of these policies on inequality decrease/social inclusion? *(please answer considering each relevant policy/measure and overall)*
4. How, in this specific context can possible unexpected/undesired effects be eliminated or at least alleviated? Do we need to modify some of the policy' features? Do we need to adopt “safeguard measures” (i.e specific measures for allowing a better tailoring of these policies towards specific categories of people)? Are these changes feasible (and which are the possible barriers? Is anything already being done to improve the situation? What?
5. Are there synergies or conflicts between mitigation and adaptation measures in the above-mentioned policies?
6. Has the Covid-19 pandemic affected the implementation of mitigation & adaptation policies? If so, how? Have any policies undergone changes in some way connected to the pandemic?



Annex IV: Experts consulted in CSAs 3 and 4

Ten experts knowledgeable about policies managing socioeconomic impact of storm and flood events in the respective Climate Change Hotspot were interviewed in CSA3 and CSA4 between January and May 2025. Their identifiers and relevant information about them are listed in Table 7.

Table 7 Interview partners and their identifiers

| Case study area (CSA) | Interview identifier | Type of expert | Affiliation | Interviewer |
|-----------------------|----------------------|-----------------|------------------------------------------------------|-------------|
| 3 | CSA3_1 | Public official | Municipality of Åbenrå | DTU |
| 3 | CSA3_2 | Public official | Municipality of Sønderborg | DTU |
| 3 | CSA3_3 | Academic | University of Southern Denmark | BOKU |
| 3 | CSA3_4 | NGO / CSO | Concito | BOKU |
| 3 | CSA3_5 | NGO / CSO | CIP Foundation | BOKU |
| 4 | CSA4_1 | Public official | Trentino Province Authority | K&I |
| 4 | CSA4_2 | Public official | South Tyrol Province Authority | K&I |
| 4 | CSA4_3 | Public official | Executive Civil Protection | K&I |
| 4 | CSA4_4 | NGO / CSO | "Croci Bianche" (Structured volunteers organisation) | K&I |
| 4 | CSA4_5 | NGO / CSO | Coordination of environmentalists NGOs | K&I |



CROSSEU Partners





Bibliography





CROSSEU Partners

| | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
|  <p>Meteo Romania</p> |  <p>University of East Anglia</p> |  <p>WORLD METEOROLOGICAL ORGANIZATION</p> |
|  <p>UNIVERSITÀ DEGLI STUDI DI PADOVA</p>  |  |  |
|  |  |  |
|  |  |  |
|  <p>UK Research and Innovation</p> |  <p>UNIVERSITY OF BUCHAREST VIRTUTE ET SAPIENTIA</p> |  |