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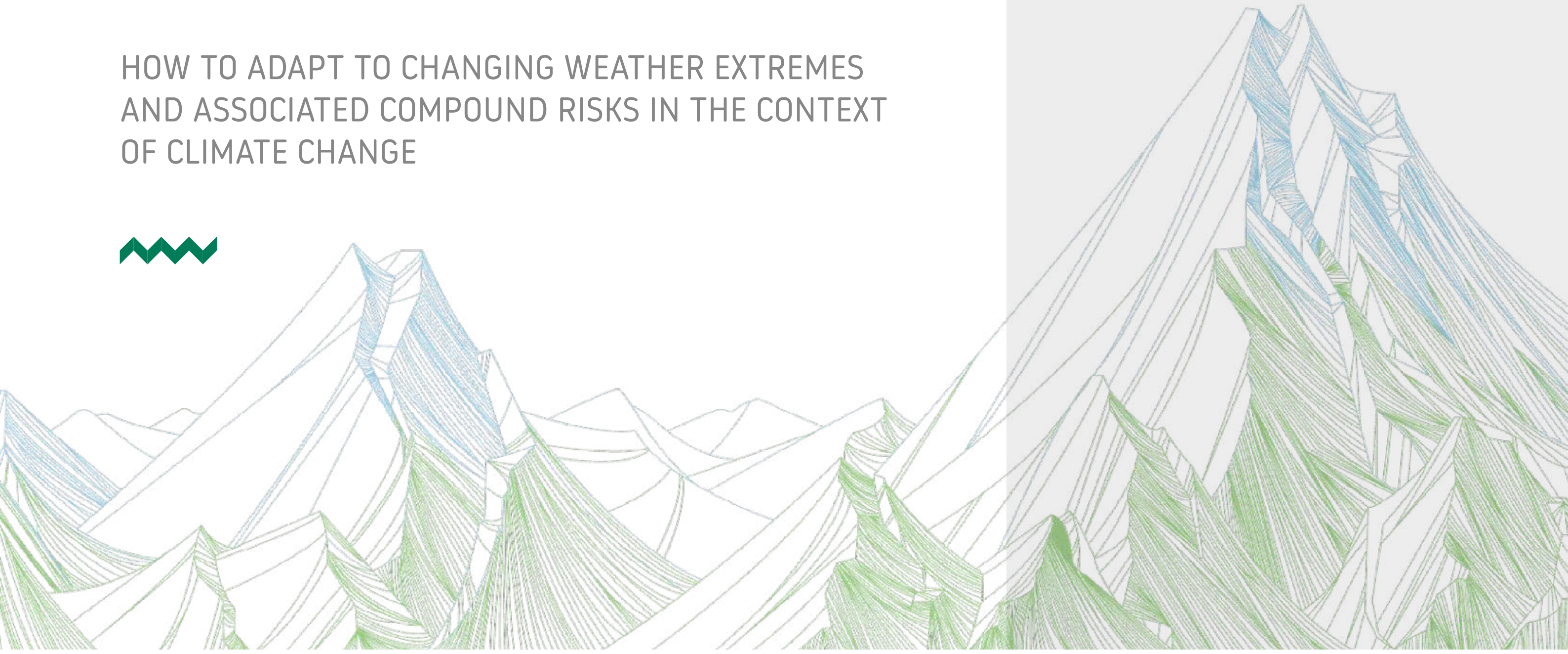
X-RISK-CC

PILOT DOSSIER

EGA VALLEY/CAREZZA IN SOUTH TYROL

HOW TO ADAPT TO CHANGING WEATHER EXTREMES AND ASSOCIATED COMPOUND RISKS IN THE CONTEXT OF CLIMATE CHANGE



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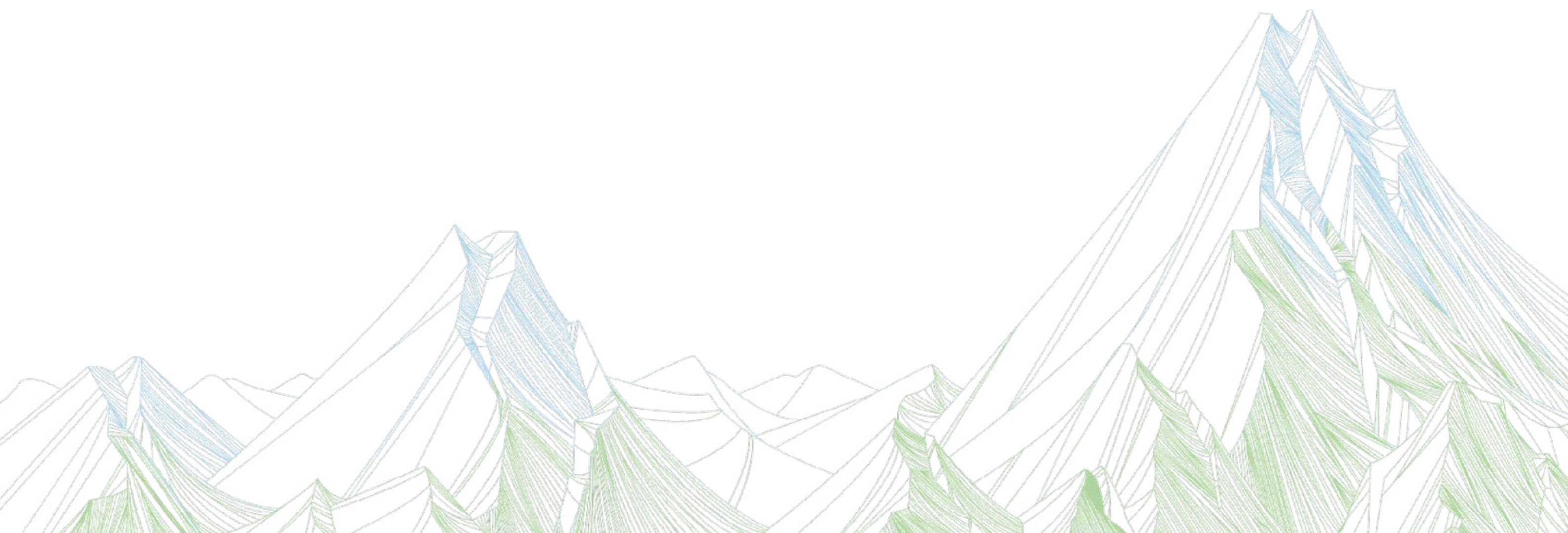
EGA VALLEY/CAREZZA IN SOUTH TYROL

HOW TO ADAPT TO CHANGING WEATHER EXTREMES AND ASSOCIATED COMPOUND RISKS IN THE CONTEXT OF CLIMATE CHANGE

THIS DOSSIER

The dossier focuses on the Ega Valley/Carezza in South Tyrol (northeastern Italy) used as a pilot area in the X-RISK-CC project. The dossier is designed to make the local knowledge developed by the project accessible to the general public. It provides information on past and future weather extremes, associated hazards and risks, and proposed actions to improve the future risk management in the area.



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X-RISK-CC - Alpine Space Programme

INTRODUCTION

THE BACKGROUND

In recent years, the Alps have experienced unprecedented weather extremes such as heatwaves and droughts, heavy rains and storms, which have had severe impacts on the environment, society and the economy. These events have challenged the risk management capacities of the affected Alpine regions. The scale (*magnitude*) and local severity (*intensity*) of such extremes can lead to multiple simultaneous (*compound*) impacts and cascading effects, resulting in complex, long-lasting or even irreversible consequences.

Recent scientific evidence indicates that climate change (CC) is increasing both the intensity and frequency of extreme meteorological events. However, the understanding of their compound and cascading impacts—and how to manage them—remains limited. On the regional level, these events are not adequately addressed within current Disaster Risk Reduction (DRR) frameworks. Similarly, where Climate Change Adaptation (CCA) plans exist, they often underestimate the severity of extreme events and associated risks, and frequently lack concrete, actionable measures.

THE PROJECT AND ITS GOALS

The **X-RISK-CC** project (full title: "*How to adapt to changing weather e***X***tremes and associated compound and cascading* **RISK***s in the context of* ***C****limate* ***C****hange*") is funded by the European Union and aims to improve the management of risks related to extreme weather and natural hazard events under climate change in Alpine regions. This goal is pursued through the collaboration of scientists, risk managers and policy makers on local, national and international levels.

In X-RISK-CC, risks are defined as the adverse consequences caused by weather extremes (e.g., heavy rainfall) triggering natural hazards (e.g., flooding), which in turn affect human systems (e.g., loss of private property). Risk is therefore not determined by weather and natural hazards alone, but by their interaction with exposure (e.g., buildings located in flood-prone areas) and vulnerability (e.g., lack of flood protection infrastructure) within socio-economic systems (***FIGURE 1***).

Understanding and managing current and future risks requires not only the analysis of weather extremes and resulting hazards, but also a consideration of the evolution of human systems in the region and potential risk management solutions. Since weather cannot be controlled, risk reduction must focus on measures that decrease vulnerabilities, reduce exposure or, where possible, mitigate the hazard itself.

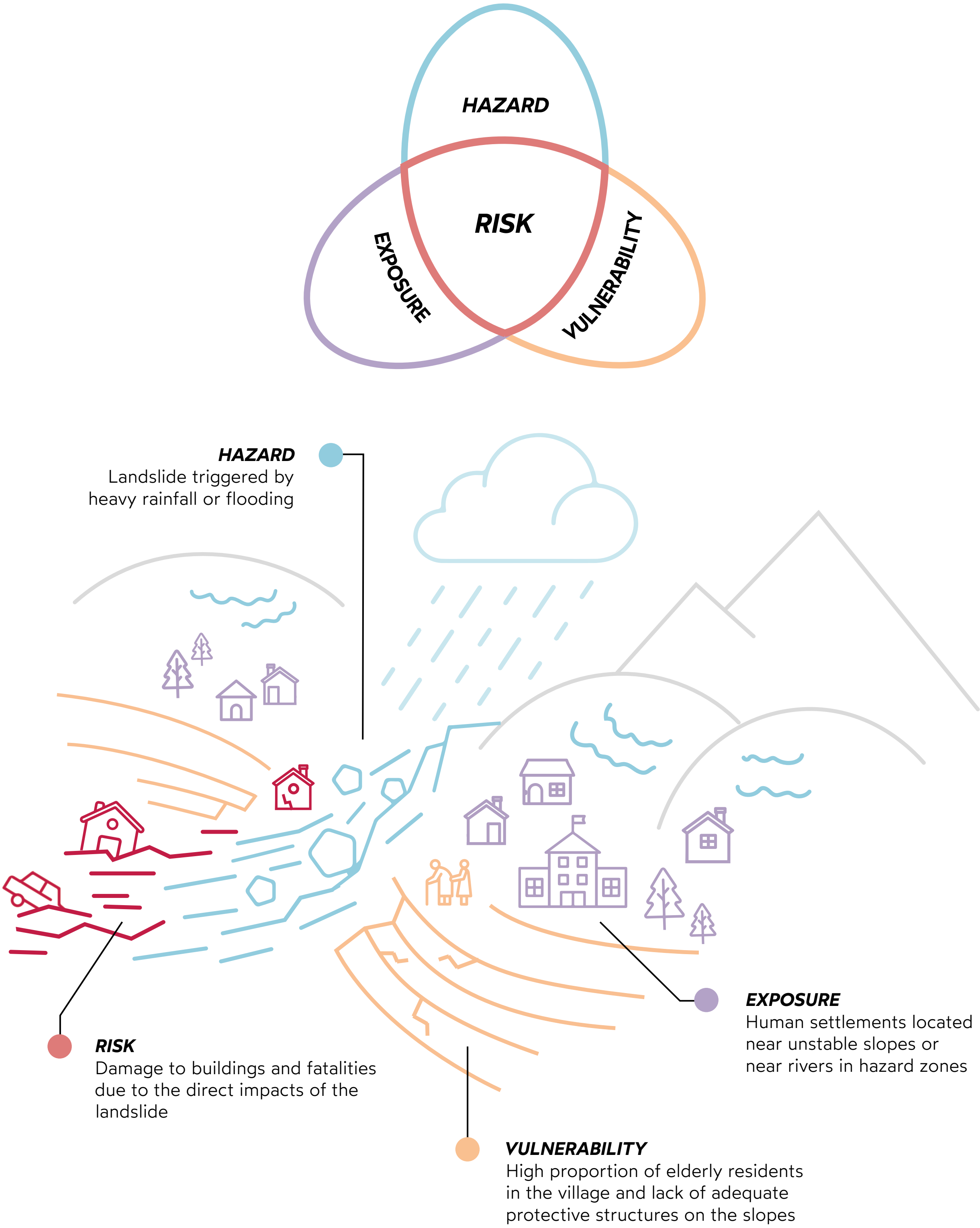


FIGURE 1: *Illustrative examples of hazard, exposure and vulnerability contributing to risk (the concept of risk is based on the framework developed by the Intergovernmental Panel on Climate Change - IPCC).*

The main questions guiding the X-RISK-CC project are:

→ Are we adequately prepared to cope with extreme weather events?

→ What gaps exist in current risk management practices, based on recent experiences?

→ How will weather extremes and related risks evolve in the Alps?

→ How can local risk management practices be improved to address future weather extremes?

The project begins with an analysis of past extreme weather events and their projected future trends, assessing the hazards they trigger and integrating these with data on exposure, vulnerability and impacts. This approach is used to evaluate existing risk management practices and to develop concrete measures that strengthen resilience to future risks.

In a complex system like the Alpine region, which is particularly prone to weather extremes and natural hazards, risk arises from multiple, often interconnected factors. Identifying effective points of intervention requires a thorough understanding of local conditions.

Widespread windthrow as a consequence of the Vaia storm on the territory of the pilot area (Source: Civil Protection Agency of the Autonomous Province of Bolzano).

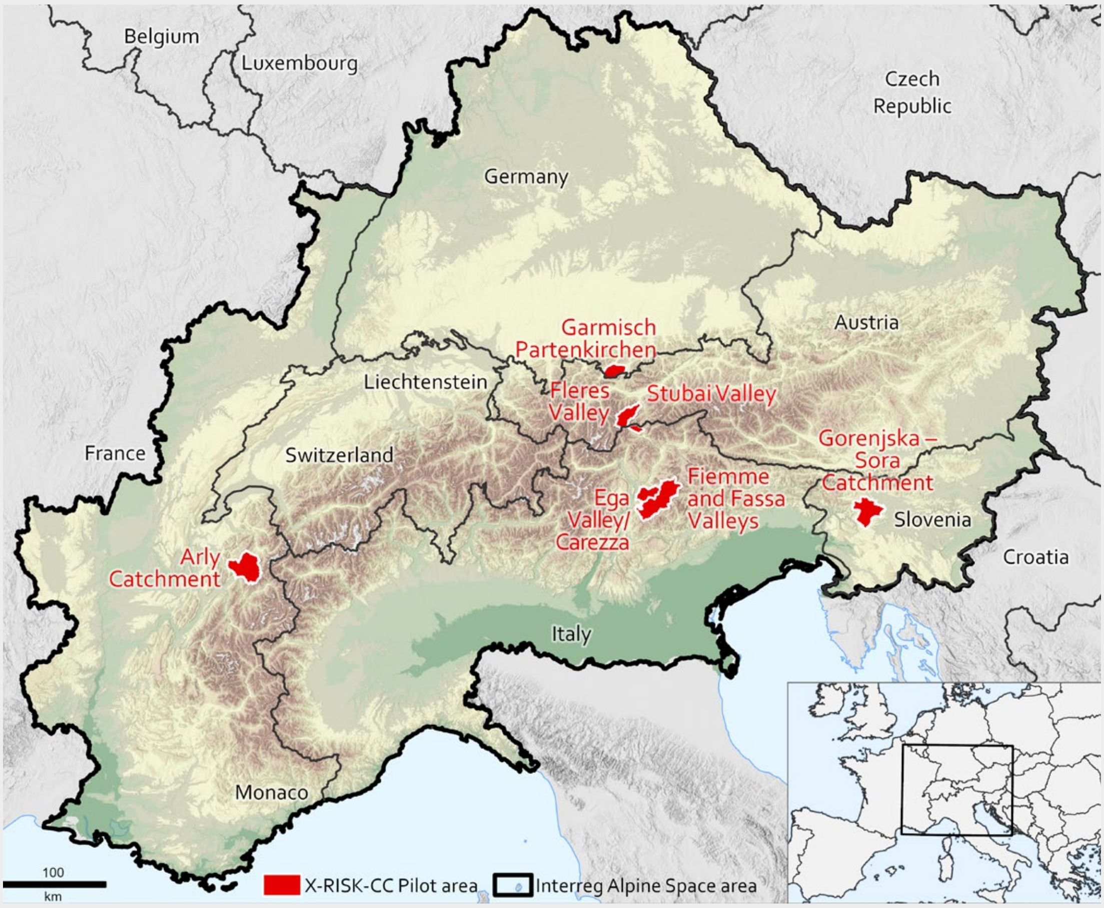


FIGURE 2: *Map illustrating the pilot areas (shown in red) of the X-RISK-CC project.*

To this end, specific pilot areas across the Alps (***FIGURE 2***) have been selected as representative case studies for detailed analyses and the development of tailored risk management solutions. In these areas, progress is driven by close collaboration with local risk managers and stakeholders. Their active involvement is essential both for identifying effective measures and for translating local knowledge into transnational recommendations.

PILOT AREA: EGA VALLEY/CAREZZA
(SOUTH TYROL, ITALY)

GEOGRAPHICAL AND ENVIRONMENTAL SETTING

The Ega Valley/Carezza is located in South Tyrol in the eastern Italian Alps (***FIGURE 3***). It covers an area of approximately 226 km^2, which is predominantly mountainous, with elevations ranging from about 450 meters (m) above mean sea level (a. m. s. l.) in the west of the valley to 2,750 m a. m. s. l. in the east. The region includes three main municipalities: Nova Ponente, Nova Levante and Aldino. All are located above 1,000 m a. m. s. l. and are well-known tourist destinations. The largest concentration of tourism infrastructure and ski areas is located in the municipality of Nova Levante.

Due to its mountainous morphology, the area is prone to natural hazards, particularly debris flows, landslides and flooding, which can have serious consequences for both residents and tourists, especially during peak seasons.

The region is largely covered by spruce-dominated forests, whose protective functions and ecosystem functions can be weakened by various disturbances, including windthrow, heavy snow loads, and prolonged drought. Disturbed forests, when combined with favourable meteorological conditions, increase the risk of bark beetle outbreaks, which further damage trees and reduce root stability.

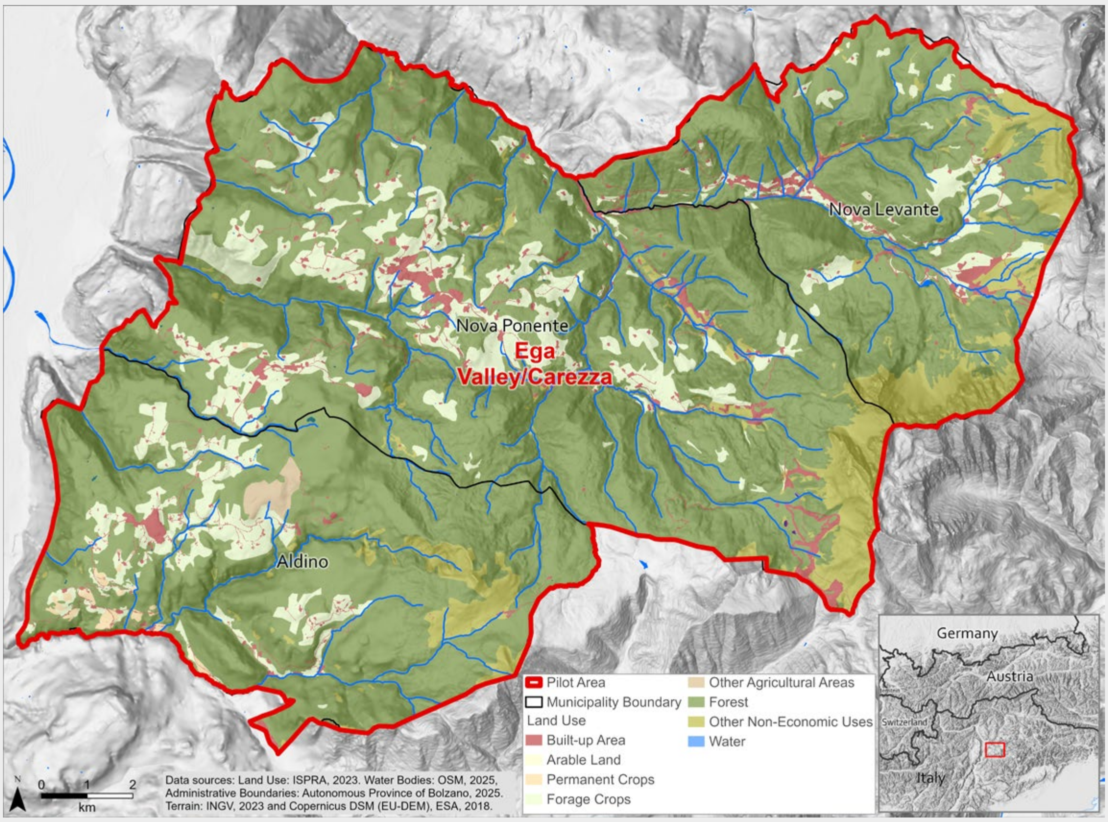


FIGURE 3: *Map of the pilot area Ega Valley/Carezza (in red).*

Additional information about the Vaia storm in South Tyrol can be found in the publications of the Autonomous Province of Bolzano:

The Climareport Extra 27-30 October 2018

The Report of Natural Hazards 2018

In 2018, the area was hit by an exceptional Mediterranean storm named **Vaia,** which crossed the eastern Alps between October 27th and 30th, causing severe damage. During the first three days of the event, most observation sites in South Tyrol and in Trentino measured **record-breaking cumulative precipitation**. About 200 mm in 72 hours were measured at stations in Ega Valley/Carezza, while even higher amounts were observed in Trentino, with some locations exceeding 400 mm and even 600 mm.

On October 29th, **exceptionally strong winds** occurred in combination with heavy rainfall. The highest wind speeds were recorded between 1,500 and 2,000 m a. m. s. l., with gusts reaching 120 km/h in the area. The combination of intense precipitation and extreme wind speeds triggered **windthrows, floods and debris flows**.

In South Tyrol, the Vaia storm affected approximately 6,000 hectares of forested land, nearly 2 % of the total forested area of the province. The Ega Valley/Carezza was among the areas most seriously impacted by the storm. The massive number of fallen trees **significantly altered the forest landscape**, and the effects of the event are still clearly visible today (***FIGURE 4***).

Within the X-RISK-CC project, we analysed how risks associated to the complex impacts of **compounded precipitation and wind speed extremes** – such as those observed during the Vaia storm – may evolve in the pilot area in the future.

FIGURE 4: *Windthrown trees after the Vaia storm in the area of Carezza Pass in South Tyrol (Source: Civil Protection Agency of the Province of Bolzano).*

PAST AND FUTURE WEATHER EXTREMES

In South Tyrol, where Ega Valley/Carezza is located, intense precipitation events occur most frequently in summer, when thunderstorms are more likely and are enhanced by the mountainous topography. However, intense precipitation events can also occur in autumn, when the region is exposed to moist air masses from the Mediterranean Sea.

Based on measurements from weather stations between 1991 and 2020, the annual maximum of daily total precipitation typically ranges between 60 and 70 mm, with the highest intensities occurring in summer and secondarily in autumn. An analysis of observations over the past 70 years reveals an overall tendency toward more intense and frequent daily or multi-day precipitation extremes. An extreme event with precipitation amounts comparable to those recorded during the Vaia storm now has a shorter return period than in the past. Additionally, the large-scale atmospheric circulation patterns that characterised the Vaia storm have become more frequent, indicating an increase in favourable conditions for similar extreme weather events.

Looking ahead, more intense and frequent precipitation events are projected. By the end of the century, daily precipitation extremes could become up to + 16 % more intense than today, depending on the global warming level or, in other words, on the effectiveness

Dealing with uncertainties

Climate projections are derived from different models, each of them providing different results. For simplicity, projections are often averaged, even though the scenarios consist in a range of plausible values, whose width depends on the level of uncertainty of the models in representing the future evolution of a certain process. Moreover, projected numbers must be interpreted as an estimate of the magnitude of changes and not as exact predictions for specific locations and dates (e.g., rainfall on a particular day in October 2050). Nevertheless, the consistent signal of increasing precipitation extremes is an important message for risk managers: the likelihood of natural hazards and cascading impacts, especially when precipitation extremes occur in combination with high wind speed, is rising.

The **return period**, also known as recurrence interval, is the estimated average time between events of a certain magnitude, expressed in years and based on 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.

of climate change mitigation efforts. An event like the Vaia storm will be less rare in the future. On average, across Trentino-South Tyrol region, the return period of such an event is projected to be halved if global warming reaches + 3 °C.

For example, the accumulated precipitation of 194 mm recorded during the Vaia storm in Cavalese (in the nearby Fiemme Valley, Trentino), which currently corresponds to a 300-year event, could have a return period of less than 100 years by 2100.

While the wind speed values measured during the Vaia storm were the highest on record at most weather stations in the area, an in-depth analysis of past changes of extreme wind speed is not possible due to the limited period covered by available observations. As for the future, no clear trend in wind conditions is projected over the area.

However, due to the projected increase in heavy precipitation, a rise in compound extreme precipitation and wind events is expected in the region, especially under the warmest climate scenarios. Under + 4 °C global warming, the annual frequency of such events could increase by + 18 % compared to current conditions.

Global warming levels are used to illustrate future scenarios where specific increases in mean global temperature with respect to the preindustrial period (1850-1900) are reached. A global warming level of + 3 °C indicates a world 3 °C warmer than in 1850-1900.

The term **permafrost** refers to the portion of soil which remains frozen (i.e., with a temperature equal or below 0 °C) for at least two consecutive years. Due to warming, permafrost in the Alps is decreasing and shifting to higher elevations. Where permafrost disappears, soil is less stable so collapses become more likely, and more sediments can be mobilized downstream.

HAZARDS IN PRESENT AND FUTURE CLIMATE

Due to the topography and climatic characteristics of the area, geo-hydrological processes are the most frequent weather-induced natural hazards occurring in the Ega Valley/Carezza. These are generally triggered by intense rainfall or rapid snowmelt and include flash floods, landslides and rockfalls. In addition to precipitation intensity, permafrost melting can contribute to increased soil instability and sediment availability, which may lead to material flowing from the mountain slopes and impacting valley floors.

The forests covering most of the area, play a protective role, helping to stabilise slopes and reduce the risk of avalanches, landslides and rockfalls. However, when root stability is compromised due to disturbances (e.g., windthrow or insect infestations), soil erosion and the occurrence of hazardous phenomena become more likely.

Although historical data from the past 20 years show no clear trend in the frequency of natural hazards in the area, the intensification of extreme precipitation events, coupled with accelerated permafrost thaw due to warming, is expected to increase the likelihood and magnitude of geo-hydrological hazards in the future.

Ongoing warming and drought conditions may also lead to more frequent forest disturbances. In particular, reduced root stability, especially in the shallow-rooted spruce forests characteristic of the area, makes forests increasingly vulnerable to windthrow and bark-beetle infestations during storm events.

In the area affected by storm Vaia, where forest cover was lost on steep slopes, the probability of hazardous processes is expected to remain high for the coming decades, until forest regeneration occurs. Conversely, the risk of further windthrows in these already affected areas is expected to remain low.

Participatory workshop held in the pilot area of Ega Vallay/Carezza during the X-RISK-CC project (Source: Civil Protection Agency of the Autonomous Province of Bolzano).

Natural hazards during the Vaia storm (October 2018)

During the Vaia storm, which struck the area at the end of October 2018, intense and persistent precipitation caused widespread instability, with several floods and mass movements recorded in the Ega Valley/Carezza. Although these events affected a large portion of the area, the magnitude of single events was not exceptional compared to other events observed over the past 20 years.

The exceptional aspect of the event was primarily the wind speed, which caused severe forest damage. Around 6,000 hectares of forest in South Tyrol experienced scattered windthrows, especially in the Ega Valley/Carezza. Together with the municipality of San Vigilio di Marebbe, this area accounted for two-thirds of all windthrows recorded in South Tyrol.

The damaged trees included many with protective functions—about 25 %—leading to a significant increase in slope instability in numerous areas. The situation worsened in the following months, as the combination of the massive volume of windthrown trees, prolonged drought and mild temperatures created favourable conditions for extensive bark-beetle outbreaks, which further damaged the forests.

Widespread windthrow as a consequence of the Vaia storm on the territory of the pilot area (Source: Civil Protection Agency of the Autonomous Province of Bolzano).

Rising temperatures and more frequent droughts may also promote the ignition and spread of wildfires. While no significant increase in wildfires has been observed to date, wildfire has been identified as an emerging hazard in the area in the near future. A review and adaptation of current risk management practices can help ensure preparedness for future wildfire-related risks in the region.

What is a Hazard Map?

A hazard map illustrates areas potentially affected by a specific natural hazard. It uses colour coding to represent the **likelihood and intensity** of a hazard occurring in each location. Hazard maps are essential tools for **disaster risk management** and **spatial planning**, as they help guide land use decisions, infrastructure development, and emergency preparedness.

CURRENT AND FUTURE IMPACTS AND RISKS

Ega Valley/Carezza includes three municipalities, all situated in a mountainous environment. Aside from the highest mountain peaks and the main centres located in lower-elevation areas, the rest of the region is characterised by small villages, agricultural land, forests, meadows and pastures at higher elevations.

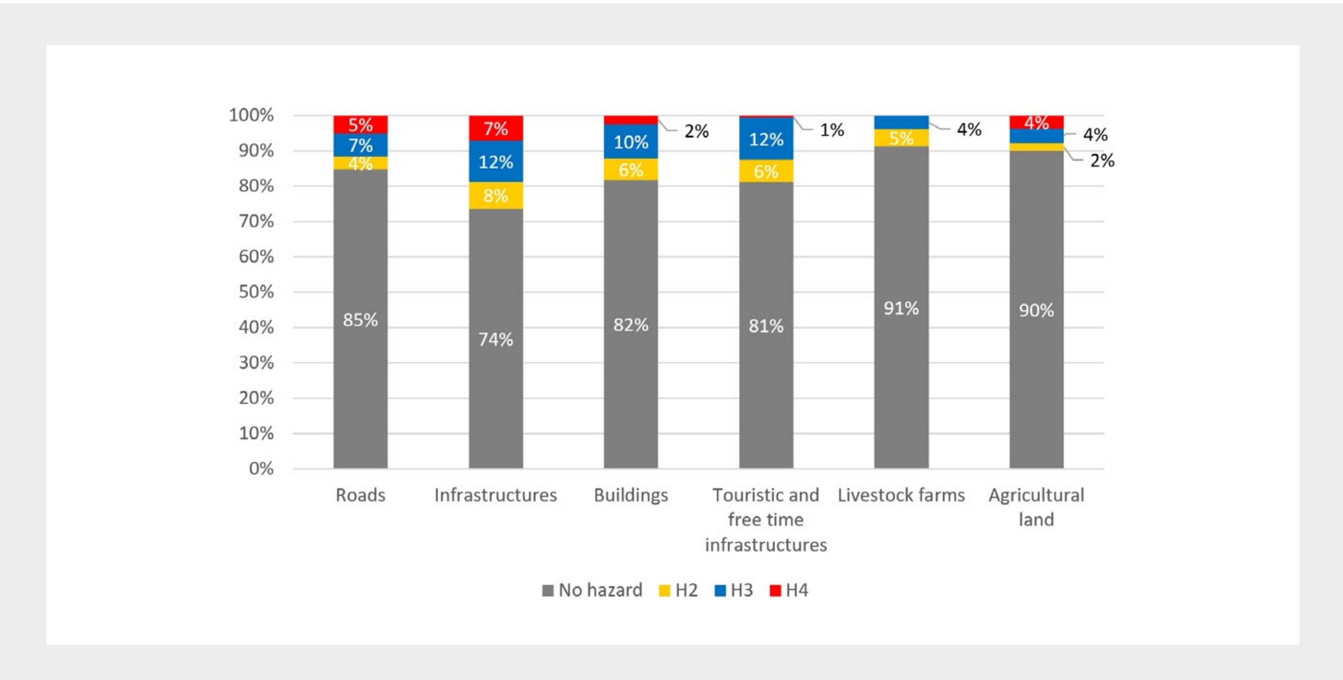


FIGURE 5: *Distribution of main exposed elements over hazard classes in Ega Valley/Carezza. The colour codes indicate the level of probability of hazard occurrence according to the provincial system: grey = low probability, H2 = medium probability, H3 = high probability and H4 = very high probability (Source: Autonomous Province of Bolzano/Bozen).*

Almost 75 % of the area is covered by forest, partly managed for economic purposes and partly serving protective and ecological functions. In this context, key elements that can be directly or indirectly damaged by geo-hydrological hazards include residents, private properties and buildings, agricultural activities (especially forestry and livestock farming), roads and bridges, and infrastructure for water and energy supply.

According to official hazard zone maps, most of these exposed elements are currently located outside designated hazard-prone areas (***FIGURE 5***). However, the area attracts thousands of visitors each year, leading to a tenfold increase in population during the summer and winter seasons. This makes tourists another major element at risk. Tourism accommodations and facilities can be severely impacted by hazards related to precipitation extremes and storms.

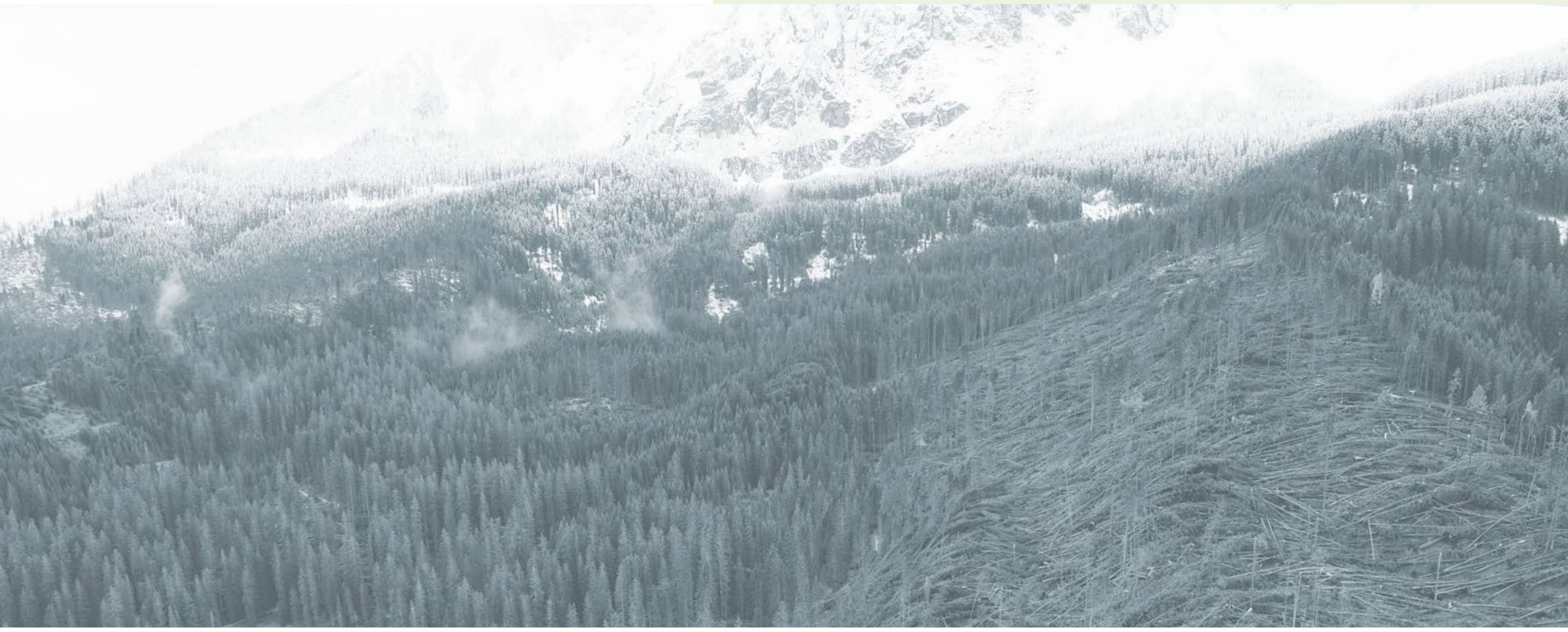
Impacts of the Vaia storm (October 2018)

During the Vaia storm in October 2018, several roads, bridges and infrastructure in Ega Valley/Carezza were damaged by floods and mass movements, limiting access to some villages. Hiking trails, cycling paths and pedestrian networks were also affected, with certain areas, particularly forested regions, remaining inaccessible for an extended period.

Extensive reconstruction and clean-up operations were required in the days and months following the event. The destruction of existing avalanche and rockfall barriers further increased risk in the area, which remained exposed to these hïazards until new protective structures were installed.

The unexpected surplus of wood to store and sell had negative economic consequences, including a sharp drop in prices and market saturation. The loss of forest cover also triggered long-term ecological impacts, particularly for wildlife, and altered the landscape and touristic appeal of the most heavily affected areas.

A complex recovery and restoration plan was launched and is still ongoing.



Widespread windthrow as a consequence of the Vaia storm on the territory of the pilot area (Source: Civil Protection Agency of the Autonomous Province of Bolzano).

While road closures and walking path damage may be resolved within a relatively short time, rebuilding accommodations and infrastructure can take months or even years, with long-term negative impacts on the tourism industry.

Forestry-related activities may also be indirectly affected by storm events as damaged trees can lead to significant losses in the wood market. In addition, the loss of protective forest cover on steep slopes may require the installation of artificial protective structures, often involving substantial costs.

If the upward trends in population growth and tourism continue, the total number of people exposed to hazards will increase. New infrastructure and buildings will be needed to meet this growing demand.

Areas designated for new development, known as "expansion zones", are mostly located outside current hazard zones. However, 93 % of these zones are already built up, leaving only 7 % available for future development. This poses a significant challenge for accommodating future construction without expanding into hazard-prone areas.

Moreover, the increasing intensity of meteorological extremes could lead to revisions in current hazard mapping, with additional areas potentially reclassified into higher hazard categories. The combined effect of intensified precipitation and the loss of protective forests will likely increase the probability of geo-hydrological hazards, even in areas previously considered at lower risk.

Participatory workshop held in the pilot area of Ega Vallay/Carezza during the X-RISK-CC project (Source: Civil Protection Agency of the Autonomous Province of Bolzano).

THE ROLE OF VULNERABILITY IN RISK

The impacts of a hazard event can be exacerbated not only by the event's intensity or the number of exposed elements, but also by other factors such as social characteristics (e.g., an ageing population, low risk perception, or lack of awareness) and the condition and maintenance of buildings and infrastructure. Tourists—particularly international visitors—are expected to be especially vulnerable, as they often lack the same level of risk awareness and familiarity with local emergency procedures.

Greater impacts are also more likely when risk management practices are inadequate—for example, in the absence of protective measures such as rockfall barriers—or when preparedness for responding to multiple simultaneous or cascading hazards is low, as during the October 2018 storm.

Forest planning and management should also reflect future challenges by increasing ecosystem resilience to extreme events. In particular, given that monoculture spruce forests are especially vulnerable to windthrow, a more diversified forest ecosystem may be preferable to enhance resilience. In this context, a thorough evaluation of how current risk management strategies need to adapt to changing climatic and socio-economic conditions is crucial for safeguarding people and their activities.

Widespread windthrow as a consequence of the Vaia storm on the territory of the pilot area (Source: Civil Protection Agency of the Autonomous Province of Bolzano).

RISK MANAGEMENT

RISK MANAGEMENT CYCLE

Effective management of natural hazard risks requires systematic planning and coordination. Risk management provides a structured and iterative process aimed at minimizing risks and enhancing community resilience. This process involves a continuous cycle of interconnected actions, as illustrated in the infographic.

The main phases of the **risk management cycle** include:

PREVENTION

PREPAREDNESS

RESPONSE

RECOVERY

The interphases —the transitions between phases— are critical components of the risk management, as they involve shifts in responsibilities, resources, and attention. These interphases (Prevention-Preparedness, Preparedness-Response, Response-Recovery, and Recovery-Prevention) require particular attention to ensure smooth transitions, clear communication across phase boundaries and to avoid potential gaps in risk management.

Participatory workshop held in the pilot area of Ega Vallay/Carezza during the X-RISK-CC project (Source: Civil Protection Agency of the Autonomous Province of Bolzano).

Activities and measures taken in advance to ensure effective response.

Early warning systems, emergency planning, training and exercises, resource pre-positioning, public awareness campaigns, and establishment of coordination mechanisms.

Capacity to act and prepare before a hazardous event strikes.

Actions taken during and immediately after an event to save lives, reduce impacts, protect the environment and meet basic subsistence needs.

This includes effective coordination, emergency operations, search and rescue, evacuation, emergency communications, and immediate humanitarian assistance.

Emergency response requires the coordinated intervention of all civil protection actors.

Measures taken to mitigate the risk. This includes structural measures and non-structural measures.

STRUCTURAL MEASURES
protective structures, nature-based solutions, retention areas, asset protection measures

NON-STRUCTURAL MEASURES
land-use planning, hazard zone maps, education, communication and legislative frameworks

Supports acceptable levels of risk society is willing to live with.

Actions taken after a disaster to overcome the event and enhance resilience through build back better principles.

This includes restoration of infrastructure and services, economic recovery, psychosocial support,participative reconstruction planning, and implementing lessons learned.

Integrates adaptive actions and long-term thinking.

*Key actions and measures associated with each phase of the risk management cycle, including both **structural** and **non-structural** measures that support prevention, preparedness, response, and recovery.*

STAKEHOLDER INVOLVEMENT APPROACH

Three participatory workshops were held in the pilot area to analyse and improve local risk management of natural hazards driven by weather extremes. Participants included different entities dealing with risk: municipalities, forest services, civil protection, torrent control authorities, local enforcement bodies, technical experts, research institutions, and representatives from different levels of administration. During **the first workshop** the recent extreme events were reviewed to evaluate what worked well and what failed in terms of risk management so to identify entry points for future improvements; in **the second workshop** participants were invited to evaluate the current capacity and potential challenges in managing similar events but in a plausible future context, based on analysed climate projections and possible socio-economic evolution; **the third workshop** was focused on developing concrete action plans for improving the management of future risks related to climate extremes. All workshops were guided by the SMART approach—setting goals that are **Specific, Measurable, Achievable, Relevant, and Time-bound**—to ensure the results were realistic, actionable, and tailored to the region's needs.

1. Workshop

ANALYSE THE PAST AND FIND THE GAPS

2. Workshop

LOOK AT THE FUTURE AND DEFINE CHALLENGES

3. Workshop

MAKE THE PLANS

Participants in the workshops in the Ega Valley/Carezza pilot area

- Civil Protection Agency Autonomous Province of Bolzano
- Mayor and Administration of the Municipalities of Aldino, Nova Ponente and Nova Levante
- Forest Inspectorates and Forest Management Planning Department of Bolzano
- Forest Stations of the pilot Municipalities
- Provincial Office for Torrent and Avalanche Control
- Provincial Office for Hydrology and Dam Structures
- Provincial Office for Meteorology and Avalanche Warning
- Provincial Warning Center
- Provincial Department of Road Services
- Provincial Department of Agriculture
- White Cross Operators
- Provincial Geological Service
- Local Electricity Operators
- Tourism Association of the Ega Valley
- Provincial Professional Fire Brigade
- Local Volunteer Fire Brigade
- Brennero Avalanche Commission

RISK MANAGEMENT GAPS

The **debriefing and analysis of the Vaia storm** in the pilot area **Ega Valley/Carezza**, carried out during the first workshop with representatives from municipalities, provincial offices, emergency services and reconstruction managers, highlighted several weaknesses in the **preparedness phase**. In particular, the need emerged to **improve monitoring and warning systems for strong valley winds**, and to strengthen **risk communication and awareness-raising** among residents, tourists and users of the area, in order to ensure better understanding of civil protection messages.

In contrast, the **response phase** was identified as the strongest element. Despite the exceptional nature of the event—multiple municipalities affected and access routes between settlements interrupted—the reaction was rapid, coordinated and sustained until basic safety conditions were restored. This was made possible thanks to effective cooperation among municipal authorities, mayors acting as local civil protection authorities, volunteer fire brigades, operational teams, the Civil Protection Service, the Provincial Office for Torrent and Avalanche Control and local companies equipped with heavy machinery.

However, **critical issues** emerged, particularly regarding **human resources**. Firefighters had to operate for many hours under **high-risk conditions**, due to the scale and intensity of the event. Moreover, responders had to work in the presence of extreme wind gusts—a scenario not fully covered in existing **self-protection and emergency training**.

Regarding **prevention**, the discussions underscored the importance of maintaining **resilient forests with diverse species and age classes**, capable of effectively fulfilling their protective function. It was also emphasized that **strong valley winds** must be recognised as a relevant hazard scenario and integrated into warning systems—something that by now has been already addressed with the introduction of the **Civil Protection Warning Bulletin for the Autonomous Province of Bolzano**, which includes **severity levels for strong winds**.

The **Warning Bulletin** provides, for the Autonomous Province of Bolzano, an assessment of the level of hazard (**none, low, moderate,** or **high** criticality), as well as the corresponding **warning levels** for **eight types of natural events**: Mass movements and debris flows, Severe thunderstorms, Flooding, Snowfall in valley areas, Avalanches, Strong winds, Extreme temperatures, Wildfires.

Provincial Warning Center

https://allerte.provincia.bz.it/en/reports/risk-potential/map

Finally, for the **recovery phase**, strong collaboration between authorities, volunteers and landowners was acknowledged. However, the enormous volume of fallen trees required **long-term support from external companies**, as the situation could not be managed with internal resources alone. The workshop also highlighted the importance of **knowledge transfer and experience exchange**, which are crucial for improving future post-event interventions.

GAPS IDENTIFIED

The key gaps identified for past events and for the projections for the future through the participatory workshop process are reported in the following sections, first for each phase of the risk management cycle, then for the interphases between them.

GAPS PER PHASE

PREVENTION

- At the time of the Vaia storm in 2018, the provincial warning bulletin was not yet operational as a daily product. Today, the risk associated with strong winds in lower valley terrain — which caused the most significant damage during the Vaia storm — is integrated into the warning assessment system. However, this assessment remains particularly challenging, as South Tyrol's alpine morphology, characterised by narrow valleys and steep terrain, amplifies local wind effects and limits modelling predictability.
- Prevention of wind impacts relies mainly on indirect measures such as forest management. There are no specific structural protection measures designed to mitigate extreme wind events (with the exception of snow fencing structures for avalanche risk related to wind-transported snow).
- The forest structure — consisting of homogeneous stands in terms of species composition and age, with a prevalence of spruce — showed higher susceptibility to windthrow and to the creation of potential hydraulic blockages. The event highlighted the need to steer forest management towards more diverse and resilient formations.
- Hydraulic structures generally performed well during the Vaia storm, although critical issues emerged regarding maintenance conditions and the possible accumulation of windthrown timber in these structures. In addition, some structures are undersized in light of increasingly intense extreme events expected under climate change, particularly in the case of compound or cascading hazards.
- Hazard mapping currently considers only simple scenarios, while cascading and compound events are not integrated adequately into hazard zone maps. Likewise, the effects of climate change on the frequency and intensity of extreme weather events — and their repercussions on the territory — are not yet incorporated into the directives governing hazard zone planning. Updated guidance on hazard scenarios is needed to properly reflect these phenomena.
- The update and revision of hazard zone plans — whether following extreme events and destructive natural processes, based on new modelling methodologies or for the construction of protection structures — does not occur systematically. Responsibility currently lies with municipalities, which are legally required to initiate these revisions. As a result, many hazard zone plans remain outdated or are not adjusted after relevant events or changes in risk conditions. A mechanism enabling updates also at provincial level, and not solely upon municipal initiative, would be necessary.

- Non-structural prevention measures — including spatial planning tools, targeted relocation, safeguarding retention areas, and investment in communication and risk awareness — remain undervalued or inconsistently applied in several cases. A clearer understanding of their strategic role in strengthening territorial resilience is needed to fully leverage their preventive potential.
- People present in the territory — particularly tourists and non-residents — are insufficiently aware of appropriate self-protection behaviour during severe wind and thunderstorm events, making it difficult for them to grasp the severity of the hazard and react appropriately.

PREPAREDNESS

- During the Vaia storm, meteorological data and monitoring networks were available, but shared operational thresholds, clear procedures, and defined organisational processes for timely and coordinated decision-making were lacking.
- Wind monitoring was not structured as an operative civil protection service (e.g., traffic-light warning systems, automatic notifications, dedicated nowcasting), which made it difficult to anticipate the development of impacts and to activate preparedness measures in time.
- During the Vaia storm, the large-scale extent and intensity of the event (driven by severe winds) over the affected area was not immediately foreseeable, and there was not yet a consolidated operational practice for intra- and inter-municipal coordination in the initial stages of an event of such magnitude.
- Exercises and training on complex and multi-hazard scenarios were not common practice, and delays were sometimes observed in operational coordination among multiple actors and structures operating at different administrative levels.
- Preparedness continued to rely largely on the availability of volunteers and staff, without a clearly defined strategy for dealing with potential shortages of human resources during prolonged or particularly intense emergency situations.

RESPONSE

- During the emergency, critical issues emerged in communication among rescue operators, particularly related to the vulnerability of cellular systems, radio battery limitations, and the lack of redundancy of emergency systems in case of blackouts and network outages.
- Managing communication to residents and non-residents proved challenging, with information channels overloaded and difficulties in providing clear, coherent and timely messages. At the same time, social media and private communication channels were heavily relied upon to inform both residents and visitors.
- Command and coordination structures generally worked, but the response highlighted a strong dependence on the prolonged commitment of operational teams, with associated risks related to fatigue, safety and maintaining operational continuity.
- Objective decision-support tools for prioritising interventions (triage) were lacking, especially in the presence of widespread, multiple damages across the territory.
- The spontaneous involvement of private citizens was positive, but not always integrated into structured procedures, resulting in uncoordinated actions or risks to volunteers themselves.
- Risk awareness among non-expert citizens — for example regarding unnecessary travels, entering unstable forested areas, or remaining in affected zones — was not always adequate, with some cases leading to additional risks and operational complications instead of reducing them.

RECOVERY

- The quantification of immediate and indirect damage caused by the Vaia storm, particularly those not immediately visible such as secondary structural damage or terrain instability, was complex and in some cases delayed, affecting the planning and organisation of post-event recovery activities.
- Some consequences of the event remain visible years later. The loss of protective forests due to wind-thrown trees, aggravated by subsequent phenomena such as warm winters, dry summers, and bark beetle infestations, reduced the protective function of forested areas and their capacity to mitigate landslides, debris flows, and other hydrogeological hazards in mountain territories.
- Local capacity to manage the fallen timber was limited due to insufficient companies and machinery. Dependence on external, including foreign, operators highlighted structural vulnerabilities of the system.
- Coordination among authorities, municipalities, forestry services, and affected landowners worked overall, but showed room for improvement, particularly in the allocation of responsibilities for reconstruction interventions, inter-agency communication, and medium-term planning.
- In the immediate aftermath of the event, recovery primarily focused on damage removal and restoration of the pre-event status quo. The “Build Back Better” principle, which later included the introduction of mixed-species forests, partial revision of hazard zone plans, and the reconstruction of roads and infrastructure more resilient to future multi-hazard scenarios, only became prevalent in a subsequent phase.

GAPS PER INTERPHASE

PREVENTION → PREPAREDNESS

- Gaps in structural prevention and territorial planning (particularly regarding wind, complex and cascading events, and forest management) significantly increase the complexity of the preparation phase, which must compensate through operational procedures, intensive monitoring, and operational management activities for the risk not reduced upstream.
- The lack of integration of compound and cascading risk scenarios into hazard maps limits the preparation phase's ability to define coherent thresholds, resources, priorities, and procedures in civil protection plans, necessitating a strong reliance on operational staff experience and real-time adaptations.
- The absence of climate change scenarios in hazard maps fails to consider projected increases in frequency and intensity of extreme events, restricting the planning of preventive and emergency management measures and the definition of adequate operational thresholds to protect the population and infrastructure.
- The limited inclusion of citizens, tourism associations, and economic operators in preventive activities makes the preparation phase more vulnerable, requiring additional interventions for communication, awareness-raising, and management of behaviour during alerts.

PREPAREDNESS → RESPONSE

- The absence of clear operational thresholds, standardized protocols for strong wind episodes, and decision-support tools makes the transition from preparation to response heavily dependent on subjective assessments, with risks of delays, inconsistencies, and decision-making overload.
- Difficulties in communicating forecast uncertainties and translating alerts into concrete actions limit response effectiveness, particularly regarding self-protection of the population and management of non-residents.
- Gaps in staff preparedness for large-scale events where inter-agency coordination is essential, in resource availability, and in communication system resilience become evident during the response, amplifying operational fatigue and risks to the safety of personnel.

RESPONSE → RECOVERY

- Decisions made during the response (intervention priorities, timber removal methods, management of infrastructure and land) directly affect the duration, cost, and effectiveness of recovery, sometimes generating side effects or rigidities that are difficult to correct later.
- The transition from response to recovery is a fragmented process, with uncertainties about roles and responsibilities of involved actors, about the management and allocation of financial resources, and the transparent communication of actions to the population.
- Information collected during the response is not always systematically and structurally transferred to the recovery phase, limiting the possibility of a comprehensive damage assessment and a real "Build Back Better" approach.

RECOVERY → PREVENTION

- Lessons learned during recovery are not always translated into concrete updates of plans, regulations, prevention tools, and management practices, creating the risk of reproducing the same vulnerabilities in future events.
- The pressure to rebuild quickly can conflict with objectives for vulnerability reduction, climate adaptation, and long-term planning, weakening the link between recovery and prevention.
- When recovery successfully integrates updated risk assessments, population involvement, and resilience principles, it becomes a key step in structurally strengthening prevention and reducing the complexity of subsequent phases.
- The timely integration of extreme events and structural protection infrastructure into hazard maps require a clear regulatory framework that establishes obligations and defined deadlines for updates, extending responsibility not only to municipalities but also to entities that build or manage works and event databases, ensuring that plans accurately reflect actual territorial conditions.
- Curiosity and the circulation of information about the post-event situation via social media have led citizens to enter areas with falling trees or unstable terrain, increasing exposure to residual risk and creating additional challenges for operational teams. This highlights the need to invest more systematically in preventive and continuous risk communication, so that the population understands the behaviour to adopt and avoid in the post-event phases.

UNDERSTANDING RISK TERMINOLOGY

Nowcasting is a short-term weather forecasting technique that provides predictions for the next minutes to a few hours. Unlike standard weather models, it focuses on very high-resolution, localized phenomena using real-time observations from radar, satellites, and ground sensors. The state of the art increasingly incorporates artificial intelligence to improve accuracy and speed in predicting the development and movement of thunderstorms, heavy rain, or strong winds. Nowcasting is particularly useful for early warnings and rapid decision making in emergency management.

Build back better means improving things during reconstruction rather than just rebuilding exactly as they were before. This approach uses lessons from the disaster to reduce future risks and prepare for climate change.

eg: instead of rebuilding the same road on landslide-prone slope, rerout it or add protective measures.

Participatory workshop held in the pilot area of Ega Vallay/Carezza during the X-RISK-CC project (Source: Civil Protection Agency of the Autonomous Province of Bolzano).

CO-DESIGNED TAILORED ACTIONS FOR THE PILOT AREA

Based on the main critical gaps in risk management capabilities identified during the participatory workshops conducted with local stakeholders and municipal authorities in the pilot area affected by the Vaia storm, a set of actions aimed at strengthening territorial resilience has been defined.

Among the identified initiatives, particular importance is given to the strengthening of the structured communication and coordination channel between the Fire Brigade, the Provincial Civil Protection Office and the technical service of Alperia, the electricity distributor in South Tyrol. This cooperation aims to improve the assessment of vulnerabilities affecting energy and telecommunication infrastructure and to ensure the optimal functioning of the radio communication system under emergency conditions.

In parallel, a forecasting system for very short-term thunderstorm prediction is currently being implemented, with the goal of increasing the accuracy and timeliness of severe storm warnings. In addition, the Provincial Functional Centre is developing a risk communication strategy to improve the dissemination of alerts not only among residents but also among tourists, with local tourism associations already expressing their interest in collaborating.

Finally, from 2026 onwards, the establishment of an intersectoral working group on hazard zone planning is foreseen, tasked with updating reference scenarios and related guidelines.

The complete list and details of the tailored action plan devised for the pilot area of South Tyrol are published in a separate document called **"Tailored Action Plan: South Tyrol"** which can be found at:

X-RISK-CC - Alpine Space Programme

https://www.alpine-space.eu/project/x-risk-cc/

CHALLENGES AND PERSPECTIVES

In the pilot area, one of the main critical issues concerns the extent of forest areas damaged by windthrow during the Vaia storm, which resulted in the loss of large sections of protective forest. At the same time, many of the remaining forest areas show vulnerability: low-diversity or monoculture stands, or stands already weakened by increasing bark beetle outbreaks, further reduce the natural protective function.

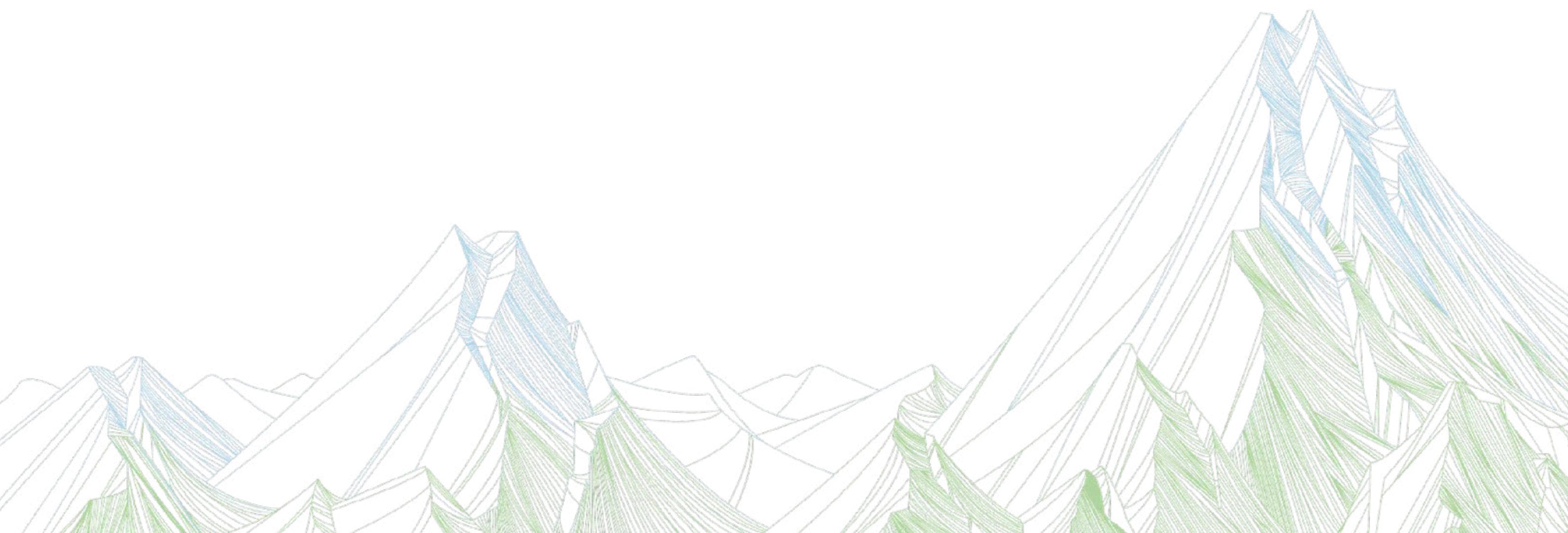
This situation leads to increased avalanche risk and reduced soil retention capacity, with potential implications for slope stability and the safety of downstream infrastructure, making the implementation of protective measures necessary.

The project has also highlighted how crucial inter-municipal cooperation and collaboration with provincial structures have been for managing the event and its post-emergency phases. The collective debriefing process carried out during the workshops was particularly appreciated by participants, as it enabled cross-sector dialogue among institutions, organisations and professionals. Although the Vaia storm has been the subject of numerous analyses and debates in recent years, the entities involved often reflected and operated in isolation within their respective areas of responsibility.

Some of the identified gaps have already been concretely addressed. In the field of civil protection, the municipalities of Aldino, Nova Levante and Nova Ponente – together with about 86% of South Tyrolean municipalities – participated in targeted information meetings organised by the Province. These initiatives strengthened the understanding of the civil protection system, stimulated cooperation and ensured that local administrations remain updated on civil protection plans and on the provincial alert and warning system.

Another identified gap concerned the absence of a short-term thunderstorm warning system. In response, the Province has initiated the development of a forecasting model capable of estimating the location of thunderstorm cells up to one hour in advance, which would provide stakeholders with more time to prepare.

Even though challenges remain in future risk management and climate change adaptation, the X-RISK-CC project represents an important first step toward greater resilience of Alpine regions to the consequences of extreme events.



USEFUL RESOURCES

The portal of Natural Hazards in South Tyrol

https://naturgefahren.provinz.bz.it/de/home

X-RISK-CC - Alpine Space Programme

https://www.alpine-space.eu/project/x-risk-cc/

X-RISK-CC – Web GIS: information on intensity and frequency of weather extremes in the entire Alpine Space

https://cct.eurac.edu/x-risk-cc

Civil Protection in the Municipalities

Comune di Aldino - Home - Argomenti - Protezione civile

Comune di Nova Levante - Home - Argomenti - Protezione civile

Comune di Nova Ponente - Home - Argomenti - Protezione civile

Climate Risk Analysis South Tyrol

https://klimaanpassung-suedtirol.eurac.edu/de

Civil Protection Broschure

https://www.provinz.bz.it/sicherheit-zivilschutz/zivilschutz/veroeffentlichungen.asp#download-area-idx151565

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The municipal administrations, provincial authorities, emergency services, infrastructure operators, and community organisations participated with professionalism and a spirit of collaboration, sharing valuable experiences gained from managing extreme events in this Alpine territory.

A special thanks goes to the municipalities of Aldino, Nova Levante and Nova Ponente for their cooperative spirit and continuous commitment to strengthening risk management practices, as well as for the warm hospitality provided during the participatory workshops.

Widespread windthrow as a consequence of the Vaia storm on the territory of the pilot area (Source: Civil Protection Agency of the Autonomous Province of Bolzano).

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