



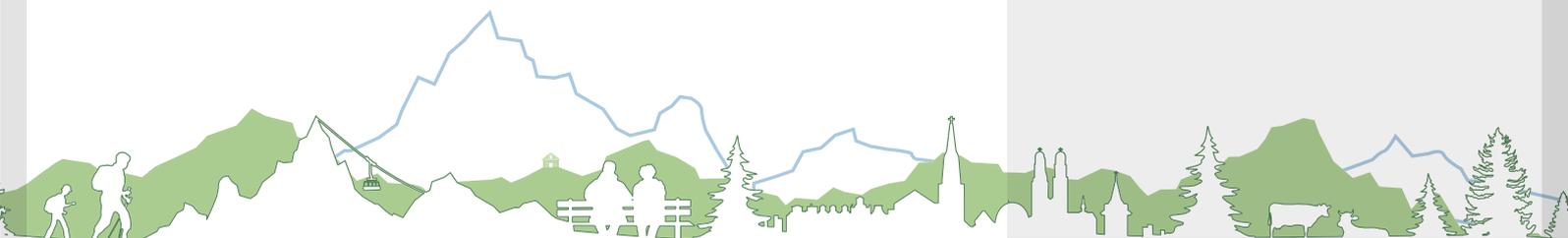
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Alpine Space

X-RISK-CC

ACTION PROPOSALS FOR MANAGING CLIMATE RISKS OF WEATHER EXTREMES IN THE ALPS

SYNTHESIS OF OUTCOMES AND TRANSNATIONAL POLICY RECOMMENDATIONS OF THE X-RISK-CC PROJECT



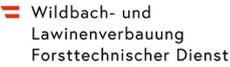
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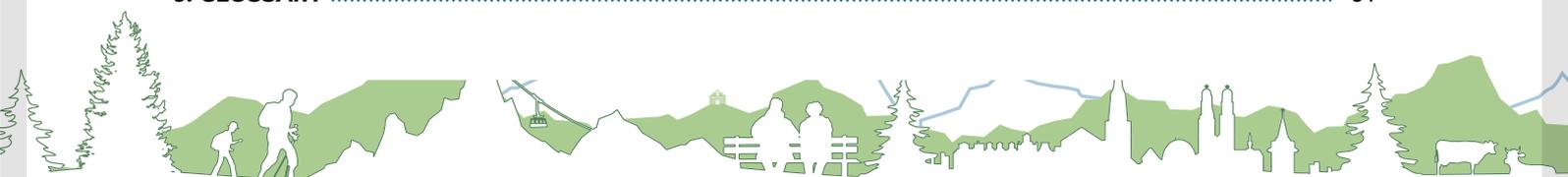
With the support, and building on the work done,
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TABLE OF CONTENTS



IMPRINT	2
TABLE OF CONTENTS	3
LIST OF FIGURES	4
LIST OF TABLES	5
ABBREVIATIONS	5
1. INTRODUCTION	6
1.1 Why these transnational action proposals?	6
1.2 For whom are the transnational action proposals?	7
1.3 What is the policy context of the transnational action proposals?	8
1.4 What does this document offer?	9
1.5 Understanding of key terms and concepts	9
1.6 About X-RISK-CC	13
2. HOW THE TRANSNATIONAL ACTION PROPOSALS WERE DEVELOPED	14
2.1 Assessing and understanding climate-related risks	14
2.2 Identifying and prioritising transnational key policy gaps and action needs	15
2.3 Developing and prioritising transnational action proposals	20
3. WEATHER EXTREMES AND CLIMATE-RELATED RISKS IN THE ALPS	22
4. TRANSNATIONAL KEY POLICY GAPS IN CLIMATE RISK MANAGEMENT	27
5. TRANSNATIONAL ACTION PROPOSALS FOR MANAGING CLIMATE-RELATED RISKS OF WEATHER EXTREMES IN THE ALPS	33
5.1 Preliminary remarks	33
5.2 Presentation of transnational action proposals	35
1 Prioritise Nature-based Solutions for climate risk management and give preference to passive risk prevention strategies	36
2 Enforce compact, land-saving and climate-resilient settlement development to contain risk exposure	38
3 Strengthen legal coupling of hazard zone planning with spatial planning and local land use decisions	40
4 Advance from hazard mapping to integrated risk assessments to support effective, risk-based prevention and preparedness strategies	42
5 Integrate climate change impacts into forward-looking hazard and risk assessments and establish a precautionary approach	44
6 Launch target group-oriented climate risk communication strategies for more risk-aware and better prepared Alpine communities	46
7 Expand localized, real-time hazard monitoring, early-warning and now-casting capabilities with improved spatial and temporal accuracy and interoperability across borders and scales	48
8 Strengthen operational linkages between early warnings and management of local responses	50
9 Strengthen preparedness and response capacities by institutionalizing knowledge exchange, learning and citizen involvement	52
10 Reform insurance and damage compensation systems to foster private risk reduction and climate-resilient reconstruction	54
11 Shape an integrated multi-level climate risk governance framework for Alpine territories	56
12 Establish systematic post-event learning and more resilient recovery in the Alpine region	58
6. GLOSSARY	61



LIST OF FIGURES



FIGURE 1	<i>Key components and interactions shaping climate-related risk and the role of climate risk management in reducing risk.</i>	11
FIGURE 2	<i>The Disaster Risk Management (DRM) Cycle.</i>	12
FIGURE 3	<i>Location of the X-RISK-CC pilot areas across the Alps.</i>	13
FIGURE 4	<i>The X-RISK-CC Policy Gap Explorer allows searching and filtering a compilation of almost 500 concrete risk management policy gaps in the Alpine region.</i>	16
FIGURE 5	<i>Stakeholders discussing experiences during past extreme events at workshop in the pilot area Stubai Valley.</i>	17
FIGURE 6	<i>Stakeholders identifying gaps and challenges at workshop in the pilot area Gorenjska – Sora Catchment.</i>	17
FIGURE 7	<i>Example of integrating local and generic gap issues.</i>	18
FIGURE 8	<i>Project partners discussing transalpine key policy gaps during 5th partner meeting in Vienna.</i>	18
FIGURE 9	<i>Prioritisation of transalpine key policy gaps at 5th partner meeting in Vienna.</i>	19
FIGURE 10	<i>Members of the Alpine Climate Board reviewing and prioritising action proposals.</i>	21
FIGURE 11	<i>Working online with concept board at the joint transnational expert workshop with EUSALP AG8 and PLANALP.</i>	21
FIGURE 12	<i>Locations of past weather extremes that overstrained existing risk management systems in the pilot areas of the X-RISK-CC project.</i>	23
FIGURE 13	<i>Projected changes in the annual frequency of heatwave days (HWD) with respect to present-day conditions (1991-2020) if a global warming of +2 °C is reached. Future increases emerge for the entire Alpine Space, reaching up to 15 extra heatwave days in a year over parts of the Alpine ridge.</i>	24
FIGURE 14	<i>Projected changes in the annual maxima of 1-day precipitation (Rx1d) with respect to present-day conditions (1991-2020) if a global warming of +4 °C is reached. Future increases emerge for most of the Alpine Space, with no clear patterns for some areas mostly located in the southern Alps (hatched areas in the map).</i>	25
FIGURE 15	<i>Areas in the Alps with an increase of potential impact events from mass movement process types 'slides', 'flows' and 'falls' for three mass movement models for the period 2005-2021. Black areas indicate where the potential impacts from all considered hazard process types have increased.</i>	26
FIGURE 16	<i>Transalpine key policy gaps along the disaster risk management (DRM) cycle.</i>	32



LIST OF TABLES



TABLE 1	<i>Summary of transalpine key policy gaps identified across the disaster risk management cycle, illustrated with exemplary evidence from pilot areas and cross-references to action proposals addressing the respective gaps.</i>	27
TABLE 2	<i>List of transnational action proposals and their position in the risk management cycle</i>	35

ABBREVIATIONS



ACB	<i>Alpine Climate Board of the Alpine Convention</i>
AG8	<i>Action Group 8 'Risk Governance' of EUSALP</i>
CAPA	<i>Climate Adaptation Platform for the Alps</i>
CCA	<i>Climate Change Adaptation</i>
DRM	<i>Disaster Risk Management</i>
DRR	<i>Disaster Risk Reduction</i>
EUCRA	<i>European Climate Risk Assessment</i>
EUSALP	<i>European Union Strategy for the Alpine Region</i>
NbS	<i>Nature-based Solutions</i>
PLANALP	<i>Natural Hazards Working Group of the Alpine Convention</i>



1. INTRODUCTION



Driven by intensifying weather extremes, the Alpine region has experienced more and more severe climate-related disaster events in recent years and is increasingly exposed to more frequent, more intense, and spatially expanding hazards, compound impacts and cascading risks. Existing risk management capacities have repeatedly been overstrained during past extreme events, and climate adaptation and risk management policies are threatened to be outpaced by rapidly evolving climate risks. Policy preparedness needs to be improved to make the Alpine region become more resilient. This document presents the transnational action proposals of the X-RISK-CC project for climate risk management of weather extremes in the Alpine region. Development of these policy recommendations was based on assessment of current and future climate-related risks from weather extremes, analysis of local risk management gaps in pilot areas and strategic gaps in generic policy frameworks, and co-development with transnational expert groups.

1.1 WHY THESE TRANSNATIONAL ACTION PROPOSALS?

The aim of these policy recommendations is to enhance the policy readiness and *resilience* of Alpine territories to increasing risks of weather extremes by integrating climate change into existing policy frameworks for risk management in a pro-active, forward-looking, and transboundary approach.

Europe is warming faster than any other continent, and temperature increases in the Alpine region surpass the European average. The Alpine region is increasingly affected by complex and *cascading climate-related risks*, driven by changes in frequency, intensity and spatial occurrence of hazard processes. Most often triggered by intensifying *weather extremes*, *hazards* like storms, floods, droughts,

landslides, debris flows, forest disturbances, and wildfires interact across the natural environment, economic sectors and borders, creating severe pressures on Alpine communities, ecosystems, infrastructures, and economies. Due to its unique geography, the Alpine region is particularly vulnerable to climate-driven natural *disasters* caused by meteorological, hydrological, gravitational, (peri-)glacial and forest-related hazards, whose effects are often exacerbated by their compounding occurrence and interactions, creating multiple risks that can cascade across sectors, scales, and levels. The X-RISK-CC project has identified multiple critical gaps in existing risk management practices and policy frameworks, revealing that preparedness for current and future climate risks is too low and policy implementation is lagging considerably behind quickly increasing risk levels. To prevent and mitigate substantial damage and loss and avoid long-lasting or even irreversible consequences, Alpine risk management policies need to adapt to emerging new realities in the wake of climate change.

Recent data analysis at European level¹ reveals the magnitude of risks and underpins the need for urgent action. From 1980 to 2023, over 240,000 people died because of weather- and climate-related extreme events in the EU-27. Weather- and climate-related extremes caused economic losses of assets estimated at EUR 822 billion during 1980 - 2024 in the European Union, with over EUR 208 billion (25%) between 2021 and 2024. Economic losses increase over time, and the last four years are all in the top five years of the highest annual economic losses since 1980. As less than 20% of total losses were privately insured, there is also an insurance protection gap creating substantial pressures on public finances. Hydrological hazards (floods), meteorological hazards (storms, including lightning and hail) and heat waves account for most of the losses, and relatively few events were responsible for most



of the total economic losses, demonstrating the need to better prepare for extreme risk scenarios, i.e. low probability-high impact events. Notably, comparison of estimated economic losses due to weather- and climate-related extremes at country level reveals that several of the Alpine countries face the highest absolute and per capita losses², demonstrating the high levels of vulnerability and risk exposure in the Alpine region.

The first European Climate Risk Assessment (EUCRA)³ has concluded that several *climate risks* have already reached critical levels and most climate risks identified could reach critical or catastrophic levels by the end of this century, if decisive adaptive action is not taken now. As severe weather- and climate-related extreme events are projected to intensify further, a comprehensive, integrated approach is required to adapt to and manage climate-related risks, and to develop strategies that deal with the remaining and *residual risks* not mitigated by *adaptation* measures. Business-as-usual development will result in constantly growing *vulnerabilities* and inflexible choices that are not fit for the future in a changing climate, such as in land-use planning and long-lived infrastructure, causing lock-ins into *maladaptive* pathways. Increasing severity of risks combined with insufficient levels of policy preparedness substantiates a need for urgent action. Exacerbating the urgency to act now are the often long lead times until adaptation measures are implemented and become effective.

1.2 FOR WHOM ARE THE TRANSNATIONAL ACTION PROPOSALS?

The transnational action proposals address **policy makers at subnational, national and transnational levels** with agenda-setting and decision-making capacity in shaping policy frameworks, instruments and measures for future management of extreme weather risks under climate change.

At **national and subnational levels**, these **primary target groups** include public authorities, regulators, agencies, scientific-technical institutions and services, emergency organisations, civil protection associations, and other institutional actors that share policy ownership for risk reduction, climate adaptation, and resilience planning in risk-related policy fields. These include natural hazard and flood risk management,

civil protection and disaster risk management, spatial planning and territorial development, climate adaptation, protection forest management, forest fire prevention, and insurance businesses.

While the exact roles and responsibilities of these actors differ, depending on the specific policy option to be implemented and the division of competences under different Alpine jurisdictions, actions for climate risk management inevitably require **cooperation and coordination across various sectors, actors, and jurisdictional boundaries**. Transcending of sector silos is needed to adequately address multiple hazards, cascading and compound risks, all phases of the risk management cycle (from prevention to recovery), and different risk sources and drivers (from hazards and impacts to exposure, vulnerability, and adaptive capacity).

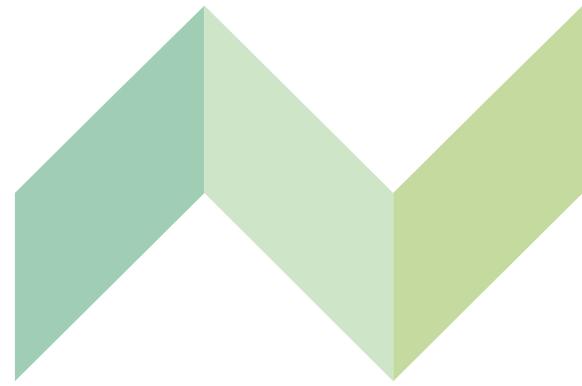
The action proposals also deliberately address **transnational actors** in the **Alpine region**. These include transnational cooperation structures (EUSALP, Alpine Convention), their relevant thematic working bodies (in particular, EUSALP Action Group 8 on Risk Governance, the Alpine Climate Board and the Natural Hazards Working Group PLANALP of the Alpine Convention), as well as EU Interreg Programmes (Alpine Space Programme, border-crossing Interreg programmes) and trans-Alpine NGOs.

While the transnational action proposals speak to different levels of governance and risk ownership and aim to support transnational cooperation, they address primarily policy gaps and action demands at higher ranking levels and with cross-border dimensions, such as political mandates, allocation of resources, regulatory and coordinative action, installment of enabling framework conditions, and provisioning of supportive governance frameworks. Regional and local actors are targeted mostly as beneficiaries. Nevertheless it should be clear that full implementation of recommended actions relies on effective governance at and across all levels, requiring a whole-of-government and whole-of-society approach. Local and regional actors have a key role in risk management and climate adaptation, which is demonstrated by the tailored action plans of localized measures developed by the X-RISK-CC pilot areas⁴. However, in many cases, municipalities and regions need 'help from above', because many climate-related challenges cannot be solved by the local level alone.



1.3 WHAT IS THE POLICY CONTEXT OF THE TRANSNATIONAL ACTION PROPOSALS?

The transnational action proposals align with **existing policy frameworks** at **EU, transnational and national levels** by contributing to their policy objectives and responding to identified overarching gaps and needs, while proposing solutions for specific climate-related challenges of the Alpine region and trans-Alpine gaps in extreme weather risk management, as identified by the X-RISK-CC project.



EU POLICIES

Increasing climate resilience is a cornerstone of strengthening *security* and *competitiveness*, both core priorities of the *European Union's policy agenda*. The X-RISK-CC transnational action proposals respond to key findings of the *European Climate Risk Assessment (EUCRA)*⁵ and to repeated calls for more systemic approaches to adaptation and climate risk management, including in particular consideration of compound, cascading and transnational risks. They resonate with the *European Preparedness Union Strategy*⁶, which aims to enhance the EU's ability to anticipate, prevent and respond to a range of threats and crises, including by means of an integrated all-hazards approach to managing natural disasters and extreme weather events exacerbated by climate change. The project's recommendations align with the *Union Civil Protection Mechanism*⁷ and translate the *EU Disaster Resilience Goals*⁸ into concrete policy options for the Alpine region. They also respond to the *EU Strategy on Adaptation to Climate Change*⁹, which calls for improved climate risk assessments and early warning systems and for adaptation and resilience measures to be embedded across all policy areas, and are in line with the *EC Communication on Managing Climate Risks*¹⁰, including its focus on transformational change and systemic action involving cross-sectoral solutions to address interlinked climate risks. The present trans-Alpine action proposals are coherent with EU sector policies addressing specific risks, such as the *Floods Directive*¹¹, the *European Water Resilience Strategy*¹², the *EU Forest Strategy 2030*¹³, and the *Wildfire Prevention Action Plan*¹⁴, and intend to contribute to the forthcoming *European Climate Resilience and Risk Management Framework*¹⁵ (also running under 'ECAP – European Climate Adaptation Plan').

TRANSNATIONAL POLICIES

X-RISK-CC has involved *EUSALP Action Group 8 (AG8)*¹⁶ and the *Alpine Climate Board (ACB)*¹⁷ and *PLANALP*¹⁸ of the *Alpine Convention* in development of its transnational action proposals. This has contributed to the work programs of these bodies and has informed renewal of the *AG8 work plan 2026-2028*, which intends to take up selected policy recommendations and work on their implementation in the forthcoming work period, in line with EUSALP's priority of 'an ecologically connected, environmentally sustainable Alpine Region that fosters climate adaptation'. The X-RISK-CC action proposals for climate risk management of weather extremes explicitly contribute to implementation of the *Alpine Convention's Alpine Climate Target System 2050* and its *Climate Action Plan 2.0*¹⁹, connecting in particular to implementation pathways in the target areas natural hazards, spatial planning, water, and mountain of forests.

(SUB)NATIONAL POLICIES

The X-RISK-CC action proposals respond to challenges and needs flagged by *national and regional strategies and action plans for climate adaptation and disaster risk reduction in the Alpine countries* while addressing specific gaps in existing risk-related policies, thus supporting their implementation and advancement. The policy recommendations also intend to inspire and contribute to development of emerging regional adaptation strategies in Alpine territories that do not have adopted policies in place, yet.

1.4 WHAT DOES THIS DOCUMENT OFFER?

At the core of the present publication are the transnational action proposals for enhancing the climate risk management of increasing extreme weather events, compound impacts and cascading risks in the Alpine region. Covering the entire disaster risk management cycle, each of the twelve transnational policy recommendations puts forward a portfolio of policy options and solution pathways tackling prioritised key policy gaps. The elaborated action proposals are presented in **CHAPTER 5**.

The preceding sections put the policy recommendations into context, outline the key issues and challenges addressed, and synthesize main outcomes of the X-RISK-CC project that the action proposals build upon. The present **CHAPTER 1** sets the stage by introducing the problem and the need for solutions, stating the rationale and the policy objective, identifying the target groups, mapping the relevance in the European and Alpine policy landscape, and framing key concepts related to climate risk management and the disaster risk management cycle. By summarising methodologies and workflow, **CHAPTER 2** makes transparent how the action proposals were developed and provides links to published project results for further reading. **CHAPTER 3** provides a synopsis of the project findings on current and future weather extremes, hazards, and climate-related risks at local pilot area level and Alps-wide scale. **CHAPTER 4** gives an overview of the most salient transnational policy gaps across the DRM cycle, illustrated by evidence from pilot areas. Key terms used in this document are explained in a glossary in **CHAPTER 6** and highlighted in the text in light blue colour code.

1.5 UNDERSTANDING OF KEY TERMS AND CONCEPTS

This document presents transnational action proposals for climate risk management of weather extremes (→ **CHAPTER 5**), including recommended courses of action that address all phases of the disaster risk management cycle. To facilitate readers' understanding, the following section introduces the most important related key concepts and terms. Definitions and explanations have been summarized and adapted from a range of authoritative sources²⁰. Further key

terms are defined in the glossary (→ **CHAPTER 6**) annexed to this publication. These key terms are highlighted in the text when they first appear, or when their understanding is central to the respective document section.

CLIMATE RISK denotes the potential for adverse consequences from climate variability, climate change or climate-related extreme events for human or ecological systems and their functions. Climate risk results from the dynamic interaction of climate-related *hazards* with the *exposure*, *vulnerability* and *adaptive capacity* of the affected system. It describes how, to what extent, and why climate change and weather extremes could cause harm to people, assets, sectors, or systems and, if possible, how likely adverse consequences are today or could become in the near or far future. Relevant adverse consequences include those on lives, livelihoods, health and wellbeing, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species.

In this document, the terms 'climate risk' and 'climate-related risk' are used synonymously to refer to potential consequences that are driven by climatic factors. While 'climate risks' refer to any current or future risk related to the changing climate that can lead to extreme weather events and slow-onset processes (i.e., related to gradually changing temperature or precipitation regimes), the focus of the X-RISK-CC project and the transnational action proposals for climate risk management is on changing *weather extremes* as a trigger for natural hazards. The concept of 'climate risk' focuses on the adverse and severe consequences on relevant human and ecological systems that need to be managed, i.e. that should be avoided or reduced. It offers a system perspective that considers the complex interplay of climatic and non-climatic *risk drivers* (hazard, exposure, vulnerability, and other underlying risk drivers). The system perspective considers in particular the importance of *compound risks*—where multiple hazards occur simultaneously or sequentially—and *cascading impacts*, where an initial hazard sets off a chain of effects across systems or sectors, whose resulting impact is significantly larger than the initial impact. Understanding these complex dynamics is essential for developing integrated, cross-sectoral approaches to risk assessment, *risk management* and disaster *preparedness*.



CLIMATE RISK MANAGEMENT, as applied by the X-RISK-CC transnational action proposals, means all policies, actions, measures, tools and mechanisms to avoid and reduce current and future *climate-related risks*, i.e. to avert, minimize and address losses and damages that may result from potential impacts related to natural and climate-induced hazards. Climate Risk Management integrates *Disaster Risk Reduction (DRR)* and *Climate Change Adaptation (CCA)*, including *risk transfer* and financing mechanisms (such as insurance) to address damages and losses from residual risk.

The management of current risk to climate extremes is typically covered by existing **Disaster Risk Reduction** systems, which include the strategic and instrumental measures employed for preventing new and reducing existing disaster risk and managing residual risk, typically by reducing existing exposure, hazard, or vulnerability under current climatic conditions. Disaster Risk Reduction is the policy objective of **Disaster Risk Management (DRM)**, which applies strategies, policies and measures for continuous improvement of disaster prevention, preparedness, response and recovery practices to strengthen *resilience*. However, traditional DRM approaches often rely on historical events, using past experiences, observations and statistical data to design *structural* and *non-structural risk management measures*, which may fail to account for increasing intensity and frequency of extreme meteorological events due to climate change, leaving Alpine regions insufficiently prepared for new or unprecedented weather extremes.

Climate Change Adaptation is the process of adjustment to actual or expected climate change and its effects, in order to moderate harm or exploit beneficial opportunities. CCA explicitly considers future and long-term climate change, its influence on changing intensity and frequency of climate extremes, and emerging climate risks. However, where CCA strategies and plans exist, they often underestimate the severity of extreme events and frequently lack actionable measures to manage associated compound and cascading risks.

Climate Risk Management combines both CCA and DRR as integral components of managing climate-related risks and understands measures of both realms as complementary parts of the same toolbox, aiming at the smartest and most effective policy mix for a given situation. Essentially, Climate Risk Management systematically considers future climatic and non-climatic developments and seeks to adapt existing DRR/DRM approaches to new challenges arising from climate change. It requires mainstreaming of CCA into DRM systems, i.e. natural hazard management and civil protection, as well as, vice versa, uptake of DRM methods and practices into CCA. Climate Risk Management aims to reduce climate-related risks mainly by lowering the – generic and specific – vulnerabilities of exposed systems, containing or reducing the degree of exposure to climate-related hazards, mitigating cascading impacts, enhancing adaptive capacity, and by direct protection against hazards (e.g., flood defences). The overall goal of Climate Risk Management is to support climate-resilient development.

FIGURE 1 illustrates the components and interactions that shape *climate-related risk*, particularly in the context of extreme events under climate change, and the entry points for **Climate Risk Management**. Triggered by climatic extremes (such as heavy precipitation), a climate-related *hazard* (such as a flood, debris flow or drought) interacts with *exposure* (who or what is in harm's way), *vulnerability* (how prone people and assets are to harm), and available *risk management capacity* (resources and policies in place to reduce risk), which are influenced by other underlying *risk drivers* (such as demographic development or urban development into hazard zones). These interactions, which may involve *cascading* and *compound impacts*, determine the overall *risk* to natural and human systems, their assets and functions. Measures of climate risk management seek to reduce risk and to strengthen *resilience* by reducing hazards, exposure, vulnerability and impacts.



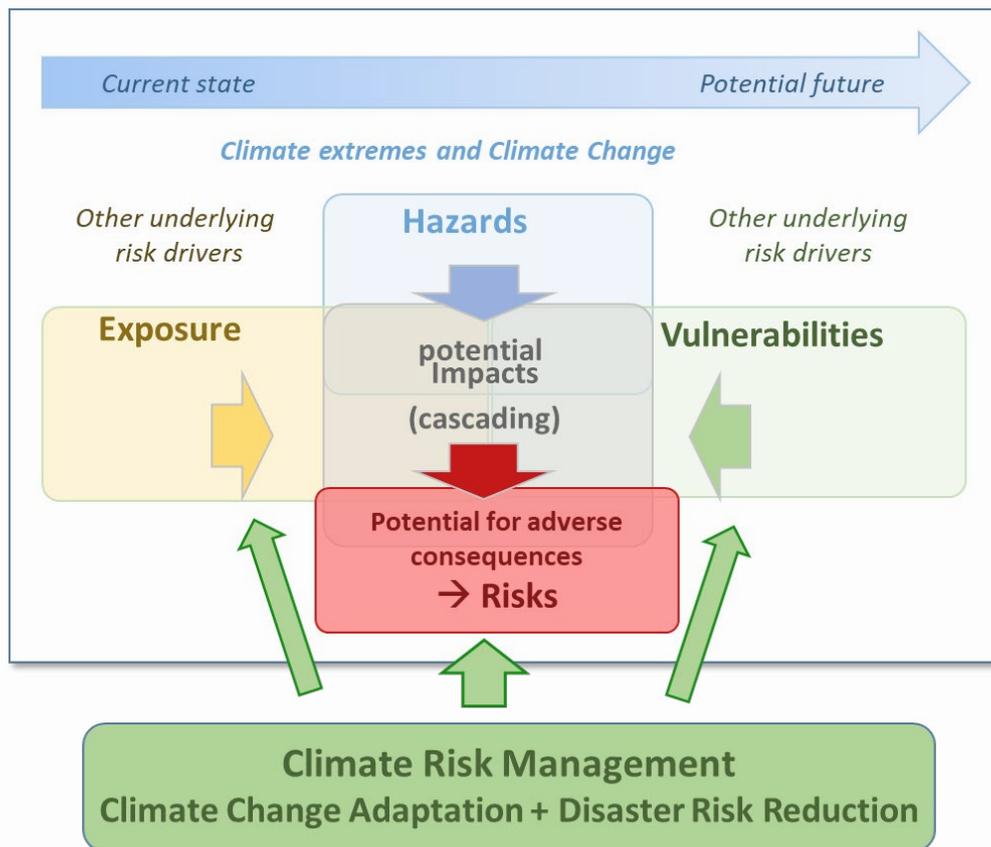


FIGURE 1: Key components and interactions shaping climate-related risk and the role of climate risk management in reducing risk (source: Zebisch et al., 2023²¹; modified).

The **Disaster Risk Management (DRM) Cycle** is a well-established, tried and tested tool for systematic planning, organisation, coordination, and continuous improvement of disaster risk management. It provides a structured and iterative process framework directed at avoiding and reducing risks and enhancing resilience. As illustrated by **FIGURE 2**, this established process involves a continuous cycle of interconnected actions, which are traditionally organised in the following main phases:

PREVENTION

PREPAREDNESS

RESPONSE

RECOVERY

These main phases of the DRM cycle overlap, with the transitions between phases (interphases) requiring particular attention to avoid coordination deficits and gaps in risk management.



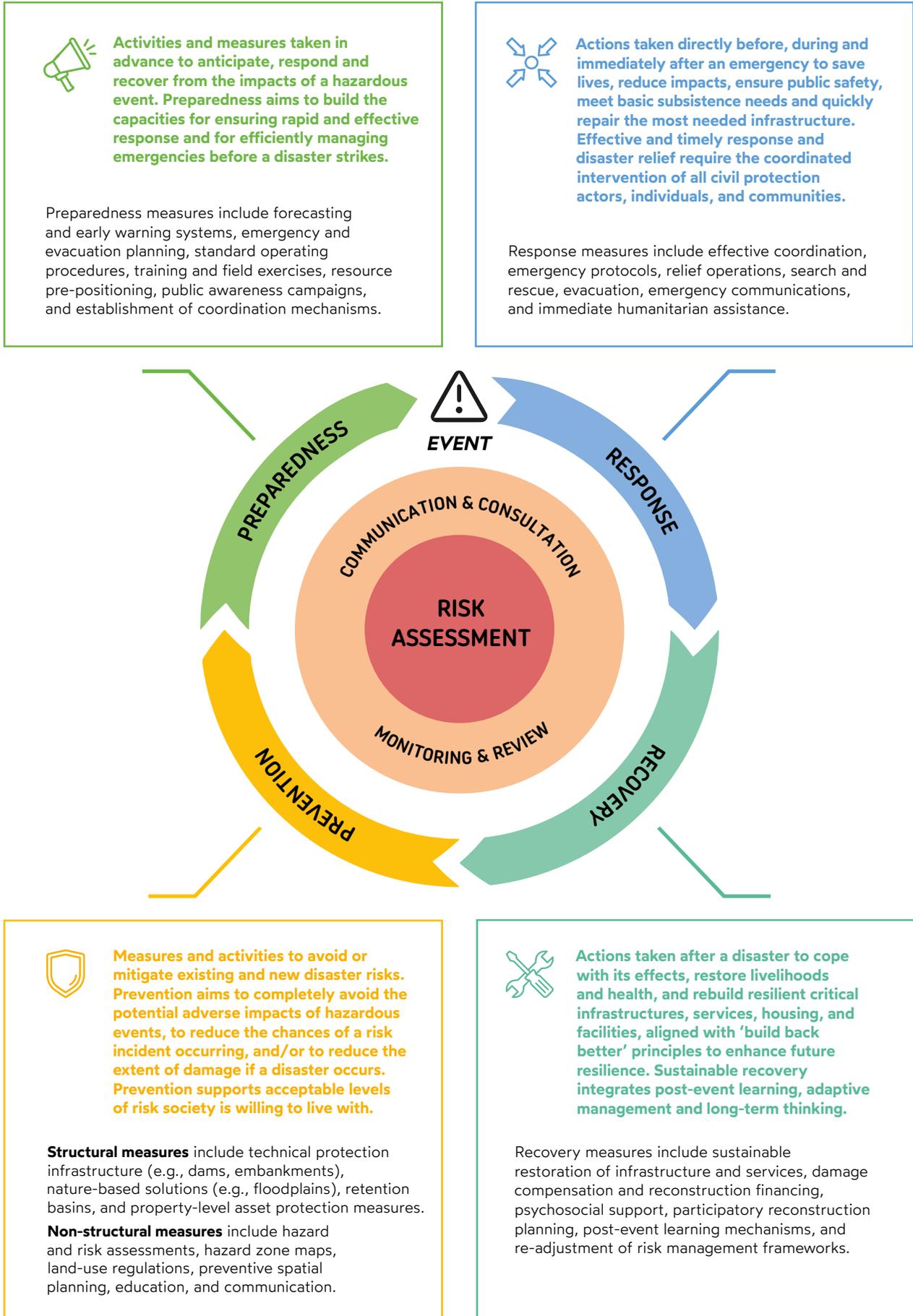


FIGURE 2: The Disaster Risk Management (DRM) Cycle.

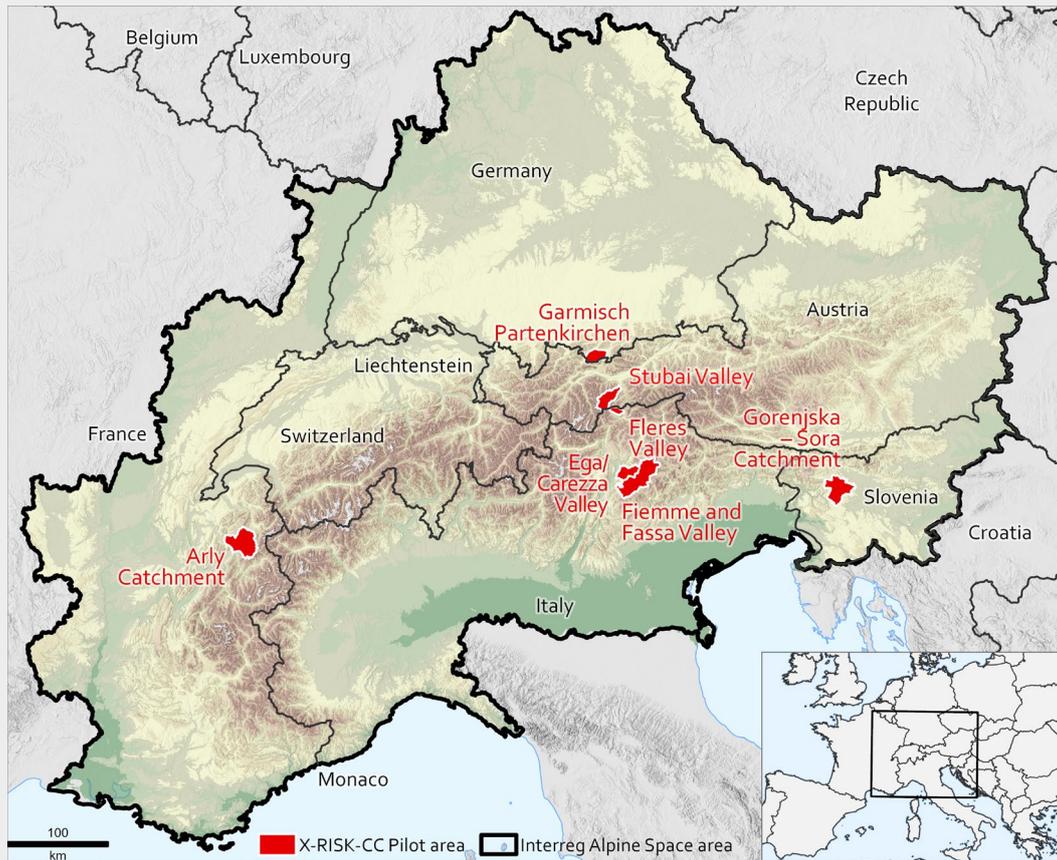


FIGURE 3: Location of the X-RISK-CC pilot areas across the Alps.

1.6 ABOUT X-RISK-CC

The project responds to scientific evidence that climate change is likely to induce more frequent and intense weather extremes in the Alps with compound and cascading effects on the environment, humans and the economy. This may induce unexpected complex, long-lasting or even irreversible consequences. However, the knowledge and management of cascading impacts and risks under climate change are still insufficient. Therefore, the X-RISK-CC project supports risk managers and policy makers in addressing the risks of climatic extremes by developing new and harmonised Alpine-wide data and knowledge on past and future extremes, local risk management actions and transnational guidelines and action proposals. The X-RISK-CC partnership includes regional risk managers, national authorities, scientists and members of EUSALP AG8, PLANALP and the Alpine Climate Board (ACB). The project results explicitly address the need for shared knowledge, actions and solutions to manage weather extremes in the context of climate change.

Actions to upgrading of current risk management and climate adaptation policies have been co-designed with risk managers in real-world pilot areas across the Alpine Space, including cross-border regions (**FIGURE 3**). Representing a distinct geographical, socio-economic, and climatic context in different Alpine countries and focussing on different prioritised risks, each pilot area has conducted an assessment of current and future weather extremes, climate-related hazards and risks, analysed risk management gaps, and developed tailored action plans for enhancing future risk management.

For co-development of its transnational action proposals, the project has collaborated with Action Group 8 of the EU strategy for the Alpine region (EUSALP) and with the Alpine Climate Board and the Natural Hazards Working Group (PLANALP) of the Alpine Convention.

Full documentation of project activities and all project outcomes are accessible at the project website of the [Alpine Space Programme](#) and included in a dedicated module at [CAPA – Climate Adaptation Platform for the Alps](#).

2. HOW THE TRANSNATIONAL ACTION PROPOSALS WERE DEVELOPED



Development of the transnational action proposals, as presented in **CHAPTER 5** of this document, was organically embedded in the overall design and workflow of the X-RISK-CC project. Building on the results gained from all project activities conducted over the course of three years, these policy recommendations have been derived in an iterative process integrating the insights gained from work in local pilot areas with transnational data and perspectives. The following section summarizes and makes transparent how the transnational action proposals were developed. It also provides external links to further resources generated by the project, including full documentation of

methodologies and findings as well as transferable products and reusable datasets.

The process of developing the transnational action proposals spans the following main steps:

- **Assessing and understanding climate-related risks** (→ [CHAPTER 2.1](#))
- **Identifying and prioritising transnational key policy gaps and action needs** (→ [CHAPTER 2.2](#))
- **Developing and prioritising transnational action proposals** (→ [CHAPTER 2.3](#))



PUBLIC REPOSITORIES OF PROJECT OUTCOMES

All project outcomes are accessible at the following main sources:

- [X-RISK-CC project website](#) (*Alpine Space Programme*)
- [CAPA – Climate Adaptation Platform for the Alps: How to adapt to changing weather extremes, compound impacts and cascading risks](#)
- [X-RISK-CC WebGIS of Alpine-Wide Climate Extremes](#)

2.1 ASSESSING AND UNDERSTANDING CLIMATE-RELATED RISKS

Adapting risk management to increasing challenges posed by climate change first requires understanding the problems and building a knowledge base on current and future climate-related risk. To prepare the ground for adaptation planning, the X-RISK-CC project has assessed past and future weather extremes, hazards, impacts, and risk pathways both at local pilot area level and at Alpine-wide scale. In pilot areas, this risk analysis has provided in-depth knowledge on climate extremes and how they are driving key risks, the hazards and impacts that are triggered by climate extremes, the exposure of populations, sectors, and assets, the factors that shape their vulnerability to impacts, and limitations of current risk management capacities. Moreover, the project has provided novel

data and information on projected Alps-wide changes of climatic extremes under climate change and developed models allowing detection of hot spots for mass movement impacts across the Alpine region. **CHAPTER 3** gives an overview of past experiences with extreme weather events in the pilot areas and summarizes the projected changes of weather extremes and the resulting landscape of climate-related risks at local level and at Alpine-wide scale.

Risk-related methodologies and results are presented in detail in **pilot area reports** and **synthesis reports**, and a **Web GIS portal** gives access to Alpine-wide data and visualisations. To upscale the project experiences, the **X-RISK-CC Risk Manual** guides regional risk managers through the workflow of a regional assessment of compound and cascading risks under current and future climate.



FURTHER READING

- [X-RISK-CC WebGIS of Alpine-Wide Climate Extremes](#)
- Digital Library at the [X-RISK-CC WebGIS](#):
 - [Alpine Space Report on projected future changes in weather extremes](#)
 - [Reports on past and future weather extremes in pilot areas](#)
- Report on past and future (compound) hazards in the pilot areas:
 - at [project website](#)
 - CAPA: [Understanding climate risks from weather extremes](#)
- Report on past and future risk pathways in the pilot areas:
 - at [project website](#)
 - CAPA: [Understanding climate risks from weather extremes](#)
- X-RISK-CC Risk Manual:
 - at [project website](#)
 - CAPA: [Understanding climate risks from weather extremes](#)
- Steger, S., Spiekermann, R., Moreno, M., Lehner, S., Enigl, K., Crespi, A., and Schlögl, M. (2025): [Impact-based early warning of mass movements – A dynamic spatial modelling approach for the Alpine region](#). EGUsphere.

2.2 IDENTIFYING AND PRIORITISING TRANSNATIONAL KEY POLICY GAPS AND ACTION NEEDS

Before useful adaptation options for improving risk management can be formulated, it is necessary to identify the most salient gaps and most promising entry points in existing risk management systems and risk-related policy frameworks. Therefore, to prepare development of the transnational action proposals presented in [CHAPTER 5](#), a thorough and comprehensive analysis of policy gaps related to the identified key risks has been conducted. Relevant gaps relate to limitations, deficiencies, weaknesses or absence of adequate policies, regulations, instruments, governance mechanisms, practices, resources, or data for managing severe risks from weather extremes.

The presence of gaps indicates insufficient levels of preparedness for increasing climate-related risks, reveals needs for action, and guides the setting of adaptation priorities. Policy readiness can be lacking because risk issues are not recognized or not addressed, existing policies are not fit-for-purpose, or actions exist largely on paper only, i.e. implementation on the ground is widely lacking or insufficient.

The analysis of policy gaps in the X-RISK-CC project covered all phases of the disaster risk management cycle and integrated local knowledge about limitations in place-based risk management capacities with strategic gaps in higher-ranking policy frameworks. The transnational key policy gaps in climate risk management are summarized in [CHAPTER 4](#). To arrive at prioritised key policy gaps of transnational relevance, the following main work steps were conducted.



1

Top-down analysis of strategic policy gaps in generic policy frameworks of Alpine countries

- A comprehensive review of relevant literature (available transnational studies, scientific assessment reports, policy studies, expert opinion reports, expert-based policy recommendations) and recent higher-level policy documents of Alpine countries (strategies and plans for climate adaptation and disaster risk management, sectoral policy documents) allowed identification of the

‘known unknowns’, i.e. policy gaps and needs that have already been detected by others. This review focused on the key policy fields of civil protection, disaster risk reduction, natural hazard management, climate change adaptation, spatial planning, protection forest and forest fire risk management.

- Identified gaps and needs were systemically mapped, thematically organised and categorised in structured policy gap repositories. A searchable online tool facilitates their interactive exploration and analysis (**FIGURE 4**).

FIGURE 4: The X-RISK-CC Policy Gap Explorer allows searching and filtering a compilation of almost 500 concrete risk management policy gaps in the Alpine region. The tool is available online at the [CAPA portal](#).



FURTHER READING

→ [X-RISK-CC Online Policy Gap Explorer](#)

→ [Transnational Guidelines for Managing Current and Future Climate Risks Related to Weather Extremes in Alpine Regions](#)

The Guidelines contain an example of a sectoral policy gap repository and a template for mapping policy gaps.

2

Bottom-up analysis of place-based risk management gaps in pilot areas

- Building on the assessment of regional climate-related risks in the project's pilot areas, a series of stakeholder workshops was key to identifying the critical local risk management gaps in a community-based approach (**FIGURES 5 AND 6**). Local gaps and entry points for improvements were identified both related to past extreme events and for plausible event scenarios under future climate change.
- Cross-analysing the findings from all pilot areas allowed identifying commonalities and specific, context-dependent challenges, resulting in a cross-pilot synthesis of risk management gaps based on local knowledge and with relevance for a broad range of Alpine regions.

3

Blending and integrating findings of bottom-up and top-down approaches

- The empirically grounded local gaps were systematically integrated with the generic policy gaps, providing local validation and enriching the policy-oriented gap analysis with real-world experience and practical relevance (**FIGURE 7**). The junction where low local preparedness levels meet upon strategic policy gaps indicates urgent needs for action. The resulting policy gap inventory spans across multiple levels of governance, reveals need for multi-level collaboration, and indicates policy entry points at different levels of risk ownership.
- In turn, the policy-oriented top-down gap repositories helped partners at pilot area level to detect 'blind spots', avoid biases that might otherwise have gone unnoticed and align development of their local solutions with higher-level support.



FIGURE 5: Stakeholders discussing experiences during past extreme events at workshop in the pilot area Stubai Valley (© WLV).



FIGURE 6: Stakeholders identifying gaps and challenges at workshop in the pilot area Gorenjska – Sora Catchment (© Sora Development Agency Archive).



FURTHER READING

- *X-RISK-CC Pilot Dossiers*: The dossiers about climate-related risk management in the X-RISK-CC pilot areas include concise compilations of the identified local risk management gaps per phase of the disaster risk management cycle.

- at [project website](#)
- CAPA: [Managing climate risks from weather extremes](#)

Integrating local gaps



Examples (natural hazard management)

Cluster topic	Local gaps	Former generic gap issue	Integrated / New generic gap issue	Category
Early warning, forecasting and alert systems	<p>Improving predictions for smaller torrents, for rainfall intensity and location of thunderstorms, and for strong winds. Warning maps need increased spatial resolution to provide more precise data (e.g. flow rates of smaller torrents) for local response forces.</p> <p>Improving predictions for smaller torrents, for rainfall intensity and location of thunderstorms, and for strong winds. Warning maps need increased spatial resolution to provide more precise data (e.g. flow rates of smaller torrents) for local response forces.</p>	Improving accuracy and reliability of event predictions	Missing or limited accuracy of predictions for small-scale events, including in particular for precipitation in mountainous terrain. Improving accuracy and reliability of event predictions, in particular for smaller torrents, rainfall intensity and location of thunderstorms, rainstorm cells, strong winds, and peak discharges. Warning maps need increased spatial resolution to provide more precise data (e.g. flow rates of smaller torrents) and spatially explicit warnings with high positional accuracy for local response forces, e.g. to enhance road safety.	Gap aspect added, concretized or confirmed by pilot areas



FIGURE 7: Example of integrating local and generic gap issues (© EAA).

4

Clustering, compacting, and pre-selecting key policy gaps

→ In interactive workshops with project partners (FIGURES 8 AND 9), the initial comprehensive inventory of policy gaps and needs was compacted, narrowed down, and evaluated for urgency, transnational relevance, effectiveness and feasibility.

→ Building on group-based expert judgments, this prioritisation resulted in a workable set of preliminary key policy gaps cutting across the stages of the disaster risk management cycle and requiring action at trans-Alpine scale while linking to local realities, providing the basis for developing transnational action proposals.



FIGURE 8: Project partners discussing transalpine key policy gaps during 5th partner meeting in Vienna (© EAA).

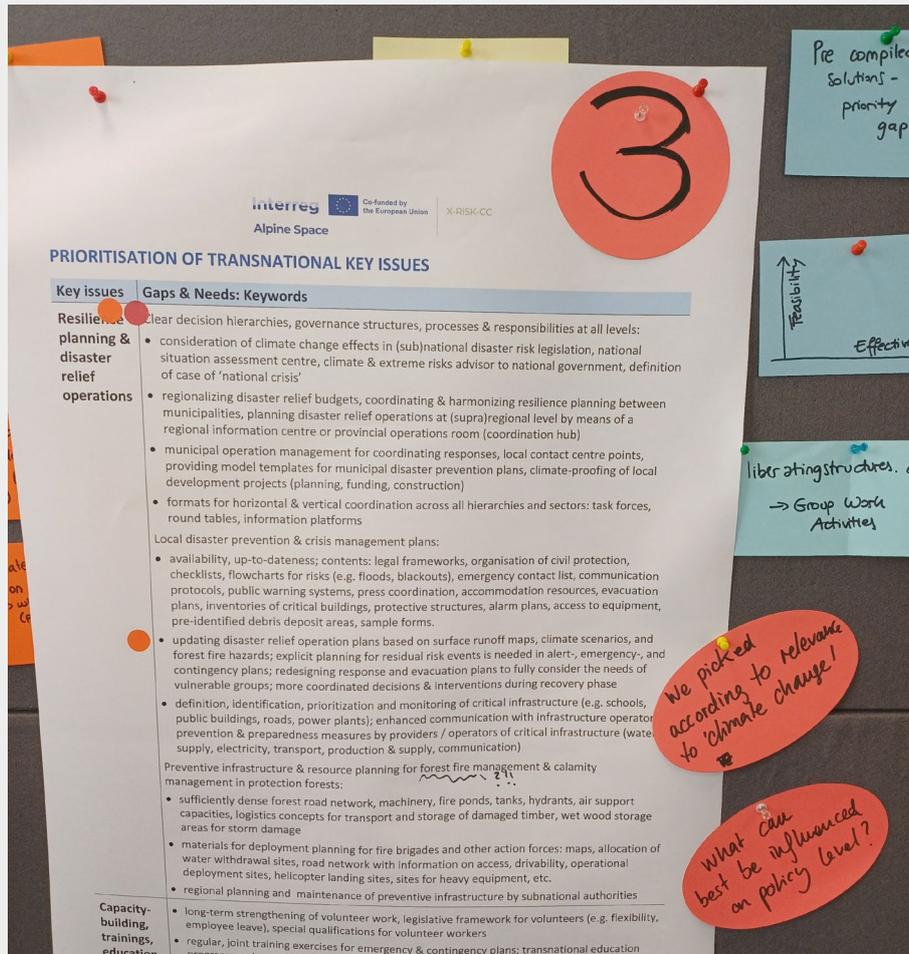


FIGURE 9: Prioritisation of transalpine key policy gaps at 5th partner meeting in Vienna (© EAA)



FURTHER READING

→ CAPA: [Transnational Guidelines for Managing Current and Future Climate Risks Related to Weather Extremes in Alpine Regions](#)

The Guidelines give process-based guidance to regional risk management actors on how to conduct all steps of a layered risk management gap analysis. The document also contains the complete list of preliminary key policy gaps, as prioritised by the project.



2.3 DEVELOPING AND PRIORITISING TRANSNATIONAL ACTION PROPOSALS

Knowledge of climate-related key risks and salient policy gaps allowed developing adaptation and risk management pathways that adequately and effectively respond to the identified risks, gaps, and

corresponding demands. Co-development with transnational experts was crucial to arrive at a set of policy-relevant action proposals that reflect joint perceptions of urgency, feasibility, and effectiveness. Deriving the transnational action proposals presented in **CHAPTER 5** involved the following main steps:

- 1 Formulating emerging action proposals**

 - Adaptation options for the priority policy gaps were identified, bundled into portfolios of measures and elaborated into draft action proposals per key gap.
- 2 Co-development and prioritisation of action proposals with transnational experts**

 - The extended catalogue of emerging action proposals was evaluated, refined, and prioritised in two joint expert workshops with transnational working bodies of EUSALP (Action Group 8) and the Alpine Convention (Alpine Climate Board, PLANALP) (**FIGURES 10 AND 11**). Apart from urgency (due to severity of risk and low preparedness), effectiveness and feasibility, the review and prioritisation of participants was guided by a set of relevance criteria (see box below) to ensure robust, actionable options for improving integrated risk management under climate change in the Alps.
- 3 Full elaboration of prioritised draft action proposals**

 - Participatory prioritisation by means of group-based expert judgments resulted in selection of a limited number of draft action proposals addressing the most pressing policy gaps and judged as most relevant across the Alpine region.
 - Adhering to the outcome of the prioritisation process, the twelve top-ranked policy recommendations were fully elaborated into structured transnational action proposals. They encompass strategic pathways and portfolios of operational measures bundled into recommended courses of actions, addressing all stages of the DRM cycle. The transnational action proposals for managing climate risks of weather extremes in the Alps are presented in **CHAPTER 5**.



CRITERIA FOR PRIORITISING TRANSNATIONAL ACTION PROPOSALS

- Transnational relevance across Alpine regions (*similarly relevant in most regions; requiring cross-border cooperation; benefitting from transnational knowledge exchange and agency of transnational actors*)
- Relevance under future climate change (*future-oriented, anticipatory, preventive risk management*)
- Multi-level governance and multi-stakeholder engagement needed (*shared risk ownership; cannot be solved by one level alone*)
- Addressing systemic issues with transformative potential, avoiding maladaptation
- Targeting multi-hazard, multi-risk issues
- Coverage of all phases of the DRM cycle (*from prevention to recovery*)



FIGURE 10: Members of the Alpine Climate Board reviewing and prioritising action proposals at joint transnational expert workshop (© EAA).



FIGURE 11: Working online with concept board at the joint transnational expert workshop with EUSALP AG8 and PLANALP (© EAA).

3. WEATHER EXTREMES AND CLIMATE-RELATED RISKS IN THE ALPS



The Alpine region is increasingly exposed to complex and cascading climate-related risks, driven by changes in frequency, intensity and spatial occurrence of hazard processes. Most often triggered by intensifying weather extremes, hazards like storms, floods, droughts, landslides, debris flows, forest disturbances, and wildfires interact across the natural environment, economic sectors and borders, creating severe pressures on communities, ecosystems, infrastructures, and economies.

To provide a knowledge base for adapting the future management of risk from weather extremes to climate change, the X-RISK-CC project has investigated past and future weather extremes, hazards, and risk pathways on both local and Alps-wide scale, contributing to a deeper understanding of extreme weather events, their often unexpected consequences, and possible solutions. This has provided novel data and insights focussing on Alpine territories, while the results align with overall findings of recent European and Alps-wide scientific assessments.

Scientific evidence from major international assessments

Major scientific assessments, such as the the IPCC's Sixth Assessment Report (AR6), the first European Climate Risk Assessment (EUCRA), and the 2nd Austrian Assessment Report on Climate Change (AAR2), have previously highlighted the role of weather extremes in creating a shifting and increasingly complex risk landscape.

Europe is warming faster than any other continent, and temperature increases in the Alpine region surpass the European average. At the same time, the Sixth IPCC Assessment Report²² (2022) concludes that adaptation in Europe is not happening at the scale, depth and speed needed to avoid the resulting risks, highlighting, e.g., flood risk management, critical infrastructure and forests. Many of the major climate risks assessed as severe and needing urgent action by the first European Climate Risk Assessment (EUCRA)²³ are closely connected to increasing weather extremes, such as heavy precipitation, drought and heatwaves, which are likely to intensify hazards like riverine and pluvial flooding, wildfires, and forest disturbances, causing growing and cascading risk to populations, ecosystems, the built environment, infrastructure and services, economy and the finance system. EUCRA has found that a range of climate risks have already reached critical severity levels and could approach catastrophic levels by the end of this century, if decisive action is not taken now.

In its chapter on the Alps, the 2nd Austrian Assessment Report on Climate Change (AAR2)²⁴ provides strong evidence that a range of natural hazards in the Alpine region will become more frequent and more intense in the future, such as wildfire and river floods, torrential flooding and pluvial flooding. Expected changes in the components of the hydrological cycle as the main driver of slope failure will facilitate the occurrence of landslides. This will affect alpine communities by causing major economic losses, specifically as the built environment and land use expand, and it will affect the transport infrastructure and



services, and thus the accessibility of mountain communities, and it may interrupt pan-European transport routes. The AAR2 thus clearly states that changes in the frequency and intensity of natural hazards in the Alps must be considered in order to adapt to climate change, emphasizing that the risk to natural hazards is subject to change also due to increased exposure and vulnerability dynamics.

Past and current weather extremes in pilot areas

Recent experiences in the pilot areas of the X-RISK-CC project (see **FIGURE 12**) illustrate this new reality. In *Gorenjska* (Slovenia), recurrent droughts,

often compounding with summerly heatwaves, are causing stress, degradation and fire risk to forest ecosystems, losses of agricultural crop yields, and local drinking water shortages, while simultaneously reducing the ability of landscapes to absorb flash floods, resulting, e.g., in the heavy 2023 floods in the *Sora Catchment* and compounding landslide events. In *Garmisch-Partenkirchen* (Germany), *Stubai Valley* (Austria) and *Fleres Valley* (Italy), increasingly heavy rainfall, often connected to large storm events with long-term extreme precipitation or consecutive episodes of short-duration rainfall extremes, interacts with unstable slopes and increased sediment availability, causing landslides and debris flows that damage settlements, transport routes, and other infrastructure. In *Ega/Carezza Valley* and in *Fiemme*

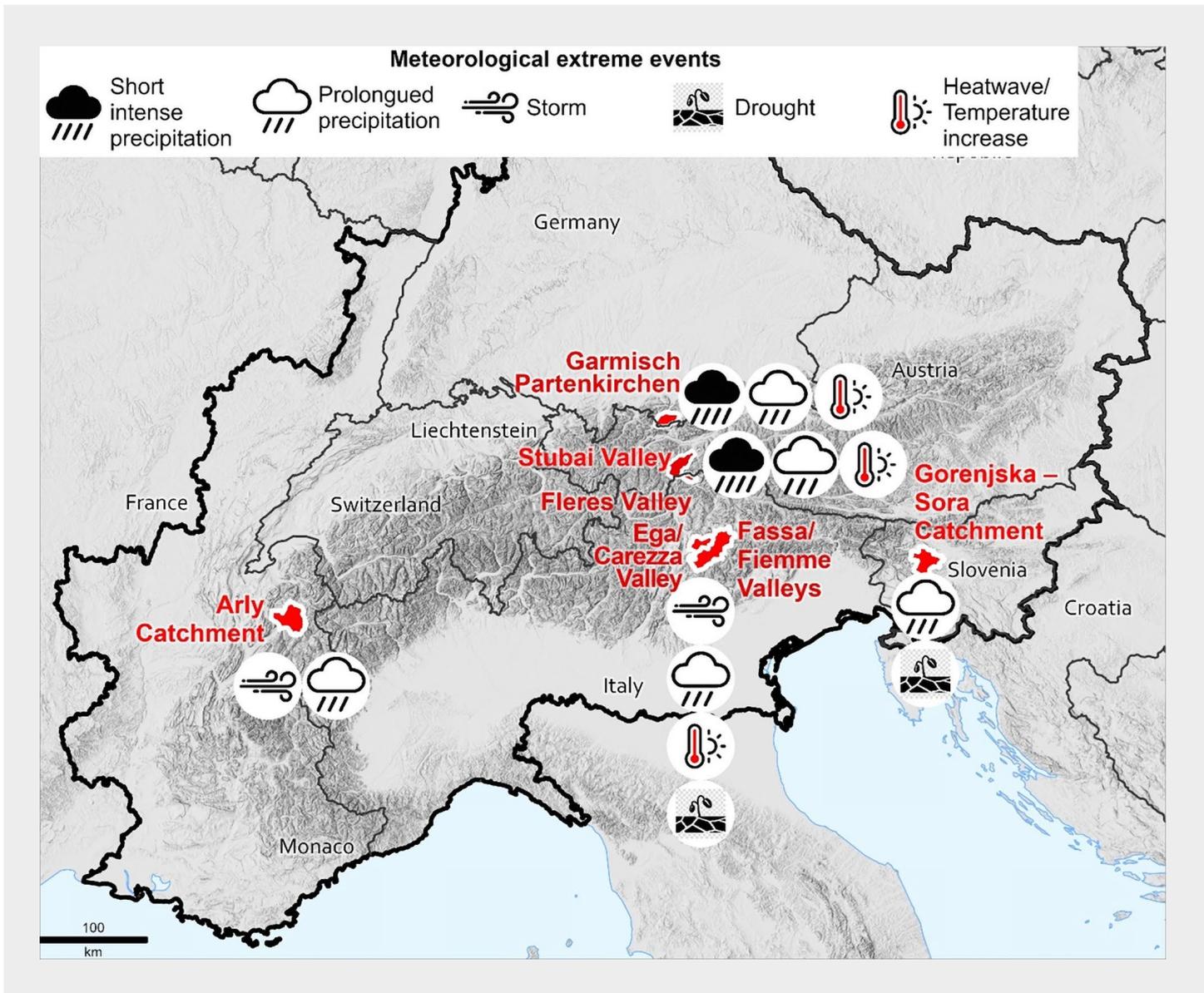


FIGURE 12: Locations of past weather extremes that overstrained existing risk management systems in the pilot areas of the X-RISK-CC project (© X-RISK-CC, 2025).

and Fassa Valleys (Italy), windthrow followed by high rainfall intensities has led to cascading landslide and flood events as well as to large-scale bark beetle infestations in the following years. In the Arly Catchment (France), storms with extremely high wind speeds, intense rainfall and rain-on-snow episodes have caused gravitational mass movements, river floods and torrential flooding, overloading available protection systems. Across all pilot areas, a variety of often compounding and cascading hazard processes and impacts triggered by meteorological extremes has repeatedly claimed human fatalities, caused severe damage to settlements and critical infrastructure, and resulted in significant economic losses. These dynamics demonstrate the limits of single-hazard approaches in risk management and highlight the urgency of shifting towards integrated, more preventive and cross-border approaches to managing climate-related risks from extreme weather events.

Future weather extremes in the Alpine region

The climate model simulations analysed in the X-RISK-CC project for the entire Alpine region project future changes in the frequency and intensity of weather extremes, with variations depending on the phenomenon considered and the level of global warming reached.

Increasing temperatures will cause more frequent and intense heatwaves across the entire Alpine region already in near-future scenarios, i.e. under a global warming of + 1.5 °C to + 2 °C with respect to the pre-industrial period (**FIGURE 13**). Warmer conditions will also lead to more frequent and intense drought episodes. This increasing trend is particularly pronounced in the south-western Alps and will affect all Alpine countries after the 2050s. Heatwaves occurring in conjunction with drought are projected to become more likely everywhere over future decades.

As regards precipitation, an overall tendency towards more intense and frequent precipitation extremes is detected, with the magnitude of these changes varying across the Alpine region. The most pronounced intensification in 1-day and 3-day annual precipitation maxima is projected for the regions north of the main Alpine ridge, but more than 60 % of the Alpine region is likely to experience an increase of extreme precipitation until 2100 (**FIGURE 14**). Precipitation events of shorter duration (e.g., during thunderstorms) can also intensify especially over the Alpine ridge; however, the signal is less clear and associated to a larger uncertainty. No clear changes in future extreme wind speed events are detected. However, with more intense and frequent precipitation extremes, the likelihood of experiencing extreme precipitation events in conjunction with windstorms will also increase in most parts of the Alpine region.

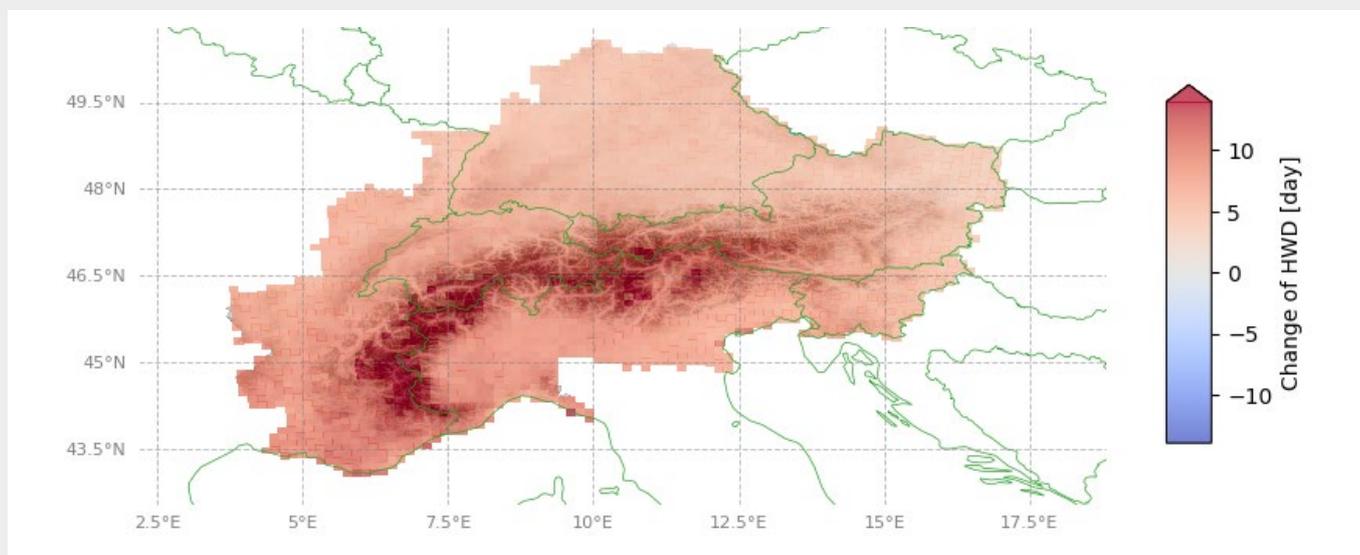


FIGURE 13: Projected changes in the annual frequency of heatwave days (HWD) with respect to present-day conditions (1991-2020) if a global warming of + 2 °C is reached. Future increases emerge for the entire Alpine Space, reaching up to 15 extra heatwave days in a year over parts of the Alpine ridge (© X-RISK-CC, 2025).

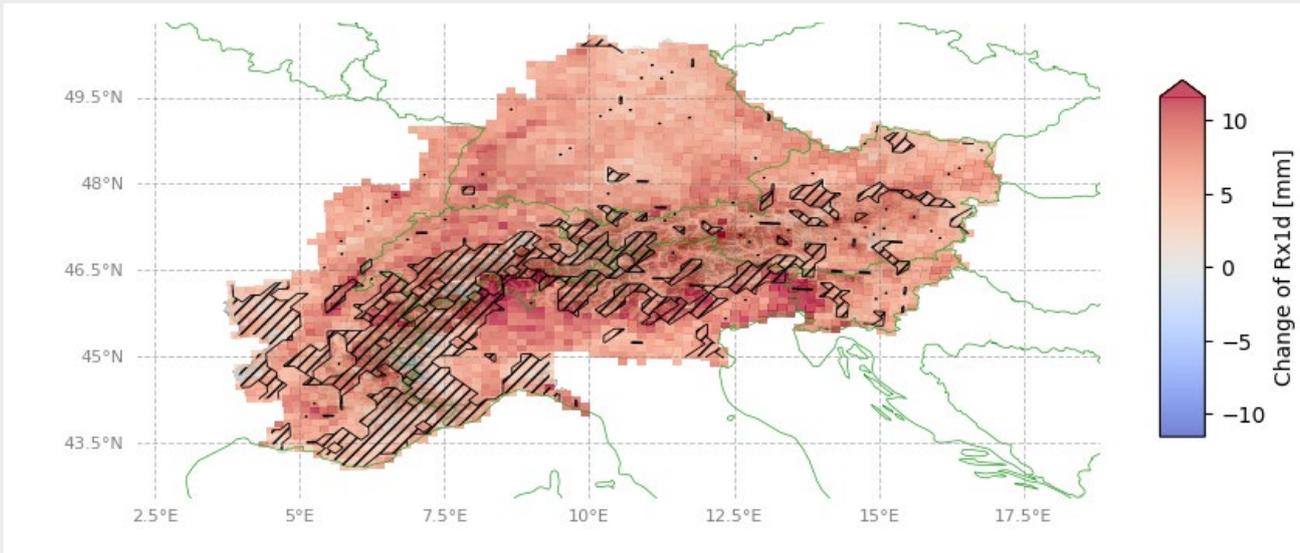


FIGURE 14: Projected changes in the annual maxima of 1-day precipitation ($Rx1d$) with respect to present-day conditions (1991-2020) if a global warming of $+4\text{ }^{\circ}\text{C}$ is reached. Future increases emerge for most of the Alpine Space, with no clear patterns for some areas mostly located in the southern Alps (hatched areas in the map) (© X-RISK-CC, 2025).

The examples of the *Stubai Valley* (Austria) and the bordering *Fleres Valley* (Italy) illustrate what the projected increases in the intensity and frequency of one-day precipitation extremes, both annually and during summer, can mean at local level. Under a $+4^{\circ}\text{C}$ global warming scenario, the intensity of one-day precipitation events is projected to increase by approximately 15 % across the region compared to current values. The frequency of such events could rise up to 46 % in the *Fleres Valley* and 23 % in the *Stubai Valley*. Return levels for rare events (e.g., 50-year events) are expected to increase by 20–28 %. Furthermore, the intensity of short-duration precipitation extremes is projected to rise substantially. With a $+4^{\circ}\text{C}$ warming, the 99th percentile of hourly precipitation could become three times as intense as today.

Future hazards and risks in the Alpine region

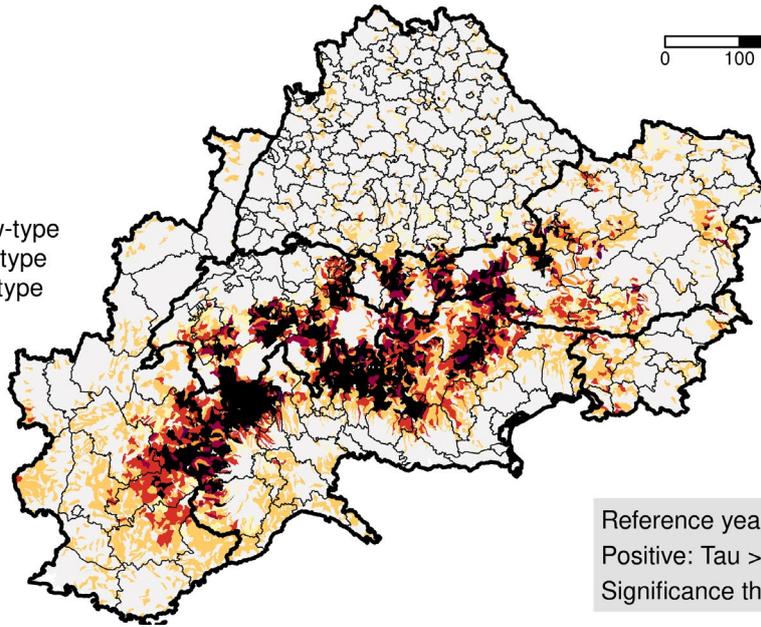
Impact models were used in the X-RISK-CC project to investigate which regions of the Alpine Space experienced significant changes in the frequency of potential mass movement impact events between

2005 and 2021 due to meteorological drivers, such as temperature, short-term precipitation and antecedent precipitation. Regions affected by an increase include northern Italy, western Austria, the French Alps, and much of southern and eastern Switzerland (**FIGURE 15**). Negative trends are less common, but examples exist in the Black Forest in Germany and eastern Austria. Further research is needed to confirm whether these changes are indeed linked to a significant change in the climate signal (e.g., changes in the frequency and magnitude of events). However, initial analyses showed strong seasonal effects, with positive changes during the autumn and winter months, in contrast to negative trends during the spring and summer months.

Local analyses performed in the X-RISK-CC project highlighted a range of risk drivers that are common to several of the pilot areas. Across the Alpine Space, emerging hazards, such as droughts, heatwaves and wildfires, and their compound effects have the potential to severely impact population and irreversibly change ecological systems. Preparedness for dealing with emerging hazards is often low due to inexperience and stresses the need for cross-Alpine collaboration with regards to knowledge exchange and learning.



Positive trend
(Tau & OR agree)



Reference years: 2005 to 2021
Positive: Tau > 0 & OR > 1
Significance threshold: p-value ≤ 0.05

FIGURE 15: Areas in the Alps with an increase of potential impact events from mass movement process types 'slides', 'flows' and 'falls' for three mass movement models for the period 2005-2021. Black areas indicate where the potential impacts from all considered hazard process types have increased (© X-RISK-CC, 2025).

It was confirmed locally that mass movement processes have been increasing in frequency and magnitude and should be expected to increase further due to more intense and frequent precipitation as well as expected changes in preconditions, such as loss of protective forests and increases in sediment availability. Considering the investigated positive trends in potential mass movement impacts, many regions in the Alpine Region should prepare for continuous intensification of mass movements. Local analyses confirm that while new development is restricted in most critical hazard zones (as defined per local hazard mapping), significant infrastructure is currently located in lower hazard zones. Under future climate conditions, frequent and intense hazards are expected to extend beyond what is currently defined as the most critical hazard zone, resulting in higher future exposure.

Many pilot regions report vulnerability of people due to demographic changes or increases in tourism as

important risk drivers. Additionally, the question of how to address the increasing residual risk to people and built environment stemming from ageing and difficult to maintain protection infrastructure remains a challenge. Promoting adaptation and learning and changing of business-as-usual practices are powerful tools in meeting the challenges of climate change adaptation in the Alpine region. The understanding of current and future climate-related risks from weather extremes is essential for risk management. X-RISK-CC has shown that raising awareness of risk managers and decision makers for the impacts of climate change on natural hazards and their cascading effects within ecological and socioeconomic systems is a crucial step. Adjustments and, to some extent, transformative changes of risk management practices and policy frameworks will be needed to address the challenges associated with growing climate-related risks, maintain acceptable risk levels, and safeguard resilient and sustainable development of the Alpine region.



4. TRANSNATIONAL KEY POLICY GAPS IN CLIMATE RISK MANAGEMENT



The X-RISK-CC project has found that current risk management approaches remain insufficiently equipped to manage intensifying, cascading and compound risks under climate change, leading to transnational policy gaps in climate risk management manifesting across all phases of the disaster risk management cycle. While in general traditions of cooperation in the Alpine region are comparatively well developed, regulatory, planning and governance systems remain diverse, fragmented and insufficiently adapted to the scale and complexity of increasing climate-related weather extremes and consequential risks. Recurring gaps identified by the project include fragmented governance, lacking provisions in regulatory frameworks, incoherent policy designs, lack of knowledge, individual risk awareness and self-responsible action, insufficient preparedness and response capacities, limited post-event learning, and uneven use of scientific knowledge as well as limited integration of climate change, cascading dynamics and transboundary dimensions into risk assessments

and risk management decisions. Taken together, these findings underscore that climate change is not only intensifying the Alpine risk landscape but also exposing systemic weaknesses, from growing risk exposure due to expansion of spatial development and narrowly framed hazard assessments to gaps in early warning systems and risk-reinforcing recovery practices.

The following table (**TABLE 1**) summarizes the most salient policy gaps identified across the DRM cycle and addressed by the transnational action proposals in **CHAPTER 5**. The key policy gaps presented below are organized by thematic clusters and illustrated by exemplary evidence from X-RISK-CC pilot areas. Further context information on these policy gaps is provided in **CHAPTER 5** for each transnational action proposal. The headers flag each gap theme with an icon, allocate it to phases of the risk management cycle, and cross-reference the action proposals addressing them.

	Phase of DRM cycle: <i>PREVENTION</i>	Action proposals: 1 2 3
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PREVENTIVE SPATIAL PLANNING AND NATURE-BASED SOLUTIONS

Key policy gaps

- Underused potentials of green and blue infrastructure for nature-based risk reduction due to underdeveloped planning frameworks and lacking inter-municipal cooperation models
- Failure of spatial planning in containing constant growth of risk exposure due to excessive land take and weak legal integration of hazard maps in spatial planning regulations and building codes
- Regulatory gaps for prevention of risks from pluvial flooding in settlement areas

Evidence from pilot areas

Stakeholders highlighted that passive and nature-based risk prevention measures remain underdeveloped. Protective forests, open spaces, and green and blue infrastructure, including wetlands and floodplains, provide well-documented ecosystem services for adaptation and hazard protection as well as multiple co-benefits, but are not consistently harnessed by spatial planning, especially in fragmented cross-border contexts. Pilot areas such as the *Fiemme and Fassa Valleys* illustrate how forest degradation, accelerated by drought and bark beetle infestations, undermines protective forest functions and generates cascading risks, and in the *Arly Catchment* the need for creating flood diversion and expansion areas is recognized. At the same time, weak enforcement of land-saving, compact, risk-sensitive settlement development constantly increases risk exposure, and existing hazard zone maps tend to lack binding legal force on land-use planning, often allowing continued development in hazard zones and reinforcing exposure.



Phase of DRM cycle: **PREVENTION, PREPAREDNESS**

Action proposals:

4

5

HAZARD AND RISK ASSESSMENTS

Key policy gaps

- Restricted hazard-focused approach and limited coverage, depth, data integration, and cross-border alignment of hazard assessments and maps
- Missing consideration of climate change in hazard and risk assessments and in the design of protective infrastructure, resulting in lacking precautionary approaches to cope with dynamic hazard patterns, shifting return intervals and uncertainty

Evidence from pilot areas

Current hazard and risk assessments remain too narrowly focused and insufficiently adapted to evolving climate risks in the Alps. Although hazard maps are widely available across the Alpine Space, they are usually based on historical data about statistical hazard return intervals and single-hazard perspectives, rarely capturing other risk factors, residual risk, hazard interactions, cascading effects or forward-looking and rapidly evolving climate scenarios. Existing approaches fail to inform risk-based decision-making in spatial planning and do hardly support transnational and cross-border assessments. The 2023 floods in the *Sora Catchment (Gorenjska)* and the increased debris-flow activity in *Stubai Valley* and *Fleres Valley* highlight how reliance on historic baselines fails to anticipate intensifying hydrological extremes and sediment dynamics under climate change. Similarly, structural protection measures are not designed with future climate change projections in mind, and methods for parametrising these changes remain unclear, which is likely to leave protective structures in *Fleres Valley*, *Fiemme and Fassa Valleys*, and *Garmisch-Partenkirchen* insufficient to cope with compound occurrence of extreme events in the future.



Phase of DRM cycle: **PREVENTION, PREPAREDNESS, RESPONSE**

Action proposals:

6

9

RISK COMMUNICATION

Key policy gaps

- Lack of individual risk awareness, self-responsible action, and compliance with warnings and civil protection plans among the population
- Lack of knowledge among citizens regarding protection goals and residual risk

Evidence from pilot areas

Residents are often reluctant to take personal responsibility for self-protection and regularly lack the knowledge of what individual preventive actions are available, as has been confirmed in *Gorenjska*, indicating a need for clear and target group-oriented communication. Communication formats often remain generic or inaccessible, particularly in multilingual or mobile contexts, resulting in a lack of knowledge among the public regarding protection goals and residual risk. Tourists, second-home owners, cross-border tourists and other vulnerable groups in the *Fleres Valley* are frequently left without tailored preparedness information. Civil protection plans, warning systems and other non-structural measures are poorly known, e.g. in the *Fiemme and Fassa Valleys*, and memory of past events is limited. In the *Arly Catchment* it was also found that the population remains ill-prepared for crisis situations and is rather unfamiliar with the correct procedures to follow in an incident.

	Phase of DRM cycle: <i>PREPAREDNESS, RESPONSE</i>	Action proposals: 7 8
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FORECASTING, EARLY WARNING AND ALERT

Key policy gaps

- Gaps in real-time, small-scale hazard monitoring, forecasting and now-casting
- Limited cross-border interoperability of monitoring and data standards
- Limited capacities to adequately communicate and act on early warnings

Evidence from pilot areas

Alpine early warning systems are constrained by technical and operational gaps in real-time, local-scale hazard monitoring, impact-based forecasting, and now-casting. Networks and models often lack the resolution needed for short-lead hazards such as flash floods, debris flows or hailstorms, and cross-border interoperability of early warning and forecasting systems is limited. In the *Arly catchment*, for example, storm-induced landslide risks illustrate the need for better real-time monitoring across jurisdictions. Lacking local precision of hydrological forecasts (*Gorenjska*) and warning systems (*Arly Catchment*) and gaps in short-term warnings for fast-moving weather events like thunderstorms (*Fleres Valley*) have been identified as gaps in several pilot areas, while in *Garmisch-Partenkirchen* local response organisations are missing access to information on conditions of bridges or protective structures. Even when warnings are issued, stakeholders pointed out that a ‘last-mile’ gap persists, e.g. in the *Fleres Valley*: alerts are not consistently translated into actionable guidance, and capacities of risk managers and civil protection personnel to adequately communicate and act upon warnings is limited. This indicates a lack of pre-drafted communication strategies for all involved response organisations, particularly in cross-border regions where linguistic and institutional differences hinder coordination.

	Phase of DRM cycle: <i>PREVENTION, PREPAREDNESS, RESPONSE</i>	Action proposals: 8 9
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PREPAREDNESS AND RESPONSE CAPACITIES

Key policy gaps

- Lack of behavioural routines, regular trainings, institutionalized capacity-building, and systematic uptake of new information and learnings
- Limited citizen involvement in resilience planning and risk governance

Evidence from pilot areas

Across pilot areas, training, capacity-building and uptake of new information, including lessons learnt from disaster events, was found to be limited, indicating also untapped potentials for transnational exchange and learning. Stakeholders and citizens are not always aware of their roles and responsibilities as regards prevention and during an unfolding event, and inter-municipal or cross-boundary coordination of response actions suffers from a lack of joint drills. Without systematic joint exercises and cross-border coordination of alerts, emergency services remain ill-prepared for the demands of complex, compounding events. For instance, in the *Arly catchment* standardized training and regular multi-stakeholder simulation exercises are lacking, civil protection plans are not regularly updated and not made operational by field exercises, and stakeholders are partly unfamiliar with protocols, resulting in low levels of collective preparedness. In the *Fleres Valley*, it was recognized that staff turnover and limited systems for retaining and transferring institutional knowledge and technical skills is limiting response capacities.

	Phase of DRM cycle: <i>PREVENTION, RECOVERY</i>	Action proposals: 10
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INSURANCE, DISASTER RECOVERY AND RECONSTRUCTION

Key policy gaps

- Disaster compensation and insurance systems lack incentives for private risk reduction

Evidence from pilot areas

Despite national differences, existing market-based insurance schemes and public damage compensation mechanisms in Alpine countries are not sufficiently used to incentivise private risk reduction and climate-resilient reconstruction but potentially undermine willingness of property owners to take individual risk precaution measures, giving way to maladaptive behaviour. Such a systemic lack of incentives for private risk reduction may contribute to the reported reluctance of citizens in *Gorenjska* to take responsibility for self-protection. In addition, stakeholders noted that insurance and compensation mechanisms seldom embed build-back-better conditions, leading to recovery that reproduces vulnerabilities instead of fostering adaptation.

	Phase of DRM cycle: <i>CROSS-CUTTING</i>	Action proposals: 6 11
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RISK GOVERNANCE

Key policy gaps

- Fragmented governance, missing or unclear responsibilities, and lack of vertical and horizontal coordination within and across Alpine countries

Evidence from pilot areas

The governance of climate-driven risks within and across Alpine countries remains structurally fragmented, often lacking clear responsibilities, effective vertical coordination and cross-sectoral collaboration to overcome policy silos, thus hampering joint action, even as climate-induced hazards transcend borders and intensify with cascading effects. Stakeholders underlined that fragmented risk governance undermines effective disaster preparedness and response across jurisdictions in the Alpine region. Cascading events, such as combined floods and gravitational hazards observed in *Gorenjska* and *Fleres Valley*, cannot be managed adequately under current frameworks, and cross-border coordination platforms are largely absent. Obstacles related to lacking coordination across sectors, territorial levels, and neighbouring municipalities have been identified across pilot areas. E.g., critical gaps in the *Fleres Valley* affect large-scale, multi-valley events, where coordination capacity is exceeded and mutual aid mechanisms remain undefined, and the need for better structured coordination between individual municipalities and the provincial crisis centre. Effective emergency response requires unified command with clear decision-making authority across all responding organisations, including in cross-border settings.



Phase of DRM cycle: **RECOVERY,
PREVENTION**

Action proposals:

12

POST-EVENT LEARNING AND ADAPTIVE CAPACITY-BUILDING

Key policy gaps

- Lack of systematic post-event documentation, analysis, debriefing, learning, and climate-resilient reconstruction.
- Missed opportunities for transforming outdated risk management approaches

Evidence from pilot areas

Several pilot areas identified a wide-spread lack of systematic, structured and standardized mechanisms for learning from disaster events, leading to missed opportunities for more climate-resilient recovery, reconstruction and reorganisation of risk management approaches. Relevant gaps relate to fragmented and incomplete documentation and post-analysis of events and losses, irregular debriefings with limited stakeholder involvement, and missing transboundary stakeholder roundtables with operational lessons-learned protocols that could guide improvement of risk management measures. Civil protection plans and hazard maps are rarely updated to reflect shifting return periods or cascading interactions, creating blind spots for planning. Recurrent smaller events, such as flash floods in the Partnach Gorge (*Garmisch-Partenkirchen*), debris flows in the *Stubai Valley* or storm-triggered landslides in the *Arly Catchment*, are only documented locally, limiting cumulative loss assessment and adaptive learning. Stakeholders also stressed that reconstruction often reinforces rather than reduces hazard exposure in the Alpine space, especially when private risk reduction and climate-resilient reconstruction are not enforced or underemphasised. Settlements are often rebuilt in high-risk zones, creating vulnerability lock-ins. After the *Vaia* storm in *Fiemme and Fassa Valleys*, for instance, salvage logging and rapid rebuilding missed opportunities to integrate resilience, while divergent standards across Alpine countries continue to hinder the diffusion of climate-resilient practices.

TABLE 1: Summary of transalpine key policy gaps identified across the disaster risk management cycle, illustrated with exemplary evidence from pilot areas and cross-references to action proposals addressing the respective gaps.



The following **FIGURE 16** illustrates the positions of the transnational key policy gaps, as listed in **TABLE 1** above, along the phases of the iterative DRM cycle.



FIGURE 16: Transalpine key policy gaps along the disaster risk management (DRM) cycle.

5. TRANSNATIONAL ACTION PROPOSALS FOR MANAGING CLIMATE-RELATED RISKS OF WEATHER EXTREMES IN THE ALPS



5.1 PRELIMINARY REMARKS

The following section presents the transnational action proposals for enhancing the climate risk management of increasing extreme weather events, compound impacts and cascading risks in the Alpine region. Responding to prioritised key policy gaps and corresponding action needs, they highlight opportunities and recommend strategic solution pathways for improving risk preparedness and enhancing resilience of Alpine territories to intensifying weather extremes under climate change.

The transnational action proposals are characterised by several common features:

- **Transnational relevance:** The recommended actions address policy gaps and action needs that are similarly relevant and urgent across most Alpine territories. Many issues addressed have transboundary dimensions, such as border-crossing hazards and impacts affecting shared resources (e.g., river basins and catchment areas) and assets (e.g., cross-border transport infrastructure). In many cases, implementation of proposed actions thus requires cooperation across national jurisdictions, benefits from trans-Alpine learning and agency by transnational actors, and aims at creating transnational added value.
- **Roles of transnational actors:** Actors operating at transnational Alpine level have important roles in facilitating solutions for climate risk management. Future fields of transnational cooperation and opportunities of transnational cooperation structures (EUSALP, Alpine Convention), working bodies (e.g., AG8, Alpine Climate Board, PLANALP) and funding programmes (Alpine Space

Programme, bilateral Interreg programmes) for contributing to specific policy options are thus highlighted for each action proposal.

- **Collaborative risk ownership:** Risk owners are persons, institutions or other entities responsible for managing hazards, exposure, vulnerabilities and resulting risk. While the transnational action proposals address primarily policy makers at higher-ranking levels of government and governance, full implementation relies on co-owned responsibilities, shared across multiple policy sectors and levels and building on coordination and cooperation. While natural hazard and flood risk management, civil protection and disaster risk management have a lead role in risk management, other policy fields like climate adaptation, spatial planning and territorial development, forest management, drought management, insurance and damage compensation regularly need to collaborate in the frame of integrated risk governance. The most relevant policy fields are highlighted in the headers of each action proposal. Assigning an individual risk owner is often not possible for climate-related risks, given the complex systemic nature of cascading effects that can spread from one system, sector and scale to another. Climate risk management thus requires a whole-of-government and whole-of-society approach. While competences and responsibilities are organised differently under the various Alpine jurisdictions, actors at distinct levels will typically have distinguishable roles in implementing the action proposals: national and subnational authorities provide regulations, strategic guidance, resources, enabling framework conditions, and



supportive governance frameworks; regional and local authorities and civil protection actors lead on-the-ground measures; scientific and technical institutions support with data, expertise, methods and tools; transnational bodies facilitate harmonization, coordination and knowledge exchange across jurisdictions; and local communities and private actors contribute through individual prevention measures, early warning adherence and post-event learning. The different roles of actors at different levels are outlined in an indicative way for each action proposal.

→ **Alignment with local pilot actions:**

The X-RISK-CC pilot areas have developed [tailored local action plans](#) for upgrading their risk management systems. In line with the multi-level, collaborative nature of risk governance, many of the transnational action proposals align with these local actions by addressing the need for higher-level support and for establishing the necessary framework conditions.

→ **Coverage of the entire risk management cycle:**

Overall, the twelve action proposals address and cut across all stages of the iterative DRM cycle, often connecting two or several of its overlapping phases, i.e. prevention, preparedness, response, and recovery. These entry points into the DRM cycle are flagged in the profile at the heading of each action proposal.

→ **Emerging climate risks:** The X-RISK-CC project put a particular focus on typically Alpine natural hazards triggered by meteorological extremes, but it has also investigated risks related to heat waves, droughts, forests (loss of protective forest functions, forest fire), and pluvial flooding, which may to some extent still be considered as emerging climate risks in the Alpine region. While these types of risks are not directly addressed by dedicated action proposals, they have been integrated transversally into the bundles of measures of most action proposals.

→ **Broad portfolios of policy options:**

Each action proposal comprises a bundle of strategic directions and operational measures targeted at achieving the same objective and responding to the identified key policy gap. These portfolios of measures outline implementation pathways covering a broad range of action types, such as actions related to data and knowledge, capacity-building and training, legislation and regulations, planning and management, insurance and risk-sharing, nature-based solutions, and technical or structural measures. The types of action employed by the action proposals are listed in their headers. Overall, the policy mixes encompass green, grey, soft, and hybrid measures, address different dimensions of climate-related risk (hazards, exposure, vulnerability, adaptive capacity, underlying risk drivers), and combine incremental with more transformative pathways. Applying a broad mix of suitable measures is essential to account for the systemic nature of climate-related risks.

→ **Focus on non-structural measures:** As a result of expert-based and participatory priority-setting, coverage of the transnational policy recommendations is by nature non-exhaustive and selective. Consequently, some potential fields of action received less emphasis than others. For instance, there is no dedicated action proposal on adaptation of structural hazard protection measures, although aspects related to technical protection infrastructure have been incorporated in specific recommendations. This does not suggest that *structural measures* are less important for managing risks in the Alpine region but rather reflects the X-RISK-CC project's focus on *non-structural* risk prevention and the preparedness, response and recovery phases of risk management. This is, *inter alia*, because it is inherently difficult to manage extreme events of exceptional magnitude and related compound and cascading risks with technical protection structures.



5.2 PRESENTATION OF TRANSNATIONAL ACTION PROPOSALS

TABLE 2 gives an overview of the elaborated transnational action proposals, listing them by title and indicating their points of intervention in the risk management cycle.

In the following, the twelve action proposals are presented in detail, structured into their objectives, desired outcome, relevance, the policy gaps they address, the risk ownership required at different levels, and the recommended courses of action.

No	Action proposal: title	DRM cycle
1	Prioritize Nature-based Solutions for climate risk management and give preference to passive risk prevention strategies	<i>PREVENTION</i>
2	Enforce compact, land-saving and climate-resilient settlement development to contain risk exposure	<i>PREVENTION</i>
3	Strengthen legal coupling of hazard zone planning with spatial planning and local land use decisions	<i>PREVENTION</i>
4	Advance from hazard mapping to integrated risk assessments to support effective, risk-based prevention and preparedness strategies	<i>PREVENTION PREPAREDNESS</i>
5	Integrate climate change impacts into forward-looking hazard and risk assessments and establish a precautionary approach	<i>PREVENTION PREPAREDNESS</i>
6	Launch target group-oriented climate risk communication strategies for more risk-aware and better prepared Alpine communities	<i>PREVENTION PREPAREDNESS RESPONSE</i>
7	Expand localized, real-time hazard monitoring, early-warning and now-casting capabilities with improved spatial and temporal accuracy and interoperability across borders and scales	<i>PREPAREDNESS RESPONSE</i>
8	Strengthen operational linkages between early warnings and management of local responses	<i>PREPAREDNESS RESPONSE</i>
9	Strengthen preparedness and response capacities by institutionalizing knowledge exchange, learning and citizen involvement	<i>PREVENTION PREPAREDNESS RESPONSE</i>
10	Reform insurance and damage compensation systems to foster private risk reduction and climate-resilient reconstruction	<i>PREVENTION RECOVERY</i>
11	Shape an integrated multi-level climate risk governance framework for Alpine territories	<i>CROSS-CUTTING</i>
12	Establish systematic post-event learning and more resilient recovery in the Alpine region	<i>RECOVERY PREVENTION</i>

TABLE 2: List of transnational action proposals and their position in the risk management cycle

1

Prioritise Nature-based Solutions for climate risk management and give preference to passive risk prevention strategies



Topic

- Preventive spatial planning
- Nature-based solutions



Policy field

- Spatial planning
- Natural hazard management



Phase of DRM cycle

- Prevention



Types of action

- Nature-based solutions
- Legislative & regulatory
- Planning & management
- Institutional & organisational



Objective

Increasing resilience to climate-related risks and enabling up-scaling of *Nature-based Solutions (NbS)* by securing spaces for *green and blue infrastructure* and keeping them free of development through preventive spatial planning. Restoring and strengthening the ecosystem-based services of natural areas, such as floodplains, protective forests, wetlands and high-altitude grasslands, by providing harmonised decision support and frameworks for inter-municipal and cross-border cooperation.



Desired outcome

Implementing NbS for climate risk management on larger scales will increase *resilience* and safety of Alpine communities against floods, Alpine natural hazards, droughts, and wildfires, while at the same time delivering multiple co-benefits for biodiversity and human well-being, including public cost savings, as compared to, e.g., the investment needs for construction and maintenance of structural protection measures.



Relevance

Green and blue spaces provide multi-functional ecosystem services for climate adaptation and hazard prevention, such as flood regulation, water retention, rainwater infiltration and groundwater renewal, both on landscape and urban scales. Such NbS are essential for climate-resilient spatial development and deliver multiple co-benefits for biodiversity and society, including recreation. Keeping natural areas free from settlement development also avoids hazard exposure, representing the most cost-efficient strategy for (passive) risk reduction. NbS require sufficient space, which is naturally limited in Alpine environments and increasingly pressured by expanding settlements. Securing areas for green and blue infrastructure demands prioritisation in spatial planning; thus, suitable planning policies and instruments are key for the large-scale NbS implementation. Yet, spatial planning in Alpine countries still centers on the built environment, overlooking ecosystems as active components of climate resilience. This challenge is particularly acute in transboundary contexts, such as shared catchments, where ecosystems and hazard dynamics span jurisdictions, but governance remains fragmented. Deploying NbS in larger areas often requires inter-municipal cooperation and overcoming of conflicts over land provision.



✓ Policy gaps

- Underused potentials of green and blue infrastructure for nature-based risk reduction
- Underdeveloped policy, regulatory and planning framework for preserving 'green spaces' and activating their adaptation functions, including in transboundary contexts.
- Lack of actionable models and frameworks for inter-municipal cooperation on NbS deployment, burden-benefit sharing, and conflict resolution over land rights.

✓ Risk ownership

National and/or subnational planning authorities are responsible for revising relevant regulations in planning laws and (re-)designing planning instruments, while regional planning associations and local governments, in cooperation with sector planning, are tasked with preparing and implementing regional and local spatial plans that are vertically coherent with higher-ranking provisions. Public administration at higher levels has a role in the provisioning of models (legal, organisational, financing) for inter-municipal cooperation and conflict management, while transnational bodies (EUSALP, Alpine Convention) should initiate and organise cross-Alpine knowledge exchange and coordination of transboundary planning efforts.

✓ Recommended courses of action

- Place the pro-active, 'positive planning' of green and blue infrastructure on equal footing with planning the built environment by upvaluing natural areas in planning frameworks and developing more differentiated instruments for landscape planning. Develop and adopt spatial planning instruments for designating and securing (transboundary) open spaces with their multiple ecosystem services for climate adaptation and risk reduction, such as natural areas for flood runoff and retention or controlled emergency relief flooding. Designate priority zones ('precautionary climate areas') for green and blue infrastructure in regional and local planning instruments and enact regulatory measures that restrict zoning, construction and intensive land use within these areas to avoid risk resulting from hazard exposure and safeguard their hazard prevention and drought management functions. Planning and management of border-crossing green and blue infrastructure and their nature-based adaptation benefits, in particular for cascading risks with spill-over effects across borders, requires transboundary collaboration, which can build on existing examples like the RHESI project²⁵.
- Shape political and legal frameworks and funding mechanisms for the restoration of rivers, floodplains, wetlands, protective forests, and other NbS, with the view to developing transnational green and blue infrastructure networks for climate resilience and risk management in the Alpine macro-region. Develop, pilot and roll out models for the mediation and resolution of conflicts over land ownership and land use rights connected to the land demands of NbS and nature restoration projects.
- Introduce and intensify application of local planning instruments (e.g., rainwater management plans for public and private areas, natural drainage areas, minimum shares of climate-active green areas, maximum sealing quotas, de-sealing requirements) for securing and activating small-scale green infrastructure (e.g., decentralised rainwater management, runoff pathways, green spaces and rooftops) to mitigate risks from urban *pluvial flooding*, drought and heatwaves.
- Set up institutional, legal and incentive-based frameworks to enable inter-municipal cooperation on NbS, incl. cross-municipal and transboundary planning instruments and processes and financial compensation mechanisms for balancing uneven distribution of burdens and benefits between municipalities (e.g., land demand for upstream flood retention versus downstream protection benefits).
- Mandate the development of robust and transparent criteria and tools for valuing and prioritizing ecosystem services and risk reduction functions of open spaces and harmonize their application in transboundary contexts.
- Build a pan-Alpine database of NbS solutions, organise transnational peer-to-peer knowledge exchange, incorporate NbS further into work programs of EUSALP and Alpine Convention, and develop a transnational strategy for NbS in the Alps to effectively coordinate efforts across regions and sectors. Building on the findings of recent studies²⁶, institutional working bodies of EUSALP and Alpine Convention should take a key role in up-scaling NbS at transnational level.

2

Enforce compact, land-saving and climate-resilient settlement development to contain risk exposure



Topic

- Preventive spatial planning



Policy field

- Spatial Planning
- Natural Hazard Management



Phase of DRM cycle

- Prevention



Types of action

- Legal & regulatory
- Enforcement & compliance
- Policy design & instruments
- Planning & management



Objective

Limit the expansion and sprawl of built-up areas to contain *exposure* to climate-related hazards and maintain nature-based adaptive capacities.



Desired outcome

Forcing land-efficient, soil-saving, inward-oriented settlement development is a key transformative action field for achieving more sustainable, climate-resilient and risk-sensitive spatial development while shaping climate-friendly settlement structures.



Relevance

The failure of spatial planning to contain growth in *risk exposure* caused by excessive land take, urban sprawl and soil sealing is a main driver of growing climate-related risks. Land take for expanding settlement and transport systems, soil sealing, and urban sprawl are persistent trends with non-sustainable growth rates across the Alps²⁷, often decoupled from population development and exceeding existing land-saving targets in Alpine countries²⁸. The excessive consumption of land causes irreversible loss of scarce, non-renewable soil resources, their multiple functions and life-sustaining ecosystem services, including mitigation of many climate-related risks. Excessive land take and dispersed settlement patterns create spatial structures and mobility systems that are opposed to climate-friendly and

climate-resilient development, acting both as a main source of greenhouse gas emissions and major driver of exposure and vulnerabilities to increasing climate-related hazards, creating growing *residual risk* and damage potentials from unexpected cascading risk scenarios. Due to the longevity of the built environment, planning decisions taken today determine the level of climate-related risks for future generations and can lead to irreversible *path dependencies* and *vulnerability lock-ins*. Related conflicts over competing land use demands are particularly pronounced in mountainous areas, where habitable space is naturally limited, and settlement growth dynamics meet upon climate-driven expansion of hazard zones, thereby making usable and safe land an increasingly scarce resource. Moreover, beyond growing hazard exposure, land consumption reduces *adaptive capacities* and can exacerbate climate impacts by various mechanisms: loss or degradation of ecosystem-based adaptation services of green spaces (e.g., hazard protection, water retention, groundwater storage, cooling spaces and cold air ventilation, climate resilience of biodiversity); escalating cost and growing unfeasibility of structural protection; amplification of *pluvial flooding*, heat and drought stress in urban areas driven by soil sealing; higher vulnerability to wildfires due to splintered settlement patterns, creating fractured wildland-urban interfaces. There is thus an urgent need to redirect spatial planning systems towards forcing compact, inward-oriented, land-saving and risk-sensitive settlement development.



✓ Policy gaps

- Lack of goal-oriented, coordinated, enforceable, consistently implemented, and effective portfolios of measures (spatial planning, financial instruments, cooperation models) to substantially reduce land take, urban sprawl and soil sealing, and thus growth in risk exposure.

✓ Risk ownership

Political will and a *whole-of-state effort* are needed to achieve substantial reductions of land consumption. Revising regulatory frameworks requires action by (*sub*)national governments with jurisdictions in spatial planning and spatially effective financial instruments, while coherent implementation in planning instruments and practices is up to *planning authorities at all levels*. *Municipalities* have own leeway in cooperating at inter-municipal scales, supported by enabling framework conditions set by higher levels.

✓ Recommended courses of action

- Set and enforce politically agreed, binding and quantified reduction targets (upper limits) for new land consumption and soil sealing, concretise (sub)national target values by allocating maximum building land quota at regional level, and embark on pathways towards net-zero land take.
- Strengthen strategic goals related to economical use of land in spatial planning laws, prioritize land conservation in the weighing of interests in planning decisions, and enact restrictive provisions in regional planning instruments with binding effects on local planning. This may include shifting (at least partly) responsibilities for land zoning from municipal to regional levels.
- Introduce, revise and concretise enforceable provisions for reducing land take, sealing and urban sprawl in planning laws and instruments, designing effective and feasible portfolios of 'stop' (for outward-oriented development) and 'go' (for inward-oriented development) measures, which may include:
 - Outer settlement boundaries; restrictive criteria for zoning of building plots, and mandatory connection of new building land and commercial zones to existing settlements;
 - Re-zoning of over-dimensioned building land reserves, particularly if vacant building plots are located in functional flood management areas, hazard zones, *residual risk* areas, and in dispersed locations contributing to urban sprawl; obligatory compensation of land take on green fields, e.g., by re-zoning building land reserves at other locations or active de-sealing;
 - Prioritising the re-use of brownfield sites and vacant buildings, and mobilising designated, but unused building land, while requiring minimum building densities and land-efficient forms of building design;
- Provisions for forest fire-sensitive settlement planning, aiming at compact settlements with clear outer boundaries to disentangle the wildland-urban-interface;
- Provisions in planning laws and instruments for avoiding soil sealing and promoting de-sealing (e.g., sealing bans, de-sealing commandments).
- Adjust financial instruments to reinforce steering effects on land use and soil protection:
 - Re-design national fiscal transfer scheme to incentivise land use sufficiency; introduce inter-municipal fiscal transfers to reward soil-saving policies;
 - Introduce or recalibrate soil-related taxes, zoning fees, sealing fees, and fees for secondary homes or vacant properties, and integrate these fiscal instruments into broader planning objectives to actively discourage urban sprawl and excessive land consumption;
 - Provide subsidies for brownfield retrofitting, moderately dense housing, de-sealing and revitalization of city centres, and integrate these incentives into broader funding programmes, e.g. for housing construction and strengthening of city centres.
- Promote inter-municipal, regional and transboundary cooperation for land-saving and climate-resilient spatial development, e.g. by: evaluating the land demand for local settlement development at regional level; inter-municipal agreements on exchanging building land contingents; joint site development of industrial, commercial and retail areas; inter-municipal management of brownfields and vacant buildings; establishing formal cooperation platforms in cross-border regions or at Alpine-wide level (e.g. Alpine-wide planning networks, transboundary inter-municipal associations).

3

Strengthen legal coupling of hazard zone planning with spatial planning and local land use decisions



 Topic	 Policy field	 Phase of DRM cycle	 Types of action
→ Preventive spatial planning	→ Spatial planning → Natural hazard management	→ Prevention	→ Legal & regulatory → Enforcement & compliance → Policy design & instruments → Planning & management → Coordination & cooperation

Objective

Enhancing the effectiveness of *hazard maps* by enacting and enforcing mandatory provisions in planning regulations for ensuring that zones exposed to climate-related hazards are kept clear from development and land use is steered in a risk-sensitive way. Closing regulatory gaps to support and enforce local planning, green infrastructure and construction measures for reducing risk of urban flooding due to heavy rainfall events.

Desired outcome

More binding requirements for respecting hazard-prone areas in local planning decisions and for considering pluvial flood hazards in urban planning will contribute significantly to keeping risk and damage to buildings, infrastructure and humans in Alpine municipalities at low and manageable levels, in particular if hazard and risk assessments are advanced to incorporate the impacts of climate change in a forward-looking way (see [ACTION PROPOSAL 5](#)).

Relevance

Trying to keep overlapping areas of hazard zones and settlements as low as possible is an established guiding principle of spatial planning. All Alpine countries are practising different types of *hazard mapping*, are regularly advancing these instruments and are considering them as technical information in land use planning, while the legal effects of these assessments and the precise ways of their implementation in planning practice differ widely, including between sub-national jurisdictions within countries. In contrast to *hazard zone planning*, *risk mapping* is currently still weakly developed in Alpine countries. Overall, the codification of *hazard maps* in planning regulations remains patchy, and implementation in practice is inconsistent. This has resulted in substantial volumes of assets being located in designated hazard zones. *Hazard maps* are potentially powerful instruments of non-structural risk prevention, especially if in the future they are advanced to *risk mapping* and to take into account the impacts of climate change (see *Action Proposal 5*), but exploiting their full potential requires further regulatory action. Localized green infrastructure, de-sealing and adjusted building design are key strategies for reducing increasing risks from *pluvial flooding* in urban areas, but up-scaled implementation is currently not sufficiently supported by planning laws and building codes.



✓ Policy gaps

- Weak legal integration of *hazard maps* in spatial planning regulations and building codes, with often unclear implications, excessive decision-making leeway for local planning authorities, and inconsistent enforcement in practice.
- Regulatory gaps for prevention of risks from pluvial flooding in settlement areas.

✓ Risk ownership

Amendments of planning laws need to be enacted by *(sub)national governments* with jurisdiction in spatial planning, while implementation is mostly up to *(local) planning authorities*, in close cooperation with *public sectoral planning* in charge of hazard and risk assessments. In their supervisory roles, planning authorities at supra-local levels are responsible for enforcing compliance with stricter regulations. *Transnational actors* (*Alpine Convention, EUSALP*) can contribute to building political momentum in member countries, support transnational harmonisation, and promote good practice approaches.

✓ Recommended courses of action

- Embed mandatory and clear requirements for consistent consideration of hazard zone maps, emerging risk maps, and flood runoff, retention and emergency relief areas in planning laws and building codes.
- Define unambiguous legal consequences with binding, restrictive effects on land zoning, building permits and building design in designated hazard zones and functional flood risk management areas, ensuring that zoning of building land in high risk areas is prohibited and that land use intensity and sensitive land uses in moderate risk areas are restricted and hazard-proof construction standards required.
- Enforce compliance with zoning and land use restrictions connected to designated hazard zones in planning practices through rigorous review of local plans by supervisory planning authorities and intensified on-the-spot checks of building plots.
- Maintain hazard maps with their coupled restrictive effects on land zoning and construction activities (e.g. in former 'red zones') after technical protection structures have been built, in order to avoid increase of *residual risk*, irreversible *vulnerability lock-ins* and inevitably high damage and loss ('*protection-development spiral*') in cases of overload, failure, or when technical protection limits are exceeded by progressing climate extremes.
- Close regulatory gaps for prevention of risks from pluvial flooding in settlement areas, accompanied by financial support systems:
 - Legal provisions supporting prohibition, restrictions, or conditions for land zoning and building permits in designated pluvial hazard zones;
 - Requirements for adjusted design of buildings and property-related protection measures in areas exposed to surface runoff;
- Enabling or requiring adaptation measures in urban development plans, such as designation of free spaces for runoff pathways, areas for de-centralized, nature-based rainwater drainage and infiltration, water retention areas, drainage concepts, green rooftops, maximum soil sealing degrees, minimum shares of unsealed areas capable of rainwater infiltration, etc. (see **ACTION PROPOSAL 1**).
- Harmonize the legal effects of hazard maps on spatial planning across Alpine territories, in particular within countries with federal state systems and different subnational planning jurisdictions, as well as across countries with regard to the transnational management of cross-border risks, while giving preference to solutions that are most effective in risk reduction.
- Exploit the full potential of preventive spatial planning at municipal level by adopting a precautionary approach to keeping potentially hazard-prone areas free from development beyond binding legal obligations.

4

Advance from hazard mapping to integrated risk assessments to support effective, risk-based prevention and preparedness strategies



Topic

- Hazard & risk assessments



Policy field

- Natural hazard management



Phase of DRM cycle

- Prevention
- Preparedness



Types of action

- Data & knowledge
- Capacity-building & training
- Policy design & instruments
- Coordination & cooperation

Objective

Strengthening evidence-based, risk-informed decision-making by advancing from single *hazard mapping* towards risk-oriented assessments and multi-risk evaluation, thus improving the usefulness and effectiveness of hazard and risk assessments in Alpine territories.

Desired outcome

Enhanced assessments will enable authorities, risk management actors, spatial planners, infrastructure providers, municipalities, and property owners to better understand, prevent and manage risks by prioritizing and designing more effective risk reduction and adaptation measures that address current and emerging climate-related risks, including currently overlooked complex, cascading and extreme risk scenarios.

Relevance

Assessments and mapping of hazards and risk are an essential foundation for the planning of technical protection measures, spatial planning and disaster

risk management. All Alpine countries have some kind of assessment and mapping for natural hazards in place, with the coverage of hazards, methodologies, and technical specifications differing widely between, and often within, countries, reflecting considerable heterogeneity in respective regulatory frameworks. The mapping of hazard areas for single hazards still prevails, while risk mapping is generally still in its infancy and most often restricted to flood risk assessment under the EU Floods Directive^{29,30}. Existing assessments often stop at single hazards, lack integration of exposure, vulnerability and damage potential, and rarely capture hazard interactions, cascading effects (e.g., channel blockage or reservoir spillover), *residual risk*, and transboundary dimensions. In so far *multi-hazard* approaches exist, they have been found to mostly provide multi-layer single-hazard information, failing to capture the interactions between hazards (e.g., impacts of windthrow on mass movements, including respective lag times). The development of risk-based prevention, preparedness and response strategies requires moving from single hazard mapping and delineation of flood lines towards integrated, multi-hazard and risk-oriented assessment frameworks, supporting also preparation for cascading effects and complex risk scenarios.



✓ Policy gaps

- Restricted hazard-focused approach and limited coverage, depth, data integration, and cross-border alignment of hazard assessments and maps.

✓ Risk ownership

Depending on a country's division of competences, national and/or subnational *public authorities* responsible for providing natural hazard and risk information have a key role in gathering political support, initiating discussions with stakeholders and experts, mandating research and development

of advanced assessment and mapping methodologies, revising regulatory frameworks and technical guidelines, and in steering and funding implementation of politically agreed steps. Stakeholders and beneficiaries at *local and regional levels*, such as *municipalities* and *risk management practitioners*, need to articulate and concretize their requirements and usability needs and should thus have a strong voice in the process. *Transnational actors* (EUSALP, Alpine Convention) can incorporate risk mapping in their work programs, contribute to agenda-setting in member countries and take supportive and facilitating roles in working towards cross-border interoperability of data and methods.

✓ Recommended courses of action

- Advance traditional hazard-focused assessments towards risk evaluation, by integrating characteristics of exposure and vulnerability of exposed assets (e.g. people, infrastructure, buildings, natural systems, cultural heritage, etc.) as equally important risk components, to enable risk-based approaches in spatial planning and land use planning.
- Develop multi-hazard mapping and multi-risk assessments that consider hazard interactions (e.g. of hydrological and gravitational hazards, forest calamities and mass movements), compound events, and cascading effects to inform and foster prevention and management of complex and extreme scenarios with otherwise unforeseen consequences. In priority risk areas identified through hazard analysis and/or risk screening, in-depth risk assessments should be conducted and result in legally binding risk zoning.
- Establish assessment and map-based visualisation of the extent of residual risk that remains after protection measures have been implemented (overload, failure, tolerated risk exceeding technical protection levels), and that emerges due to climate change-related uncertainties, to inform residual risk management in spatial planning, building codes, and civil protection and contingency planning.
- Establish and advance databases, risk assessments and early warning systems for emerging climate-related risks, including in particular pluvial flood risks, drought, forest fires (e.g., forest fire indices, wildfire risk maps), and biotic and abiotic forest disturbances (e.g., bark beetle, windthrow, ice breakage), which can act as pre-disposing factors, triggers and amplifiers of other natural hazard processes.
- Enhance relevance and usability of hazard and risk maps for decision-making by developing formats that support identification of feasible risk management options, such as prioritization and allocation of protection and adaptation measures.
- Promote transnational and cross-border risk assessments for shared resources (e.g., river basins), hazard hotspots and assets (e.g., transport corridors), with alignment of methodologies across Alpine countries.
- Establish shared Alpine-wide data platforms and standards for risk assessment inputs and outputs, to ensure comparability, foster mutual learning, and enable coordinated risk management strategies across borders.

5

Integrate climate change impacts into forward-looking hazard and risk assessments and establish a precautionary approach



 Topic	 Policy field	 Phase of DRM cycle	 Types of action
<ul style="list-style-type: none"> → Hazard & risk assessments → Structural protection measures 	<ul style="list-style-type: none"> → Natural hazard management 	<ul style="list-style-type: none"> → Prevention → Preparedness 	<ul style="list-style-type: none"> → Data & knowledge → Capacity-building & training → Policy design & instruments → Legislative & regulatory → Technical & technological

Objective

Ensuring that hazard and risk assessments as well as technical protection infrastructure in the Alpine countries adequately respond to the influence of climate change on hazard dynamics (frequency, intensity, spatial occurrence, hazard interactions), exposure and vulnerabilities in a forward-looking way and that uncertainties are considered in decision-making based on a precautionary approach. Mainstreaming climate adaptation into natural hazard and disaster risk management by incorporating expected climate change impacts into assessment methodologies (hazards, risks, design events of structural protection systems), supported by harmonized standards and iterative updating processes.

Desired outcome

Future-oriented hazard and risk information and technical protection structures that account for climate change are needed to safeguard that spatial development, infrastructure investment and risk reduction measures are climate-resilient, decisions taken today remain robust under a range of plausible future climate conditions, and disaster-driven damage and loss is mitigated.

Relevance

Available hazard and risk assessments in Alpine countries hardly consider current and expected future climate change impacts on hazard processes, vulnerability and exposure. Established *hazard zone mapping* and calculation of design events of *structural protection measures* rely on historical data and static hazard patterns, leaving *hazard maps* outdated in the face of shifting climate extremes. Criteria for hazard zone delineation and protection levels do not reflect changing statistical *return periods* or cascading processes, and revisions have been described as infrequent, even after major events. Precautionary approaches to dealing with dynamic hazard patterns are largely lacking in risk assessments and are weakly institutionalized in land use planning, resulting in planning and investment decisions that may underestimate future risks and create irreversible *path dependencies*, locking in long-term vulnerabilities and exposure. Taking into account long lead times until new climate change-aware assessment approaches are established and become effective, there is thus high urgency to take action.



☑ Policy gaps

- Missing consideration of climate change in hazard and risk assessments and in the design of protective infrastructure, resulting in lacking precautionary approaches to cope with dynamic hazard patterns, shifting return intervals and uncertainty.

☑ Risk ownership

Reviewing existing assessment approaches and incorporating future climate-related risks is a joint task of *(sub)national authorities* responsible for natural hazard and flood risk management and affiliated *scientific and technical institutions*, such

as geological, hydrological and meteorological services. Embarking on that pathway requires political decisions at *governmental level* and a robust political mandate. To become effective in practice, also regulatory frameworks related to spatial planning, building codes, and infrastructure investments will need to be adjusted. Thus, early involvement of *municipalities, planning authorities, and stakeholders* is recommended to increase feasibility of this action proposal. In some countries, *local authorities* are also main responsible for revising hazard and risk maps, e.g. after events or when new knowledge becomes available. *Transnational bodies* have roles in facilitating trans-Alpine knowledge transfer, putting the issue on policy agendas, and ensuring that approaches are aligned across borders.

☑ Recommended courses of action

- Promote transnational knowledge exchange and conduct joint research initiatives on future-oriented approaches to assessment, mapping and planning of (protection) infrastructure that respond to climate-driven changes in frequency, intensity, and spatial patterns of hazard processes.
- Evaluate and readjust the assessment basis and delimitation criteria for the determination and updates of hazard and risk zones and develop methodologies, guidelines and standards that account for future climate change, extreme events, changing hazard dynamics, and associated uncertainties. Developing forward-looking assessment approaches to address shifting return periods, changes in extreme events and peak loads, outdated hazard maps and design events, and increasing uncertainties due to climate change may, e.g. involve:
 - incorporating climate scenarios and climate impact assessments,
 - incorporating characteristics of exposure and vulnerability, as additional risk indicators besides hazard frequency,

- introducing climate change correction factors or safety margins in hazard and risk mapping, in the designing and dimensioning of structural protection measures, and in planning of technical infrastructure (e.g., drainage or sewage systems),
- flexible design of protection systems and technical infrastructure to allow for adaptive retrofitting and upgrading,
- working with the decision-making framework of 'adaptation pathways'³¹ to support long-term, flexible risk management in the face of climate change uncertainty.

- Prescribe and conduct more frequent reviews and updates of hazard maps and risk assessments to mirror the pace of climate change; in particular, hazard and risk maps need to be checked and revised after extreme events.
- Incorporate climate scenarios, climate-related risks and precautionary principles into national and Alpine-wide disaster risk assessments, preparedness and prevention planning, and investment decisions.

6

Launch target group-oriented climate risk communication strategies for more risk-aware and better prepared Alpine communities



Topic

- Risk communication
- Risk governance



Policy field

- Civil protection



Phase of DRM cycle

- Prevention
- Preparedness
- Response



Types of action

- Communication & behavioural change
- Capacity-building & training

Objective

Improving public risk awareness, promoting individual, self-responsible risk prevention measures, and enhancing preparedness of diverse population groups for climate-related and cascading risk events to strengthen the *resilience* of communities in Alpine territories.

Desired outcome

Designing and delivering risk communication strategies that are tailored to crucial and vulnerable target groups, address critical gaps in awareness, knowledge and behaviour, and are coordinated and aligned across levels, borders, and risk management actors is key to developing a future-proof Alpine risk culture.

Relevance

Although the frequency and intensity of hazards such as flash floods, landslides, debris flows and forest fires is rising, large segments of the population, including tourists and second-home owners, remain unaware of local hazards and how these may evolve or cascade under climate change. Protection from hazards is often perceived as the sole responsibility of public authorities, leaving a substantial private risk reduction gap. Knowledge of existing *non-structural measures* (e.g. hazard maps, civil protection plans), individual property-related prevention options, and appropriate behavioural responses in emergency situations remains limited, and compliance with alerts and contingency plans is often lacking (e.g.,

onlookers hindering relief operations). People are regularly not aware that the effects of existing public protection systems are limited to defined design events and respective protection levels and always leave exposure to *residual risk*, including through technical failure and overload. The effectiveness of existing risk communication strategies thus appears limited, especially in transboundary or multilingual regions, *inter alia* because they are too generic, fragmented, inaccessible due to language or technological barriers, and do not sufficiently consider needs of vulnerable groups.

Policy gaps

- Lack of individual risk awareness, compliance with warnings and civil protection plans, and self-responsible action among the population, often resulting from lack of knowledge.
- Ambiguity and lack of knowledge among citizens regarding protection goals and residual risk.

Risk ownership

Evaluating, upgrading and implementing tailored (climate) risk communication to strengthen more effective private risk precautions of civil society is a shared task co-owned by many actors at all governance levels. *Public authorities* active in disaster risk management at (*sub*)national level have key roles in bundling and coordinating in a partnership approach the communication activities of diverse institutional actors (ministries, subnational governments, municipalities,



technical agencies, emergency organisations, civil protection associations, insurances, etc.) as well as in providing information materials, guidelines, counselling and trainings. Their closeness to target groups places *regional risk managers and municipalities* at

the right level to co-develop overarching concepts, tailor strategies to local needs, and deliver activities in context-sensitive ways, while *transnational bodies* can facilitate cross-border cooperation, knowledge transfer, capacity building, and learning.

✓ Recommended courses of action

- Design and deliver targeted, multilingual and transboundary communication campaigns and training formats to increase public knowledge and understanding of local hazard contexts, non-structural risk reduction measures (e.g., hazard maps, early warning systems, contingency plans), appropriate behavioural responses, and compliance with emergency measures, including for cascading events. Communication activities should be embedded in national and transnational risk communication strategies and streamlined across all governance levels, different risk governance actors (e.g., civil protection authorities, emergency response organisations, insurance companies), and their respective communication channels and information services.
- Co-develop culturally appropriate and easily accessible risk communication materials in partnership with municipalities, tourism operators and local organizations, tailored to residents and specific population groups that may lack local knowledge and face language barriers, such as second-home owners, tourists, and cross-border commuters.
- Develop and apply communication approaches to deal with limited risk awareness due to long *return periods* of events, the human forgetfulness curve, seeming singularity of extreme events, and a lack of personal experience with extreme events, which can also limit routine in responding to an event, e.g., by capitalising on the memory of elder inhabitants.
- Embed real-time alerts and behavioural guidance into widely used and regionally accepted digital platforms (e.g., tourism websites, weather and transport apps), including geo-targeted push notifications, to ensure timely and actionable communication before and during events.
- Establish pro-active, tailored advisory services, counselling offers and information campaigns to foster private risk precaution of property owners and households, such as property-related technical protection measures, insurance, or household-level emergency plans. Compile a transnational toolbox for private risk precaution measures, building on available, tested and quality-assured materials in all Alpine countries, and broker it via a transnational capacity-building program³².
- Communicate clearly, in accessible terms, and with appropriate care the extent of existing protection levels in the target area, limitations of public protection measures, the possibility of failure or overload of technical protection systems, the residual risk that remains despite structural protection, and the private responsibility in addressing this 'accepted' residual risk. Stress the importance of complementary non-structural and individual measures, targeting also municipal decision-makers, spatial planners, and businesses. Provide and visualize residual risk information in spatial plans, such as local development concepts, zoning and construction plans, to foster residual risk awareness of municipal decision-makers, property owners, and the population. Introduce mandatory information about residual risk levels for planning, selling or buying properties in risk-prone areas.
- Ensure inclusive outreach strategies that proactively address the needs of vulnerable and hard-to-reach groups (e.g., children, elderly, disabled persons, low-income households, immigrants, other non-native speakers), through adapted formats and dedicated engagement channels.
- Develop and roll out a communication concept for awareness-raising on forest fire risk and for building fire-smart communities, targeting especially forest fire prevention by citizens, recreational users and tourists, behaviour in case of a fire event, and the management of the contact zones of forests and settlements (wildland-urban interface).

7

Expand localized, real-time hazard monitoring, early-warning and now-casting capabilities with improved spatial and temporal accuracy and interoperability across borders and scales



☑️ Objective

Strengthening local preparedness and disaster risk management in the Alpine region by improving hazard monitoring, early-warning and *now-casting* capacities and the interoperability of forecasting and alert systems across borders.

☑️ Desired outcome

Implementation will enable authorities, response and emergency services, infrastructure providers, property owners, and Alpine communities to anticipate and respond to weather extremes, climate-related hazards and impacts timelier and more effectively throughout the entire risk management cycle, reducing potential consequences for human lives, infrastructure, buildings, regional economies and ecosystems. Improved local monitoring and forecasting will also foster trust in warning systems and support evidence-based, timely decision-making at municipal, regional and transnational levels.

☑️ Relevance

Past extreme weather events and assessments of future risks under climate change have revealed gaps in tailored hazard monitoring and early warning services across the Alpine region. Embedded in different monitoring and alert infrastructures in the Alpine countries, currently different types of hazards are monitored to different degrees and with varying density and quality of measurements, but overall coverage and performance of monitoring is fragmented and incomplete. The X-RISK-CC project has identified a lack of high-resolution, *real-time hazard monitoring* and *impact-based forecasting* as critical gaps. Current systems often provide insufficient spatial and temporal detail to support effective local response, particularly in hazard hotspots such as mountain valleys, small catchments or areas prone to flash floods, debris flows, hail or strong winds. The absence of integrated now-casting and community-level forecasting capabilities reduces communities' preparedness and negatively impacts their ability to implement timely protective measures. Limited cross-border harmonization of monitoring and data standards constrains joint early-warning efforts in transboundary regions.



✓ Policy gaps

- Gaps in real-time, small-scale hazard monitoring, forecasting and now-casting in terms of availability, spatial and temporal accuracy, reliability and coverage of hazards, scales, territories, and influencing factors.
- Limited cross-border interoperability of monitoring and data standards, constraining joint early warning efforts in transboundary regions.

✓ Risk ownership

Public actors at national and subnational levels, in particular authorities and agencies in the field of natural hazard management, disaster risk management and civil protection, have essential roles in translating

the respective gaps into policy agendas, in mandating, financing, organizing and coordinating the advancement and deployment of monitoring, forecasting and warning systems, and in the provisioning of knowledge, technologies, and data infrastructure. *Regional and local risk management actors*, together with all relevant services and stakeholders at community-level, are driving the demand and are at the appropriate level to set place-based priorities, tailor tools and methods to their specific contexts, and implement and apply them. Design, planning and roll-out of monitoring and warning infrastructure requires close coordination at and across all levels and builds on involvement of *researchers, specialized services (meteorological, geo-hydrological), and technical experts*. *Transnational actors* can fulfil important agenda-setting, care-taking, networking and support roles in harmonizing and interlinking approaches, standards and procedures across country borders.

✓ Recommended courses of action

- Invest in decentralized real-time monitoring systems with comprehensive territorial coverage and improved spatial and temporal accuracy, particularly in hazard hotspots, ensuring cross-scale data integration for regional and local decision-making.
- Support the development of reliable now-casting and community-level forecasting capabilities for multiple hazards, enabling short lead-time warnings and rapid local response.
- Extend the coverage of monitoring and connected early-warning systems by covering additional meteorological hazards (e.g., thunderstorms, wind, hail, torrential rain, drought) and emerging hazards (e.g., forest fire), hazard triggers, predictions of impacts of weather extremes and related hazards, compound and cascading effects, cross-border hazard hot spots, and exposed critical infrastructure (e.g., bridges, energy facilities)
- Enhance predictions of small-scale meteorological and hazard events, including rainstorm cells, strong winds, hail, torrents, peak discharges, and localized flash floods, enabling spatially explicit warning with high positional accuracy and short lead times for local response forces (e.g., to set up roadblocks or deploy temporary protective measures).
- Invest in higher density of measurement networks and make use of new technologies, such as de-centralized sensors and remote sensing methods (e.g., radar measurements, satellite data, aerial surveys, drones) to enable hazard detection with higher resolution and to improve accuracy and reliability of predictions.
- Promote harmonization and interoperability of monitoring and forecasting systems, warning protocols and alerts across Alpine countries and territories and establish interlinkages to warning systems at European levels to facilitate cross-border coordination and shared response planning, working towards a transnational, integrated, multi-hazard monitoring and alert infrastructure for the Alps (e.g., macro-regional monitoring hub).

8

Strengthen operational linkages between early warnings and management of local responses



 Topic	 Policy field	 Phase of DRM cycle	 Types of action
<ul style="list-style-type: none"> → Forecasting, early warning & alert → Preparedness & response capacities 	<ul style="list-style-type: none"> → Civil Protection 	<ul style="list-style-type: none"> → Preparedness → Response 	<ul style="list-style-type: none"> → Capacity building & training → Communication & behavioural change → Institutional & organisational

Objective

Ensure that early warnings issued across the Alpine space reliably trigger timely, coordinated and effective local response actions, bridging the gap between the issuing of alerts and their translation into adequate local and transboundary responses.

Desired outcome

Building social, institutional and community response capacities by means of training and improved routines and practices for responding to alerts will protect lives, minimize economic and environmental damages, enhance *resilience* to increasingly frequent, complex and cascading climate-related risks and extreme events, and build trust towards public risk management.

Relevance

There is evidence that operational linkages between early warnings and effective local action are often limited. Even if reasonably accurate monitoring and alert systems are in place, the lack of capacity to translate measurements and forecasting data into adequate messages and action chains and missing definitions of what actions should follow after warnings constrain their effectiveness. Current warning systems often leave a 'last mile' gap between the issuing of a warning and the measures to be taken by civil protection officers, response forces, and the population. Warnings are not always translated into clear, actionable instructions adapted to the local context, and not all local actors have the resources, training or protocols to act swiftly and properly. In transboundary Alpine regions, differences in languages, institutional structures and operating procedures further hinder coordinated responses. As a result, warnings may not be acted upon in a timely or coordinated manner, undermining their effectiveness and potentially eroding public trust in both the warning systems and the broader governance of climate-related risks.



☑ Policy gaps

- Limited capacity of risk managers and target groups to adequately communicate and act on information provided by early warning systems.

☑ Risk ownership

Enhancing capacities to communicate and act on warnings requires shared efforts and collaboration across all levels, from local to national, and across borders. *Civil protection authorities and agencies at (sub)national levels*, in collaboration with *emergency organisations and disaster risk experts*, have important roles in providing quality requirements, guidance and model templates to regional and local levels, in organizing central trainings of local actors, and in supporting exercises at community level and in transboundary settings. Developing and exercising tailored courses of action, institutionalizing procedures, and active learning are, on the other hand, the collective responsibilities of *risk managers and civil protection personnel in the municipalities and regions*.

☑ Recommended courses of action

- Prepare clear local and transboundary action chains and standard operating procedures for different extreme scenarios (e.g. flash floods, landslides, heatwaves), including compound and cascading impacts, clarifying roles, responsibilities and (in the case of cross-border settings) differences in legal and governance frameworks, from the receipt of warnings to first responses.
- Provide multi-language interoperability protocols in the relevant languages to ensure consistency in warning communications and response standards across borders.
- Organize regular civil protection exercises and other capacity-building initiatives with mayors, municipal staff, emergency services and volunteers for training capabilities to

communicate on warnings, to purposefully implement the standard operating procedures, and to improve operational linkages under time pressure and in transboundary contexts.

- Establish and maintain two-way communication channels and feedback mechanisms (e.g. consultations, debriefings, digital platforms, hotlines, community liaisons) to ensure warnings are understandable, context-sensitive, adequate, and continuously improved based on user feedback.
- Ensure that learnings from experienced extreme events are reviewed, discussed with all stakeholders, and integrated into updated procedures and protocols (see [ACTION PROPOSAL 12](#)).

9

Strengthen preparedness and response capacities by institutionalizing knowledge exchange, learning and citizen involvement



 Topic	 Policy field	 Phase of DRM cycle	 Types of action
<ul style="list-style-type: none"> → Preparedness & response capacities → Risk communication 	<ul style="list-style-type: none"> → Civil Protection → Natural hazard management → Spatial Planning 	<ul style="list-style-type: none"> → Prevention → Preparedness → Response 	<ul style="list-style-type: none"> → Capacity-building & training → Coordination & cooperation → Institutional & organisational

Objective

Strengthening local and transboundary preparedness levels and response capacities for current, emerging and cascading climate-related risk events by embedding behavioural routines, involving actively civil society, and institutionalizing knowledge transfer, trainings and capacity building in a transnational approach.

Desired outcome

Stronger risk management capacities of civil protection agencies, municipal decision makers, stakeholders and the population will foster resilient and adaptive Alpine communities and result in improved disaster response performance, thus mitigating disaster shocks and containing damage and loss in Alpine regions even under progressing global warming trajectories.

Relevance

Capacities for local and transboundary disaster preparedness and response in Alpine regions are currently limited by persistent obstacles related to

information uptake, learning and public participation in risk planning. These gaps are particularly pronounced when it comes to transboundary settings, hindered by differences in language, institutional structures and governance traditions, which indicates underused potentials for transnational exchange, learning and training. Despite growing recognition of the importance of learning from past events (see ***ACTION PROPOSAL 12***), knowledge exchange remains irregular or insufficiently targeted at all levels, weakening preparedness and response capacities for emerging and cascading climate-related risks, including in a cross-border context.

Policy gaps

- Lack of established behavioural routines, regular trainings, institutionalized capacity-building, and systematic uptake of new climate risk information and post-event learnings.

- Limited citizen involvement in resilience planning, risk governance and emergency exercises.



✓ Risk ownership

Closing existing gaps in capacity-building for disaster preparedness and response requires shared efforts of multiple actors across governance levels. Competent *civil protection authorities and agencies at (sub) national levels* are required to mandate development and steer institutionalisation of structures and formats for knowledge exchange, training, counselling,

and citizen participation. They also need to provide supportive and enabling framework conditions for *local and transboundary actors*, who in turn must provide own resources (time, staff, expertise, co-financing) to benefit from learning outcomes. *Transnational cooperation structures* have important roles in political agenda-setting, piloting initiatives, and facilitating and hosting trans-Alpine formats and structures.

✓ Recommended courses of action

- Integrate information about climate-related risks in disaster risk information programmes and materials. Implement cyclical trainings and knowledge exchange formats for civil protection personnel (e.g., authorities, emergency organisations, municipal staff, civil protection associations, fire fighters, volunteers), including joint emergency exercises with local populations and in cross-border settings, employment of cascading climate risk scenarios, and transnational learning and knowledge transfer.
- Install national and transnational knowledge and training centres for disaster risk management, or re-adjust the mandates and roles of existing institutions, and incorporate preparedness to increasing climate-related risks, emerging climate-related risks (e.g., forest fire, drought), compound events and cascading risks into research and teaching curricula.
- Launch and expand advisory services for municipalities by establishing a network of local climate hazard advisors, who provide tailored audits, counselling and capacity-building activities to municipal decision makers and administrative staff (building on examples like the 'Natural hazard and Climate Change Check for Municipalities' in Austria³³), designed to address local vulnerabilities and action needs, including within transboundary risk contexts.
- Establish participatory risk governance processes that actively engage civil society and multiple stakeholders to improve robustness and acceptance of risk assessment and management, while increasing local and individual risk ownership. This can be achieved by mandating public consultation and active involvement of citizens in planning of protective measures, in deciding about protection levels and tolerated *residual risk*, and in preparing contingency and emergency plans, as well as by assigning responsibilities in emergency situations to volunteers. In doing so, involve socially vulnerable groups with lower adaptive and response capacities, such as home renters, lower income households, and elderly, health-impaired or disabled people.
- Regularly update contingency plans by incorporating new information on increasing climate-related risks, such as surface runoff maps or forest fire hazards, and include risk scenarios based on residual risk events, cascading events, and climate projections, building on closer cooperation with climate adaptation communities of practice. Prioritize and monitor critical infrastructure accordingly (e.g. schools, public buildings, roads, bridges, electricity, water supply) and enhance communication with operators.
- Strengthen spatial basic research, as a regular part of all planning processes, by establishing climate-induced natural hazards, climate risks, and adaptation needs as a statutory subject. Enhance the usability, translation and transfer of climate risk knowledge for spatial planners and increase capacities and qualifications of planners to deal with climate risk issues, through professional education, practical work aids, decision support tools, planning guidelines, and compendiums of pan-Alpine good practices. Preparing these resources will benefit from a transnational approach and shall support integration of climate risk considerations, especially cascading and residual risks, into spatial planning of Alpine territories.

10

Reform insurance and damage compensation systems to foster private risk reduction and climate-resilient reconstruction



Topic

- Insurance, disaster recovery & reconstruction



Policy field

- Risk transfer & disaster financing



Phase of DRM cycle

- Prevention
- Recovery



Types of action

- Insurance & risk-sharing
- Policy design & instruments
- Communication & behavioural change

Objective

Incentivising private risk reduction, coercing climate-resilient recovery, and promoting financial disaster preparedness in the Alpine region by improving the design and layering of hazard insurance systems and damage compensation schemes.

Desired outcome

Fostering pro-active individual risk precaution measures at property-level will benefit households and firms through more safety and lower insurance costs, governments and taxpayers through relief of public budgets, lowering of macro-economic disaster risks, and improved social justice, and insurance companies through improved financial viability, while increasing overall societal *resilience* to climate-driven disasters.

Relevance

Different systems of insurance and public damage compensation are in place in Alpine countries, ranging from publicly backed natural hazard insurance schemes with broad or mandatory coverage to market-based systems with variable market penetration, often complemented by ad-hoc or discretionary public support³⁴. Some countries without compulsory

natural disaster insurance rooted in solidarity principles have low insurance coverage and are facing a significant financial protection gap, forcing the government to step in with post-disaster financing in case of large-scale events³⁵. Currently, there is no structured platform in the Alps for cross-country exchange on the design and implementation of financial instruments that would support risk prevention and climate adaptation. Despite different national approaches, existing insurance and recovery mechanisms are not sufficiently used to incentivise private risk reduction and climate-resilient reconstruction, potentially giving way to *maladaptive* behaviour³⁶. Public disaster funds can inhibit risk precaution, because households can feel less motivated to take individual pro-active risk reduction measures, relying on public damage compensation, and thus sustaining *risk exposure*. By inadvertently stimulating free-riding behaviour, the costs of individual inaction are re-distributed to the collective of taxpayers. Similarly, market-based household insurance schemes can inhibit behavioural changes by creating false feelings of security, undermining the willingness of property owners to take individual adaptation measures. Failure to incentivize property-level protection and adaptation measures can exacerbate existing constraints of - private and public - *risk transfer* systems, particularly in the face of increasing climate pressures.



✓ Policy gaps

- Lack of incentives for private risk reduction measures, and potentially maladaptive effects, of public disaster compensation funds and market-based insurance schemes.
- Limits to viability of market-based insurance systems and risk of overstraining governmental compensation and recovery capacities.

✓ Risk ownership

Re-designing risk transfer systems requires cooperation and shared efforts by *national governments*, *public authorities* with competences in disaster risk reduction and disaster financing, *public (re-)insurers*, *national disaster funds*, and *market-based insurance companies*, based on political will and agency. *Transnational cooperation actors*, such as Alpine Convention and EUSALP, have a key role in facilitating and organizing transnational dialogue and learning.

✓ Recommended courses of action

- Facilitate transnational dialogue and peer exchange, including through platforms like Alpine Convention and EUSALP, among regulators, national governments, insurance companies, and experts on comparative (dis) advantages, gaps and optimisation potentials of different natural hazard insurance models and multi-layered, pre- and post-disaster financing instruments. This may include stress testing under disaster shock scenarios and exploration of opportunities for macro-regional or cross-border disaster contingency funds. Establish a transnational learning process on how to incentivize private risk reduction and climate-resilient recovery through insurance and public compensation mechanisms, e.g., by sharing effective practices and co-developing joint guidance.
- National governments shall mandate insurance product regulators and public disaster relief funds to re-design their policies by embedding build-back-better conditions at the property level, linking the amount of financial compensation to demonstrated risk reduction, thus counteracting maladaptive free-riding behaviour and incentivizing more resilient reconstruction with higher future levels of prevention and preparedness.
- Public insurers, market-based insurance companies, and national and regional disaster funds, in cooperation with authorities in charge of disaster risk reduction, natural hazard management and climate adaptation, shall revise their policies to incentivise and reward risk reduction measures of property owners by aligning premium discounts, deductible modulation and amount of public damage compensation with individual protection and risk levels. Incorporating mechanisms for avoiding maladaptive behaviour of policy holders is important also for Alpine countries with solidarity-based, compulsory natural hazard insurance models, because it benefits the long-term social acceptance and financial viability of these systems.
- Re-designing both market insurance and public compensation schemes can contribute to overcoming severe constraints that both layers of risk transfer are facing under climate change. While insurance policy holders taking pro-active adaptation measures will benefit directly from lower insurance premiums, higher prevention and lower damage levels may allow insurances to keep premium ratings affordable for all, which can in turn increase market penetration and thus viability of insurance systems. Incorporating build-back-better conditions in public disaster relief funds can help avoid overstraining of governmental compensation and recovery capacities, with severe subsequent macro-economic risks, which may occur in case of (repeated) unabated large-scale disaster losses.
- Implement insurance-led climate resilience education programs to increase awareness and encourage proactive risk management among households and firms.
- Establish mandatory protection certificates for property transactions, disclosing the level of protection and remaining risk of buildings (analogously to energy certificates), to enhance transparency and drive adaptation investments.

11

Shape an integrated multi-level climate risk governance framework for Alpine territories



Objective

Increasing the effectiveness of climate risk management across the Alpine region by strengthening coordination and cooperation across multiple levels, sectors, actors, and borders.

Desired outcome

A more coherent and integrated multi-level governance framework for climate-driven natural hazards is needed to enhance risk management capacities and performance, particularly in view of increasing transboundary climate risks (e.g., floods, permafrost thawing, droughts, wildfires).

Relevance

Due to different governmental systems, administrative traditions and risk cultures, the Alpine countries have developed diverse approaches to 'steering their common risk affairs'¹³⁷, complementing to varying degrees hierarchical governmental action and regulatory frameworks with cooperation and network-based governance modes. Despite strong cooperation traditions and shared risks, risk governance of climate-driven natural hazards within and

across Alpine countries remains structurally fragmented, often lacking clear responsibilities, effective vertical coordination, and cross-sectoral collaboration to overcome policy silos, thus hampering joint action, even as climate-induced hazards transcend borders and intensify with cascading effects. Existing transnational cooperation bodies (e.g., PLANALP, Alpine Climate Board, EUSALP AG8) provide strategic and technical input but lack authority and agency for establishing transboundary coordination mechanisms. As a result, key climate risk governance functions often remain disconnected across administrative levels, sectoral mandates, and jurisdictional borders, risking insufficient and incoherent policies and practices.

Policy gaps

→ Fragmented governance, missing or unclear responsibilities, and lack of vertical and horizontal coordination in disaster risk management within and across Alpine countries.



✓ Risk ownership

Shaping risk governance frameworks is by definition a multi-level task. On the one hand, risk governance solutions are context-sensitive, need place-based innovations and require active commitment

of diverse *local and regional actors*. On the other hand, *public authorities and institutional actors at all levels* have important roles in setting the framework conditions, defining the goals of governance processes, establishing institutional arrangements and rules, and providing necessary resources.

✓ Recommended courses of action

- Develop and strengthen coherent multi-level governance frameworks for climate-related disaster risk management within Alpine countries, aiming at clear vertical decision-making hierarchies, structures, processes and responsibilities, with coordination mechanisms across sectoral mandates, at all levels.
 - *National/subnational level:* Mainstream climate-related risks into national DRM policies; closer alignment of climate adaptation and DRM policy frameworks and communities; installing national situation assessment centre; appointing climate risk advisor to national government; national commissions for forest fires and droughts (incl. for rating of hazards); providing common minimum requirements for contents of local and regional civil protection and disaster risk management plans.
 - *Regional level:* Install coordination hubs like regional information centres, permanent provincial operations rooms, and regional coordinators for forest fire and drought; regionalizing disaster relief budgets; coordinating and harmonizing resilience planning between municipalities; planning response and relief capacities (logistics, infrastructure, resources) for large-scale events; facilitating sharing of resources and pre-identification of debris deposit areas; providing institutional frameworks for inter-municipal cooperation in risk management (e.g., cross-municipal planning instruments, financial compensation mechanisms); providing model templates for local civil protection plans.
 - *Municipal level:* Installing local contact centre points for coordinated involvement of stakeholders and households;
 - establishing municipal operation management for coordination of disaster responses; climate-proofing of local developments and public investments.
- *Vertical and horizontal coordination:* Establishing formal and informal bodies and formats for coordination and cooperation, such as committees, task forces, round tables, dialogue fora, information platforms; integrating forest fire risk management, drought management and protection forest management in policy frameworks for disaster risk management, climate adaptation, and spatial planning at different levels.
- Develop an Alpine-wide climate risk governance framework for coordinating management of transboundary hazards and cascading risks:
 - Build political momentum among Alpine countries, e.g., through a joint political declaration under the Alpine Convention or a strategic initiative under EUSALP.
 - Launch a governance pilot, involving committed regions or countries, to test cross-border coordination mechanisms and demonstrate added value.
 - Map institutional mandates, establish multi-stakeholder dialogues in cross-border regions, and develop operational transnational protocols for key risk management functions, such as early warning, pooling of specialized equipment and emergency units across borders, and joint transboundary interventions.
 - Establish scalable coordination mechanisms and a standing governance forum under the Alpine Convention to enable sustained dialogue, oversight and future expansion.

12

Establish systematic post-event learning and more resilient recovery in the Alpine region



Objective

Increasing *adaptive capacity* and *resilience* of Alpine regions to climate-driven disasters by ensuring systematic post-event learning and timely implementation of lessons learned.

Desired outcome

Utilizing ‘windows of opportunity’ for scrutinizing, enhancing and revising risk management policies across all phases of the DRM cycle is indispensable for shaping future-proof Alpine risk management systems, reducing concrete risks to Alpine communities and mitigating macro-economic disaster impacts to entire countries.

Relevance

The project has identified a wide-spread lack of systematic, structured and standardized mechanisms for learning from disaster events in Alpine regions, leading to missed opportunities for more climate-resilient recovery, reconstruction and reorganisation of risk management approaches. Relevant gaps relate to fragmented and incomplete documentation and

post-analysis of events and losses, irregular debriefings with limited stakeholder involvement, missing transboundary stakeholder roundtables, operational lessons-learned protocols that could guide improvement of prevention, preparedness and response measures, and missing mechanisms for monitoring and evaluating their implementation in practice. Limited structured learning mechanisms often result in getting trapped in reactive, ‘business-as-usual’ modes and risk management approaches that may be outdated in the face of increasing climate-related risks, preventing the necessary transgression from immediate coping, repair and aftercare to ‘building-back-better’ and foresighted transformation of risk management policies.

Policy gaps

- Lack of systematic post-event documentation, analysis, debriefing, learning, and climate-resilient reconstruction.
- Missed opportunities for transforming outdated risk management approaches.



☑ Risk ownership

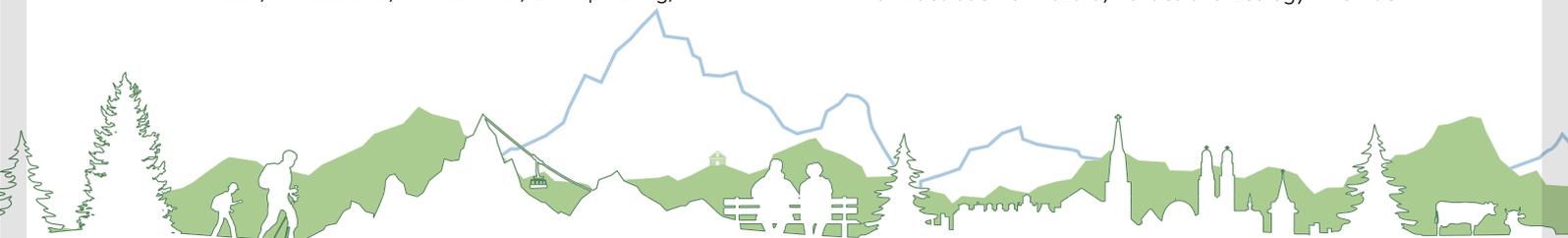
While conducting learning processes and direct benefitting from outcomes is primarily *community-driven*, more systematic post-event learning at regional levels needs a supportive and enabling framework by higher government levels. *National and subnational authorities* with competences for disaster risk management, civil protection, natural hazard protection and climate adaptation have key roles in setting up central infrastructure for event

and loss data, providing expertise for event analysis and organisational support for (transboundary) multi-stakeholder involvement, preparing standard operating procedures, guidelines, tools and training formats, and in updating national risk management and adaptation strategies, informed by lessons learned in regions affected by disasters. Creating a transnational learning environment and facilitating cross-border collaboration in resilient recovery is a field of action by *transnational actors*.

☑ Recommended courses of action

- Establish standardized, well-structured and comprehensive event and loss documentation by installing a centralized digital platform at (sub)national level. Ensure that spatially allocated damage data are tracked, also small-scale and cascading events are recorded, obligatory reporting procedures for local and regional authorities are in place, the database is accessible to local and regional stakeholders, and documentation of transboundary events and damage costs is supported, e.g., based on cross-border interoperability standards.
- Conduct more systematic post-event analysis, supported by standardisation and covering entire sequential impact chains (from pre-disposing factors and meteorological drivers to interacting hazard processes to damage and loss), all risk components (hazards, exposure, vulnerability), and risk management capacities and gaps through all phases of the risk management cycle.
- Organize structured debriefings and multi-stakeholder roundtables, including in transboundary settings and involving all relevant actors in a more inclusive approach, such as local governments, emergency services, infrastructure providers, researchers, civil society, and representatives of vulnerable social groups.
- Prepare operational lessons-learned protocols and embed them into national and regional disaster risk management systems. Use 'windows of opportunity' accordingly by reviewing and updating hazard maps and civil protection plans, checking and upgrading technical protection infrastructure and protection concepts, and integrating learnings into existing measures, tools and procedures. Consider transformative options to overcome outdated risk management approaches, such as managed retreat and relocation in high-risk areas with repeated damage events and predictable transgression of technical or economic protection limits in the near future.
- Use damage to structural protection measures as 'policy windows' for building back better and for establishing climate-responsive strategies for the design, long-term maintenance, reconstruction and retrofitting of technical protection systems. This may include: better integration of overload and cascading failure scenarios into design standards; incorporating climate stress, *multi-hazard* impacts, and degradation (e.g., increased sediment loads, freeze-thaw cycles) of protection structures in regular performance evaluation and maintenance planning; staggered (instead of linear) maintenance and retrofitting to cope with dynamically changing risk situations; revision of outdated design events and insufficient protection levels in consideration of climate change; shifting from the concept of design events based on past statistical *return intervals* to a more risk-based and precautionary approach (see **ACTION PROPOSAL 5**).
- Organize knowledge exchange and learning partnerships between municipalities and regions with recent event experience and those with fewer recent impacts and lacking response experience, including through Alpine-wide training formats or EU Interreg-supported pilot initiatives.

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6. GLOSSARY



Adaptation (Climate Change Adaptation, CCA): In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; in some natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC, 2022, World Bank, 2026).

Adaptive capacity: The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities or to respond to consequences (MA, 2005; IPCC, 2022).

Cascading events: A sequence of interconnected events where one initial event triggers subsequent events, often amplifying impacts as they progress. Cascading events are particularly relevant in *risk management* and disaster studies, as they can result in unexpected and widespread consequences (e.g. heavy rainfall causes a river to overflow, triggering floods that damage homes, disrupt transportation, contaminate water supplies, and lead to economic and social crises) (IPCC, 2019).

Cascading hazards: Cascading *hazards* occur when one hazard triggers another, creating a chain reaction of events. Any natural hazard might trigger zero, one or more secondary natural hazards. The secondary natural hazard might be identical or different from the primary hazard (Tilloy et al., 2019). An example in the Alpine context might be a landslide caused by intense rainfall that subsequently blocks a river, leading to flooding (X-RISK-CC, 2025).

Cascading impacts: Cascading impacts from *weather extremes* (extreme weather/climate events) occur when an extreme *hazard* generates a sequence of secondary events in natural and human systems that result in physical, natural, social or economic disruption, whereby the resulting impact is significantly larger than the initial impact. Cascading impacts are complex and multi-dimensional, and are associated more with the magnitude of *vulnerability* than with that of the *hazard* (IPCC, 2022). Interconnected, and escalating effects triggered by a climate-related hazard that impact multiple sectors or systems, amplifying *risks* (X-RISK-CC, 2025).

Climate risk (climate-related risk): Potential for adverse consequences from climate variability, climate change or climate-related extreme events for human or ecological systems and their functions. Climate risk results from the dynamic

interaction of *hazards* with the *exposure*, *vulnerability* and *adaptive capacity* of the affected system. It describes how, to what extent, and why climate change and weather extremes could cause harm to people, assets, sectors, or systems and, if possible, how likely adverse consequences are today or could become in the near or far future. It is often represented as the probability that a hazardous event or trend occurs multiplied by the expected impact. Relevant adverse consequences include those on lives, livelihoods, health and wellbeing, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species (World Bank, 2026; IPCC, 2021a; Zebisch et al., 2023).

Climate Risk Management: Climate Risk Management includes all mechanisms and measures (such as plans, actions, strategies or policies) to reduce current and future *climate risks*. The management of current risk to climate extremes is typically covered by the existing *Disaster Risk Reduction (DRR)* mechanisms. *Climate Change Adaptation (CCA)* involves the process of adapting current *risk management* practices to the actual or anticipated impacts of climate change in order to limit damage or take advantage of positive opportunities. This includes adapting to the increasing intensity and frequency of climate extremes, as well as slow-onset processes (such as sea-level rise) and emerging *climate risks*. Today, CCA and DRR are seen as integral constituent parts of successful Climate Risk Management (Zebisch et al., 2023).

Compound events: The combination of multiple drivers and/or *hazards* that contributes to societal or environmental *risk*. In the framework of weather phenomena, compound events involve two or more individual meteorological processes that occur simultaneously or within a short timeframe (e.g., a heatwave coinciding with a drought) (IPCC, 2021b).

Compound hazards: Different *hazards* resulting of the same triggering event. In this case there is not a primary and a secondary hazard as the different hazards occur simultaneously or sequentially within a reasonably short timeframe, often interacting to amplify overall impacts. For example, a prolonged drought followed by an intense rainfall event can lead to flash flooding and soil erosion (Tilloy et al., 2019; X-RISK-CC, 2025).

Compound risks: They arise from the interaction of *hazards*, which may be characterised by single extreme events or



multiple coincident or sequential events that interact with exposed systems or sectors (IPCC, 2022). Compound risks emerge when multiple climate hazards occur together or in succession, interacting with exposed and vulnerable systems to amplify impacts (X-RISK-CC, 2025).

Disaster Risk Management (DRM): Processes for designing, implementing and evaluating strategies, policies and measures to improve the understanding of current and future disaster *risk*, foster *disaster risk reduction* and *transfer*, and promote continuous improvement in disaster *preparedness*, *prevention* and *protection*, *response* and *recovery* practices, with the explicit purpose of increasing human security, well-being, quality of life and sustainable development (IPCC, 2022). Disaster risk management is the application of *disaster risk reduction* policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage *residual risk*, contributing to the strengthening of *resilience* and reduction of disaster losses (UNDRR, 2017).

Disaster Risk Reduction (DRR): Disaster risk reduction is aimed at preventing new and reducing existing disaster risk and managing *residual risk*, all of which contribute to strengthening *resilience* and therefore to the achievement of sustainable development. DRR denotes both a policy goal or objective, and the strategic and instrumental measures employed for anticipating future disaster *risk*, reducing existing *exposure*, *hazard*, or *vulnerability*, and improving *resilience* (UNDRR, 2017; IPCC, 2022).

Disaster: Serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of *exposure*, *vulnerability* and *capacity*, leading to one or more of the following: human, material, economic and environmental losses and impacts. The effect of the disaster can be immediate and localized, but is often widespread and could last for a long period of time. The effect may test or exceed the capacity of a community or society to cope using its own resources, and therefore may require assistance from external sources, which could include neighbouring jurisdictions, or those at the national or international levels (MA, 2005; UNDRR, 2017).

Exposure: The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected (IPCC, 2022). The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas. Measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific *vulnerability* and *capacity* of the exposed elements to any particular hazard to estimate the quantitative *risks* associated with a *hazard* in the area of interest (UNDRR, 2017).

Green and blue infrastructure: A strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of

ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, green infrastructure is present in rural and urban settings. Green Infrastructure is based on the principle that protecting and enhancing nature and natural processes, and the many benefits human society gets from nature, are consciously integrated into spatial planning and territorial development. Compared to single-purpose, grey infrastructure, green and blue infrastructure has many benefits. It is not a constraint on territorial development but promotes natural solutions if they are the best option. It can sometimes offer an alternative, or be complementary, to standard grey solutions (EC, 2013).

Hazard: A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. Natural hazards are predominantly associated with natural processes and phenomena. Hazards may be single, sequential or combined in their origin and effects. Each hazard is characterized by its location, intensity or magnitude, frequency and probability (UNDRR, 2017).

Hazard map (hazard mapping): Geographic map that identifies and shows areas potentially affected by a specific natural *hazard*. It visually represents where hazards are likely to occur, how severe they may be, and sometimes how frequently they happen. They are typically created for hydrometeorological and geophysical hazards, such as riverine floods, torrential floods, debris flows, rockfall, or avalanches. In simple terms, hazard mapping answers the question: 'what can happen, and where?'. Hazard maps are essential tools for *disaster risk management* and spatial planning, as they help guide land use decisions, infrastructure development, and emergency *preparedness*.

Hazard zone planning: *Hazard maps* that use zonation to categorize the likelihood and intensity of a *hazard* occurring in specific locations. For example, hazard zones may relate to flood events with statistical return intervals of every 30 or every 100 years, or they may represent areas with different degrees of susceptibility to landslides. Usually, colour coding is used to represent different hazard zones, such as red zones to delineate areas where a potential hazard is so severe or frequent that permanent settlement activities are considered ineligible, and yellow zones where building permissions can only be granted if certain protection requirements are complied with.

Impact-based forecasting: Impact-based hazard or event forecasting is an approach to forecasting that goes beyond predicting the physical characteristics of a *hazard* (such as rainfall amount, or wind speed) to instead forecast the likely impacts and consequences of that hazard on people, infrastructure, services, and the environment. The goal is to communicate forecasts in terms of what the event will do, rather than only what the event will be. Impact-based forecasting supports better *preparedness* and early *response* action by making forecasts more relevant and actionable for emergency managers, authorities, and the public.



Maladaptation (maladaptive action): Actions that may lead to increased risk of adverse climate-related outcomes, including via increased greenhouse gas (GHG) emissions, increased or shifted *vulnerability* to climate change, more inequitable outcomes, or diminished welfare, now or in the future. Most often, maladaptation is an unintended consequence (IPCC, 2022).

Multi-hazard: The specific contexts where hazardous events may occur simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects (UNDRR, 2017).

Nature-based Solutions (NbS): Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively. Therefore, they provide human wellbeing and biodiversity benefits (IUCN, 2016). Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build *resilience*. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions. Nature-based solutions must benefit biodiversity and support the delivery of a range of ecosystem services (EC, 2015).

Non-structural measures: Measures not involving physical construction which use knowledge, practice or agreement to reduce disaster *risks* and impacts, in particular through policies and laws, public awareness raising, training and education. Common non-structural measures include building codes, land-use planning laws and their enforcement, research and assessment, information resources and public awareness programmes (UNDRR, 2017).

Nowcasting: Weather forecasting on a very short term mesoscale period of up to 2 hours, according to the World Meteorological Organization. This forecast is an extrapolation in time of known weather parameters, including those obtained by means of remote sensing, using techniques that take into account a possible evolution of the air mass. This type of forecast therefore includes details that cannot be solved by numerical weather prediction models running over longer forecast periods. The strength of nowcasting lies in the fact that it provides location-specific forecasts of storm initiation, growth, movement and dissipation, which allows for specific preparation for a certain weather event by people in a specific location.

Path dependency: In generic terms, path dependency is the concept that decisions, actions, or developments made in the past constrain or shape the options available in the present and future, even when alternative choices might now be more efficient or desirable. It describes the situation where decisions, events, or outcomes at one point in time constrain *adaptation*, mitigation or other actions or options at a later point in time, because earlier choices create self-reinforcing effects—such as established infrastructure, regulations,

investments, habits, technologies, or social norms—that are difficult or costly to change. Risk of adverse path dependencies is a characteristic of *maladaptation*, i.e. adaptation measures that, simultaneously with high future uncertainty, are irreversible or inflexible, and thus are impossible or difficult to correct, re-direct, or retract. Detrimental path dependencies can cause *vulnerability lock-ins*, reduce *adaptive capacities* and solution space over time, inhibit transformative change, and result in high and unavoidable damage and loss, if adaptation limits are reached (EPA IG CCA, 2025).

Pluvial flooding: Pluvial floods occur when extreme rainfall creates flooding independent of overflowing water bodies. They can happen in urban or rural areas, even without nearby bodies of water. Surface water floods occur when the ground's ability to absorb water or the capacity of urban drainage systems is overwhelmed, while flash floods are characterized by intense, high-velocity water torrents triggered by torrential rain or sudden water releases from upstream levees or dams.

Preparedness: Activities and measures taken in advance to anticipate, respond and recover from the impacts of a hazardous event. Preparedness aims to build the capacities for ensuring rapid and effective *response* and for efficiently managing emergencies before a *disaster* strikes (based on: UNDRR, 2017). Preparedness measures include forecasting and early warning systems, emergency and evacuation planning, standard operating procedures, training and field exercises, resource pre-positioning, public awareness campaigns, and establishment of coordination mechanisms.

Prevention: Measures and activities to avoid or mitigate existing and new disaster *risks*. Prevention aims to completely avoid the potential adverse impacts of hazardous events, to reduce the chances of a risk incident occurring, and/or to reduce the extent of damage if a disaster occurs. Prevention supports acceptable levels of risk society is willing to live with (based on: UNDRR, 2017). Prevention involves *structural* and *non-structural measures*.

Protection-development spiral: Denotes the phenomenon that implementation of *structural* hazard protection measures regularly triggers development intensification with new construction activities, expansion of settlement areas and in-migration of residents in former hazard zones and on now supposedly 'protected' land. In conjunction with increasing *hazards* due to climate change, such development pathways can increase *exposure* to (growing) *residual risk*, damage potentials and severity of consequences in case of overload or technical failure. Especially if spatial planning policies encourage withdrawing of *hazard zone maps* and associated restrictions for the zoning of building land after protective infrastructure has been erected, this can create irreversible vulnerability lock-ins and inevitable damage and loss when technical protection limits are exceeded by escalating climate change. The resulting *maladaptive path dependency* is also called 'safe development paradox' or 'building land-revision dilemma' (EPA IG CCA, 2025).



Real-time monitoring: Refers to the continuous and immediate observation, measurement, and analysis of data, events, or processes as they occur in real time. Real-time hazard monitoring uses continuous data collection and AI to instantly detect, analyse, and alert about potential dangers, e.g. from *extreme weather events* and natural *hazards*. It allows real-time alerts and rapid *response* actions to prevent and minimize damage, including by interfering in chains of events before they escalate.

Recovery: Actions taken after a *disaster* to cope with its effects, restore livelihoods and health, and rebuild resilient critical infrastructures, services, housing, and facilities, aligned with 'build back better' principles to enhance future *resilience*. Sustainable recovery integrates post-event learning, adaptive management and long-term thinking (based on: UNDRR, 2017). Recovery measures include sustainable restoration of infrastructure and services, damage compensation and reconstruction financing, psychosocial support, participatory reconstruction planning, post-event learning mechanisms, and re-adjustment of *risk management* frameworks.

Residual risk: The risk related to climate change impacts that remains following *adaptation* and mitigation efforts (IPCC, 2022). The disaster *risk* that remains even when effective *disaster risk reduction* measures are in place, and for which emergency response and recovery capacities must be maintained. The presence of residual risk implies a continuing need to develop and support effective capacities for emergency services, *preparedness*, *response* and *recovery*, together with socioeconomic policies such as safety nets and *risk transfer* mechanisms, as part of a holistic approach (UNDRR, 2017). The concept of residual risk is closely related to the determination of protection goals. Protection goals denote the level of security that responsible risk management actors aim to achieve, and the threshold of risk that protection measures in place are designed to protect against (controlled, i.e. intolerable risk), e.g. a 100-year event. In that context, the risk related to events that exceed the protection goals (accepted, uncontrolled risk), e.g. due to cases of overload or failure, constitutes a crucial part of residual risk. Residual risk comprises also those risks that are related to unawareness and/or ignorance, an incorrect assessment of risks or inappropriate measures to control them (Schneiderbauer et al., 2018).

Resilience: The ability of a system, community or society exposed to *hazards* to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazardous event, trend or disturbance in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through *risk management*. The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance (UNDRR, 2017; IPCC, 2022).

Response: Actions taken directly before, during and immediately after an emergency to save lives, reduce impacts, ensure public safety, meet basic subsistence needs and quickly repair the most needed infrastructure. Effective and timely *response* and disaster relief require the coordinated intervention of all civil protection actors, individuals, and communities (based on: UNDRR, 2017). Response measures include effective coordination, emergency protocols, relief operations, search and rescue, evacuation, emergency communications, and immediate humanitarian assistance.

Return period: Also known as the recurrence interval, it is the estimated average time between events of a given magnitude. It is expressed in years and derived from statistical analysis. For example, a 100-year return period for a flood means there is a 1/100 (or 1 %) chance of such a flood being exceeded in any given year (X-RISK-CC, 2026).

Risk (disaster risk): The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. (Disaster) risk is determined probabilistically as a function of *hazard*, *exposure*, *vulnerability*, and *capacity*. Relevant adverse consequences include those on lives, livelihoods, health and well-being, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species (IPCC, 2021a). In the context of climate change impacts, risks result from dynamic interactions between climate-related *hazards* with the *exposure* and *vulnerability* of the affected human or ecological system to the hazards. Hazards, exposure and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence, and each may change over time and space due to socioeconomic changes and human decision-making (IPCC, 2022).

Risk drivers: Processes or conditions, often development-related, that influence the level of *disaster risk* by increasing levels of *exposure* and *vulnerability* or reducing *capacity*. Underlying disaster risk drivers — also referred to as underlying disaster risk factors — include poverty and inequality, climate change and variability, unplanned and rapid urbanization and the lack of *disaster risk* considerations in land management and environmental and natural resource management, as well as compounding factors such as demographic change, non-disaster risk-informed policies, the lack of regulations and incentives for private disaster risk reduction investment, complex supply chains, the limited availability of technology, unsustainable uses of natural resources, declining ecosystems, pandemics and epidemics (UNDRR, 2017).

Risk exposure: The extent to which an entity is subject to potential loss or harm from a specific *risk*.



Risk management capacity: The combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce *disaster risks* and strengthen *resilience*. Capacity may include infrastructure, institutions, human knowledge and skills, and collective attributes such as social relationships, leadership and management (UNDRR, 2020)

Risk management: Plans, actions, strategies or policies to reduce the likelihood and/or magnitude of adverse potential consequences, based on assessed or perceived *risks* (IPCC, 2022).

Risk map (risk mapping): Geographic map that shows not only where a hazardous event may occur and its characteristics (intensity, likelihood, extent) but combines the *hazard* with information on *exposure* and *vulnerability*. It shows the potential consequences of a hazard on people, buildings, infrastructure, and the environment, accounting for factors that determine potential damage and loss, such as population density, building quality, land use, and coping capacity. In simple terms, risk mapping answers the question: ‘what can happen, who or what will be affected, and how severe could the impacts be?’ More widespread and systematic application of risk mapping can crucially support risk-based decision making on land use and building design, enabling differentiated allocation of different forms and intensities of land use according to their risk levels.

Risk owner: Risk owners are persons, institutions or other entities responsible for managing *hazards*, *exposure*, *vulnerabilities* and resulting *risk*.

Risk transfer: The process of formally or informally shifting the financial consequences of particular risks from one party to another, whereby a household, community, enterprise or state authority will obtain resources from the other party after a disaster occurs, in exchange for ongoing or compensatory social or financial benefits provided to that other party. Insurance is a well-known form of risk transfer, where coverage of a risk is obtained from an insurer in exchange for ongoing premiums paid to the insurer. Risk transfer can occur informally within family and community networks where there are reciprocal expectations of mutual aid by means of gifts or credit, as well as formally, wherein governments, insurers, multilateral banks and other large risk-bearing entities establish mechanisms to help cope with losses in major events. Such

mechanisms include insurance and reinsurance contracts, catastrophe bonds, contingent credit facilities and reserve funds, where the costs are covered by premiums, investor contributions, interest rates and past savings, respectively (UNDRR, 2017; IPCC, 2022).

Structural measures: Any physical construction to reduce or avoid possible impacts of *hazards*, or the application of engineering techniques or technology to achieve hazard resistance and *resilience* in structures or systems (UNDRR, 2017). Common structural measures for disaster risk reduction include dams, flood levies, retention basins, property-level asset protection measure, or evacuation shelters.

Vulnerability: The propensity or predisposition to be adversely affected. The conditions are determined by physical, social, economic or environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of *hazards*. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2022; UNDRR, 2017).

Vulnerability lock-in: Refers to a situation in which people, communities, systems, or places become trapped in patterns of *vulnerability* due to past decisions, structures, or practices that are difficult to change, even when those vulnerabilities are well understood. It occurs when *path-dependent* choices—such as settlement patterns, infrastructure investments, institutional arrangements, or livelihood strategies—create self-reinforcing conditions that continue to *expose* actors to *hazards* and limit their *capacity* to adapt or reduce risk.

Weather extreme (climate extreme, extreme weather or climate event): The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classified as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., high temperature, drought or heavy rainfall over a season). For simplicity, both extreme weather events and extreme climate events are referred to collectively as climate extremes (IPCC, 2022, 2021a).



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