CLIMAAX climate ready regions

Deliverable Phase 1 – Climate risk assessment

Context specific climate risk assessment and adaptation strategies for the Valchiavenna Alpine territory (CMV4Clima)

Italy, Lombardy Region - Valchiavenna

HORIZON-MISS-2021-CLIMA-02-01 - Development of climate change risk assessments in European regions and communities based on a transparent and harmonised Climate Risk Assessment approach

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Abbreviations and acronyms

Abbreviation / acronym	Description
ARPA	Regional Agency for Environmental Protection of Lombardy
ATS	Health Protection Agency
CMV	Comunità Montana della Valchiavenna
EUCRA	European Climate Risk Assessment
FLA	Fondazione Lombardia per l'Ambiente
ISPRA	Italian Institute for Environmental Protection and Research
ISTAT	Italian National Statistics Institute
GCM	Global circulation model
LUISA	Land-Use based Integrated Sustainability Assessment
NAP	National Adaptation Plan
PGT	Urban plan
RAS	Regional Adaptation Strategy
RASDA	Raccolta Schede Danni (collection of reports on damage)
RCM	Regional circulation model
RCP	Representative Concentration Pathway
RP	Return Period

Executive summary

This deliverable presents the results of Phase 1 of the CMV4Clima project, which aims to develop a climate risk assessment and the basis for an adaptation strategy for the Alpine territory of Valchiavenna, in Northern Italy. The main purpose of this phase was to initiate a structured evaluation of climate risks using the CLIMAAX methodology and tools, focusing on two key hazards: heavy rainfall and river flooding.

Valchiavenna is a rural and mountainous area characterized by complex geomorphology, scattered settlements, and a high exposure to hydro-meteorological hazards. The local institutions, led by the Mountain Community of Valchiavenna, are committed to improving risk understanding and resilience by integrating climate considerations into territorial planning and emergency preparedness.

The main activities carried out in Phase 1 included the selection and application of two CLIMAAX workflows (Heavy Rainfall and River Flooding), data collection from local and European sources, and preliminary testing of hazard scenarios under climate change conditions. Site-specific and regional-scale analyses were conducted using Intensity-Duration-Frequency (IDF) curves, civil protection thresholds, and economic damage estimates based on land use and exposure data.

In Lombardy, the Civil Protection alert (early-warning) system uses rainfall and flood thresholds to manage hydraulic and hydrological risks during both the forecasting and monitoring (i.e., ongoing events) phases. The critical rainfall thresholds represent average rainfall intensity values for specific zones and determine the transition from one risk scenario to another.

The analysis revealed both the strengths and limitations of the available datasets and models. While the workflows demonstrated the potential to inform decision-making, the results also showed significant variability and uncertainty, particularly in future scenario modeling. This highlighted the need for more robust statistical treatment, clearer interpretation of differences among data sources, and the importance of managing and communicating uncertainty.

Stakeholder engagement was initiated, with local institutions and service providers actively contributing to the process. However, future phases will need to enhance participatory mechanisms and involve additional actors from sectors such as infrastructure, energy, and civil society.

This deliverable contributes to the overall CLIMAAX objectives by testing a replicable approach in a real-world context, identifying challenges and opportunities for local adaptation planning, and laying the groundwork for risk quantification, stakeholder co-design, and monitoring in future phases.

Key takeaways from this phase include:

- The urgent need for meaningful and usable climate data at local level;
- The importance of addressing uncertainty transparently;
- The value of combining local expertise with European-level tools;
- The necessity to expand and deepen stakeholder involvement;
- A solid foundation for building a territorial adaptation strategy tailored to Valchiavenna's needs.

1 Introduction

1.1 Background

Valchiavenna is a **rural Alpine area** located in northern Italy, in the Lombardy region, bordering Switzerland to the north. It covers a territory of 57,681 ha and has a population of 24,440 inhabitants. The region has a north-south vertical orientation, with an altitude range from 199 m to 3279 m asl. It features a main valley (Piano di Chiavenna) and two lateral valleys branching off from the main valley after Chiavenna: the Valle Spluga, oriented north-south, and the Val Bregaglia, oriented east-west. The territory is administratively divided into **twelve municipalities**. In addition to the more populated centers, the valley is characterized by **numerous scattered villages** (at least 76 permanently inhabited) which have remained unchanged over time and represent an important element of local identity.

Demography and social impact

The distribution of the population across the territory is heavily influenced by its geomorphology: The main valley, characterized by a wide valley floor, hosts nearly the 80% of the total population, while each of the two side valleys, marked by narrow floors, steep slopes, and increasing altitude, hosts approximately the 10%. A slow but steady **migration from the side valleys to the main valley** is occurring due to their isolation, the gradual decline of essential services and commercial activities, and **frequent hydrogeological disruptions** that impact the internal road network, with social and ecological consequences for these areas.

From a social perspective, the analysis of demographic indicators, such as birth rates, average age, and emigration rates, clearly pointed out an aging population. This demographic shift is reshaping the social structure, increasing social-welfare spending, and potentially weakening the community's resilience. A **decreasing and aging population** can reduce the region's ability to respond effectively to disasters and adapt to change.

Economic sectors

Economically, Valchiavenna relies mainly on **agriculture, tourism, and small-scale industries sectors** highly vulnerable to climate variability and extreme weather events. Tourism, in particular, is strongly related to the region's natural attractions and is expected to be significantly impacted by climate change, posing a major challenge to local economic stability.

Water is a vital resource for valley ecosystems, increasingly affected by climate change. In dry years, water availability may become limited, creating competition between ecosystems and the numerous reservoirs used for hydroelectric power production. Conversely, in rainy years with intense precipitation events, these reservoirs can serve as a crucial resource, acting as a water storage system. They help regulate water availability by retaining excess water during heavy rainfall to prevent flooding and releasing stored water during droughts to sustain the flow of downstream watercourses.

Infrastructure

Access to the valley is primarily dependent on the SS36, the main road running through the central valley up to Chiavenna, where it splits into two routes leading to the Swiss border. A railway line runs alongside the road up to Chiavenna, providing additional, though limited, connectivity. However, frequent hydrogeological issues threaten to isolate Valchiavenna, as no alternative transport routes exist.

The region also faces critical infrastructure challenges. Many protective measures against natural hazards are outdated and inadequate given the current level of risk. Limited financial resources make it difficult to maintain and upgrade infrastructure to withstand increasingly severe weather events, placing additional strain on the community's long-term sustainability.

Environment and Biodiversity

Valchiavenna has a rich environmental and cultural heritage territory. It includes **protected areas** regulated by the Directive 2009/147/EC on the conservation of wild birds which covers the protection, management and control of wild birds and lays down rules for their exploitation. There are also areas regulated by the Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora.

Biodiversity is one of Valchiavenna's greatest treasures. Several factors contribute to the richness in both plant and animal biodiversity, including the vast extent of the territory, the significant difference in elevation, from 199 meters to 3,279 meters at its highest peak and the presence of Lake Mezzola at the valley's mouth, which helps moderate the climate in the lower areas. The geological, geomorphological, and pedological diversity further enhances the variety of vegetation types found here. Valchiavenna is rich in **environmental resources** such as water, wood and pastures, which, depending on how they are managed, can contribute to increasing or limit the problems linked to climate change. Valchiavenna has an extensive network of aquatic ecosystems, including **two main rivers, Mera and Liro**, which merge after Chiavenna in the main valley, as well as numerous streams, creeks, brooks, alpine lakes, and reservoirs.

1.2 Main objectives of the project

The Valchiavenna region is committed to strengthening resilience and minimizing vulnerability to climate change across its entire territory. To achieve this, the Mountain Community of Valchiavenna aims to conduct a comprehensive Climate Risk Assessment (CRA) based on the three-phase methodology established by CLIMAAX. With this assessment an in-depth understanding of scope and scale of climate risks on the territory will be provided to plan and implement adaptation and climate risk management responses. Through this analysis, multiple objectives will be pursued:

- **Increase knowledge and risk awareness among local communities, policy makers and stakeholder.** Detailed risk assessments will inform residents about immediate and long-term climate risks, fostering a culture of preparedness and proactive response. Increased awareness will also encourage the community to engage in climate action by encouraging participation in resilience-building activities and the implementation of personal and collective risk reduction measures.
- **Strengthen local policies such as adaptation strategies and risk management plans**. The knowledge gained from the study will help local authorities to prioritize interventions, allocate resources more efficiently and design targeted actions to address the most pressing climate risks, basing choices on concrete evidence. This approach ensures that adaptation measures are not only effective but also adapted to the specific needs and vulnerabilities of the community.

- **Integrate climate resilience** into urban planning to ensure that infrastructure development, spatial planning and conservation efforts are sustainable and climate-proof.
- **Safeguard the well-being of our community**, protect economic heritage and preserve the natural environment. The proposed activity will enable our region to better anticipate, react and recover from climate-related hazards.

The **expected benefits** of applying the CLIMAAX Handbook include **substantial support** in adopting state-of-the-art methodologies enhanced by a user-friendly **toolbox** tailored for risk quantification. The Mountain Community of Valchiavenna will have the opportunity to be guided by the expertise of experts in implementing the climate assessment, to be **engage in constructive exchanges** during consultation sessions and through the community of practice, gaining valuable insights and methodologies on climate risk assessment and, more broadly, on climate adaptation.

Its application and implementation will enable local decision-makers and stakeholders to **take ownership of climate risks** and **tailoring policies** to mitigate climate risks effectively. The benefits will extend to other groups of stakeholders and beneficiaries, including:

- **Businesses** which will receive support in adapting their operations and strategies to future conditions, ensuring economic sustainability
- **Civil protection and emergency services** which will use the study to improve preparedness, and response strategies
- **Utility companies** and infrastructure managers of water, energy, and transportation networks which will find the study crucial for planning the resilience of critical infrastructure
- **Academic institutions and researchers** that can leverage the study's data for further research, contributing to the global understanding of climate adaptation and resilience.

The **main expected benefits** will include a raised awareness of the necessary actions to enhance a climate assessment process (data, information needed) as well as to address risks. Furthermore, Valchiavenna will have the opportunity to engage with other regions /entities that have used the same methodology, fostering valuable exchanges and insights.

1.3 Project team

The project team is composed as follows:

Name	*Description*	*Role in the project*
Comunità Montana Valchiavenna (CMV)	A **public local authority** representing the union of 12 municipalities in Valchiavenna, dedicated to protecting and enhancing the mountain territory. It serves as a socio-economic and territorial-urban planning body, as well as a coordinating entity that manages functions and services, either directly or on behalf of the municipalities.	- **Project beneficiary** - **Main interlocutor** with European institutions and CLIMAAX project coordinators - Coordinating project activities - Engaging stakeholder - Dissemination, communication, and presentation of project results

		- Providing FLA with scientific data collected directly by the Mountain Community or through other relevant entities, institutions, or authorities
Fondazione Lombardia per l'Ambiente (FLA)/Ecometrics ltd	A **non-profit legal entity** engaged in research activities on environmental protection and pollution prevention. Its main mission is to conduct and disseminate studies, research, projects, and information to enhance awareness and understanding of environmental issues.	- **Technical experts** - Guiding CMV in the development and achievement of the project's objectives and the technical analysis

1.4 Outline of the document's structure

This deliverable is structured into five main sections:

- **Section 1 – Introduction**: Provides contextual information on the Valchiavenna territory, including demographic, environmental, infrastructural, and socio-economic characteristics. It also outlines the objectives of the CMV4Clima project and introduces the project team.
- **Section 2 – Climate Risk Assessment – Phase 1**: Describes the methodology and approach used during the first phase of the climate risk assessment. It covers the scoping, selection of hazards, workflows applied, scenario choice, and key results related to heavy rainfall and river flooding.
- **Section 3 – Conclusions**: Summarizes the main outcomes of Phase 1, highlighting achievements, challenges, and directions for future phases of the project.
- **Section 4 – Progress Evaluation and Contribution to Future Phases**: Reflects on the added value of the activities carried out in this phase and identifies elements to be further developed or refined in subsequent phases.
- **Section 5 – Supporting Documentation**: Includes relevant references and supplementary material used throughout the assessment.

2 Climate risk assessment – phase 1

2.1 Scoping

2.1.1 Objectives

The Mountain Community of Valchiavenna is part of the European Mission on Adaptation to Climate Change and signatory of the **Mission Charter**. This commitment reflects its willingness to act to create the necessary conditions for achieving climate resilience and actively support the objectives of the mission.

The first crucial step is to conduct a **comprehensive climate risk assessment** which is aimed at:

- Understand the effect of climate change on the main risk factors present on the territory, and improve the characterization of exposure, and climate-related vulnerability factors.
- identify possible cascade effects between risks that could trigger negative consequences on other systems.
- Establish an accessible and usable knowledge base (data and information) valid for the territory for present and future analysis and management of climate-related hazards, impacts, exposures and vulnerabilities.

The **projects** will include the following **objectives and outcome**:

- Enhance knowledge and risk awareness among local communities, policymakers, and stakeholders, encouraging preparedness and assigning the ownership of risks.
- Insights gained from this assessment will enable local authorities to prioritize interventions, allocate resources more efficiently, and design targeted actions to address the most pressing climate risks, ensuring decisions are grounded in concrete evidence.
- Tailoring the adaptation measures to the specific need and vulnerabilities of the community to be more effective in the response to climate impacts.
- Greater awareness will also inspire community engagement in climate action by promoting participation in resilience-building initiatives and the adoption of both individual and collective risk reduction measures.
- Safeguard community well-being, protect economic assets, and preserve the natural environment for future generations.

The project outcomes will **improve policy and decision-making** by integrating climate resilience into:

- urban planning and development policy instruments
- emergency and disaster risk management instruments
- land protection and maintenance instruments

This will help **improving the sustainability and climate-proofing** of infrastructure projects, spatial planning, and conservation efforts and adjusting hazards and risks management to the climate signals. By providing insights on the current and future climate threats, the project will support the Mountain Community in fulfilling its institutional role more efficiently and reliably, ultimately leading to more adaptive and forward-thinking policies that safeguard both the environment and local communities.

Due to resource and time constraints, the present risk assessment focuses only on heavy rains and river flooding. It intends to contribute to the existing instruments for hazard and risk management with a stronger analysis of climate factors and their relative change along short and mid-term time horizons and will need to be complemented with the assessment of other major risks (e.g. avalanches, temperature regime, snow availability, permafrost degradation, ect.). Yet, particular attention will need to be given to the **inherent uncertainty of the outputs** and to the most appropriate way to deal with it, in terms of usability within decision-making and policy-making instruments and of communicating the same uncertainty to different stakeholders.

Challenges may also include, in the subsequent phases, engaging specific stakeholder groups (e.g. energy companies, insurances, etc.), difficulties in accessing reliable locally valid data, ensuring effective coordination across sectors and government levels, and raising awareness about the urgent need for climate adaptation.

2.1.2 Context

The Mountain Community, as both a **socio-economic and territorial-urban planning body** and as the coordinating entity responsible for managing and overseeing functions and services, either directly or on behalf of its municipalities, has consistently played a crucial role for the Lombardy Region in tackling these issues. Prevention and consequences management have been approached through various plans, protocols, and procedures, which have engaged institutions at municipal, provincial, and regional levels in a hierarchical, vertical approach. However, this approach has yet to fully integrate climate change considerations, highlighting the need for a more coordinated and forward-looking strategy.

Several policy instruments are highlighted here as key tools implemented at the regional and local levels to manage natural and climate-related risks:

The **Civil Protection Plan (PPC)** is a set of operational intervention procedures designed to manage foreseeable disasters within the territory. Drafting this plan provides an in-depth understanding of potential risks and enables the efficient allocation of human and material resources, as well as the strategic planning of actions and activities necessary to respond promptly and effectively to emergencies.

The **Urban Plan (PGT)** must be supported by a specific **geological study** (Studio Geologico Depoli Dott. Claudio, 2023) that supports municipal urban planning. This study identifies areas at risk from geological, hydrogeological, hydraulic, and seismic hazards. The geological component of the PGT integrates basin planning data and serves as a tool for proposing modifications and integrations to existing basin management plans.

The **Flood Risk Management Plan** (Po River Basin District Authority, 2021) is the official framework in Italy for identifying and planning actions to mitigate the negative impacts of floods on human health, land, the environment, cultural heritage, and economic and social activities. It includes flood hazard maps, which classify flood probability into low, medium, and high categories, as well as flood risk maps, which assess potential adverse consequences in terms of population exposure and affected economic activities. The exposure assessment is categorized into four risk classes: moderate/null, medium, high, and very high.

The **River Contract** is a governance tool for hydrographic basin management ensuring the sustainable use of water resources while enhancing river territories and mitigating hydraulic risks. In 2023, the **Mera River Contract** was drawn up. It includes all the lateral valleys and tributary rivers of the Mera River within the Valchiavenna territory. The River Contract supports the objectives of the European Water Framework Directive (2000/60/EC) and the Floods Directive (2007/60/EC) by promoting policies and initiatives that strengthen resilient river communities. It plays a key role in mitigating and repairing the environmental pressures caused by unregulated urbanization.

At **national level** the planning and implementation of climate change adaptation actions are regulated by:

- National Climate Change Adaptation Strategy - adopted by Decree CLE prot. 86/CLE 16.06.2015
- National Climate Change Adaptation Plan - in progress of approval with Decree No. 434 of 21 December 2023.

The **National Plan on Adaptation to Climate Change** (NAP, 2023) provides a comprehensive knowledge on the current and future climate scenarios as well as a complete framework of the risks associated with climate change across the Italian territory. NAP aims to enhance resilience by identifying vulnerabilities and proposing adaptation objectives and measures to mitigate adverse effects of climate change.

At the regional level, the Lombardy Region has recently updated its **Regional Strategy on Adaptation to Climate Change** (RAS). This Strategy identifies five macro-sectors that encompass key environmental and socioeconomic components exposed to climate change. For each macro-sectors connections have been established between climatic drivers and both direct and indirect impacts on exposed factors. This analysis was carried out with support of scientific literature and the expertise and experience of technicians and managers from regional business sectors.

Although a comprehensive multi-sectoral risk assessment has not been conducted, valuable insights have been gained from the **European Climate Risk Assessment (EUCRA)**. The EUCRA report complements the risk analysis by evaluating key policy characteristics, including policy horizon, risk ownership, and policy readiness, to assess the urgency of risk reduction measures. For the Regional Strategy, this source provides a valuable reference for understanding the risk assessment process and gaining clarity on risk ownership and the urgency of action also at the regional scale.

In recent years, Valchiavenna has demonstrated its commitment to strengthening climate resilience by signing the **EU Charter Mission on Adaptation to Climate Change** in 2023. Actually, Valchiavenna is still receiving support from the MIP4Adapt Technical Assistance.

Additionally, in 2023, the Mountain Community of Valchiavenna signed the "**Valencia Charter**", issued by the ENCORE (Environmental Conference of the Regions of Europe) network of European regions.

The Mountain Community of Valchiavenna is actively involved in several **Interreg projects** focused on addressing climate change, fostering cross-border cooperation, and enhancing regional resilience through innovative adaptation strategies.

NAME-Project	***Description***
AMALPI MORE (Alps in Motion, Movement in the ALPS: Monitoring and Resilience)	The project promote the implementation of a monitoring network for slope movements (rockfalls, rockslides, landslides, movements related to the permafrost creep) and for key hydro-meteorological parameters (precipitations, temperatures, snow, humidity, water quality) that will allow to assess and quantify climate change impacts on high mountain territories in an integrated way (sediment transfer and sediment cascades from upstream to downstream, impact on the quantity and quality of water resources). By analysing climate change impacts at both regional and local scales, the initiative will

	enhance natural hazard prevention and strengthen the resilience of affected territories by improving adaptation strategies.
EURADAPT (Improving regional policies at EURopean level to increase ADAPTation to climate change)	The project connects more developed regions with stronger climate adaptation experience to support and guide less developed, more vulnerable regions, often with low adaptive capacity, in identifying solutions tailored to their specific climate impact and economic context. By facilitating interregional knowledge exchange, the project enhances learning opportunities and promotes the adoption of best practices in key areas, including sustainable land use and food systems, policies addressing water scarcity and innovative water distribution models, the protection of critical infrastructure, and effective governance. Additionally, it fosters citizen engagement and multi-stakeholder collaboration, enabling the co-creation and sharing of data, knowledge, and solutions to build climate resilience.

Major Impacts on Key Sectors in Valchiavenna

Valchiavenna region falls within the **mountainous biogeographical zone**, where temperatures are projected to increase at a rate higher than the European average. Additionally, the area is traversed by numerous water courses, which significantly contribute to a high hydrogeological risk level.

Climate-related hazards are having significant impacts on the territory, posing an ongoing threat to communities, infrastructure, and local economies. An initial assessment of these climatic hazards highlights their known effects on Valchiavenna's key sectors:

Communities and settlements may be affected by extreme weather events, flooding, landslide drought, avalanches resulting in evacuation from homes and an increase in maintenance and recovery costs. In January 2021 a landslide that occurred in the municipality of Novate Mezzola, resulted in the evacuation of 83 people.

Infrastructure (roads, railways) may be affected by extreme weather events (more intense and frequent), flooding, landslide and avalanche that can cause disruption to services and an increase in maintenance and recovery costs. Latest episode, in March 2025, in the municipality of Verceia a landslide following heavy rain caused the disruption of the railways service.

Agriculture may be affected by extreme weather events (more intense and frequent), heatwaves and heat extremes, flooding and hail which can results in changes in water availability and security, crop losses.

Tourism may be affected by extreme weather events, heatwaves and heat extremes. Higher temperature may result in shifts in tourism patterns, rising summer tourism demand with increased pressures on infrastructure and environment such as receptivity, water consumption, waste production, traffic, etc. Higher temperature may result in a reduction in winter snowfall with reduced attractiveness of mountain tourist destinations.

Water management may be affected by extreme weather events, heatwaves and heat extremes drought with a decrease in water resources, an increase in water demand in economics sectors like agriculture, manufacturing and for the communities, an acceleration in glacier melting, a reduction on hydropower production, groundwater wells contamination and challenges in water supply storage and increased competition for water resources.

Biodiversity and ecosystem may be affected by extreme weather events (more intense and frequent), heatwaves and heat extremes resulting in a degradation of landscapes and natural ecosystems, loss of habitat and species, an increase in threats to flora and fauna and shift in flora and fauna distribution.

When reflecting on possible **outside influences** on the problem, some factors need to be addressed:

- Valchiavenna shares borders with Switzerland and some orographic and hydrographic basins are therefore distributed across the two States, leading to possible cross-border management issues. There are three reservoirs for hydroelectric power generation (Orden, Albigna and Lobbia) that are part of the Mera river basin but are in Switzerland territory and influence Mera hydrogeological regime.
- These reservoirs help regulate water availability, but their management becomes particularly critical during periods of scarcity. When water resources are limited, careful management is essential to balance the needs of economic sectors with the protection of local habitats, which may otherwise be at risk.

Table 2-1. Surface and volume data of the Valchiavenna reservoirs

Name (Owner)	*Surface (km2)*	*Volume (millions of m3)*
Villa di Chiavenna (a2a)	0,11	0,94
Montespluga (a2a)	1,7	28
Isolato (a2a)	0,18	1,76
Madesimo (a2a)	0,04	0,16
Prestone (a2a)		0,082
Truzzo (a2a)	0,72	14
Val di Lei (*)	4	197
Moledana (Edison)		0,1

(*) the reservoir is in Italian territory, while the dam is in Switzerland. A percentage of the energy produced by the Swiss company is redeployed to Italy

Option for Adaptation

The Mountain Community of Valchiavenna has not yet defined clear objectives and priority actions for an effective territorial adaptation to climate threats. However, the increased awareness of risks and vulnerabilities gained through the CLIMAAX project will enable the development of an adaptation action plan. The NAP and RAS provide respectively a national and a regional framework for implementing adaptation measures across various socio-economic and environmental sectors and can serve as a starting point for defining localized and specific actions tailored to the mountainous territory of Valchiavenna.

2.1.3 Participation and risk ownership

The first steps taken by the Community of Valchiavenna to set-up the stakeholder involvement process is described as follows:

1. Identification of all the potential stakeholder among organizations, private and public institutions that can have an interest in the project.

2. Analysis of stakeholder' knowledge and interest in the project.
3. Categorization of stakeholder into groups: public institutions (local and regional level), social cooperatives, voluntary associations, forestry consortia, utilities company, educational establishments.
4. Definition of the reason and degree of engagement during the project phases.

Table 2-2. Stakeholder mapping result

WHO			WHY	WHEN	HOW
Name	*Role*	*Sector*	*Why should they be engaged?*	*Project Phase*	*Level of participation*
Mountain Community of Valchiavenna	public	governance	protect, enhance, and develop the territory through effective spatial planning tools.	1,2,3	Core
Municipalities	public	governance	local territorial authorities with expertise in territory management and spatial planning functions	1,2,3	Involved
Province of Sondrio	public	governance	territory management and spatial planning functions at province level	1,2,3	Peripheral
Lombardy region	public	governance	spatial planning at the regional level PGRA (Flood Risk Management Plan)	1,2,3	Supportive
Local action group (GAL)	public/private	governance	knowledge of the territory, territorial development	3	Peripheral
Pian di Spagna e Mezzola Lake National Reserve	public	environment and land care	management of the Nature Reserve (SCI) through the implementation of plans and programs	2,3	supportive
BIM (bacino imbrifero montano dell'Adda)	public	governance	administers the common fund derived from hydroelectric production in the territory, employing it for the economic and social progress of the population	2,3	supportive
social cooperatives	private, cooperative	social	knowledge of the territory and vulnerable groups	3	supportive
Caritas	private, non-profit organization	social	knowledge of the territory and vulnerable groups	3	supportive
WWF Valtellina e Valchiavenna	private, non-profit organization	environment and land care	knowledge of the territory, territorial development, environmental education, dissemination	3	supportive
Legambiente Valchiavenna	private, non-profit organization	environment and land care	knowledge of the territory, territorial development, environmental education, dissemination	3	supportive
Forestry consortium	private, non-profit organization	environment and land care	knowledge of the territory, as well as the maintenance and preservation of forest lands	2,3	supportive
CAI Chiavenna	private, non-profit organization	environment and land care	knowledge of the territory, territorial development as well as the maintenance and preservation of forest lands	2,3	supportive
A2A	private, power company	utilities, electricity	knowledge and data on hydroelectric power plant and water management	2,3	supportive
SIEC Soc. Cooperativa	private, power company	utilities, electricity	knowledge and data on hydroelectric power plant and water management	2,3	supportive
Edison	private, power company	utilities, electricity	knowledge and data on hydroelectric power plant and water management	2,3	supportive
SECAM	private, water management	utilities, water	knowledge and data on water management	2,3	supportive

WHO			*WHY*	*WHEN*	*HOW*
Name	*Role*	*Sector*	*Why should they be engaged?*	*Project Phase*	*Level of participation*
University	public	research	research and dissemination	2,3	supportive
Educational institutions	public	education	training and dissemination	3	Peripheral
Citizens	-	-	they live on the territory	1,2,3	involved
Enterprises	-	-	they work on the territory	1,2,3	involved

Considering here the focus of the present risk assessment on heavy rainfall (particularly related to indirect hazards such as urban floodings, flash floods, debris and mudflows, landslides, etc.) and river flooding, priority groups can be identified in the following categories:

- The **general population living in urban areas** scattered across the territory, with particular attention to the more **vulnerable groups** such as the elderly and the fragile individuals, who may have a lesser response capacity to natural catastrophe.
- **Farmers and livestock** operations are particularly at risk, especially those located in flood-prone areas or with parts of their farmland situated in zones used for emergency floodwater retention.

Risk Ownership

The specific risk ownership of the two considered risks (Havey rainfall, Flooding) can be considered somewhat fragmented.

The management of urban drainage networks is entrusted to the operator of the **Integrated Water Service**, specifically SECAM S.p.A., a joint-stock company entirely publicly owned by the 77 municipalities of the Province of Sondrio, the five Mountain Communities, and the Provincial Administration of Sondrio. The operator is also responsible for the cleaning and maintenance of the network and its structures to ensure proper operation.

Obviously, yet, Municipalities are in charge of the urban planning, including the underground utility network.

For what concerns, possible structures and infrastructure exposed to risk (thus in need of some form of risk management), it should be mentioned that:

- in Italy, roads are managed by different entities depending on their classification: national, provincial, or municipal roads. National roads, in particular, are managed by a special-purpose company, ANAS S.p.A., a private entity tasked with managing strategic assets of public interest
- similarly, the railroad network is managed by a formerly state-owned company, as well as some major IT and energy production and distribution infrastructures

The Po River Basin District Authority is responsible for the hazard and risk assessment of river flooding, as well as for the general maintenance of the river network in the territory of Valchiavenna. Moreover, the emerging Mera River Contract brings together various stakeholders who share responsibilities and interests related to the river and will surely be engaged in the second phase of the CMV4Clima project.

The **reservoir operators** (energy companies) are responsible for the management of the basins, the controlled release operations, and the risk management related to dam failure.

In general terms, local-level emergency planning and civil protection response are primarily the responsibility of individual municipalities. Yet, the **CMV**, in its role as a **body responsible for socio-economic and territorial-urban planning**, as well as a coordinating authority that manages and oversees functions and services—either directly or on behalf of its municipalities—it holds responsibility for **risk management**.

At present, there is no official definition, nor a well-established characterization of an **acceptable level of risk** for the community.

Nevertheless, it is possible to infer information about this aspect from the analysis of certain factors:

- The thresholds used by the Civil Protection Early-warning system tend to be rather precautionary, being used to activate the response of the local Civil Protection system and minimize any possible consequence on the ground. The thresholds are risk specific and the ones used for Heavy Rainfall and Storms are going to be explained in paragraph 2.3.1. It suffices to say here that the threshold that brings to the activation of the highest level of alert on the territory of Valchiavenna corresponds to a precipitation event with a Return Period of about 4-6 years.
- Similarly, concerning River Flood risk, it could be observed that the local hazard areas are defined through 3 levels, related to the probability of occurrence of flooding cause by the overtopping of the embankments. The first hazard level considered (narrowest area, highest frequency) is related to events with a Return Period of 30 years, with most of the peak discharge being contained within the embankments.
- Other such quantification could be derived by further investigation on the design processes of urban drainage networks and hydraulic structures, particularly those related to the management of reservoirs for hydroelectric power generation
- The assessment of rainfall events and their probabilities is essential for the sizing of stormwater drains and sewer systems. In general, the design is based on time intervals ranging from 15 minutes for storm drains and small sewers to one hour for larger sewer systems. To avoid oversizing the infrastructure, and provided there is no risk to human life, the design relies on lower-intensity events that occur more frequently. As such, rainfall events with return periods of 10 to 20 years are considered for areas of high urban value, while return periods of 2 to 5 years are used for zones of lower importance
- As for natural watercourses, major crossing structures must be sized based on detailed watershed studies, while minor works—such as culverts serving watercourses with small catchment areas and relatively low flood discharges (intended to evacuate upstream water accumulation and flooding, particularly in low-slope areas)—are typically designed considering events with return periods not exceeding 25 years.

Project Results Communication

The project's results will be effectively disseminated to stakeholders at both local and regional levels through a range of activities. These will include:

- **public events** open to all stakeholders: kick-off meeting, presentations of intermediate results (1st deliverable and 2nd deliverable), presentation of the project's results
- **workshops** dedicated to the educational system
- **face to face meeting** with institutional groups (Region Lombardy, Province, Swiss cross-border authorities)
- **publication of articles and press releases** in local newspapers and on the Mountain Community of Valchiavenna website throughout the project
- **participation in events** organized by European projects
- **dissemination** in other project in which Mountain Community is partner

All the communication material (leaflets, press release, newspaper articles, etc.) and the deliverables will be published on the Mountain Community website. Any other relevant communication channels that may emerge in the future could also be used.

2.2 Risk Exploration

2.2.1 Screen risks (selection of main hazards)

Valchiavenna does not have yet an established and comprehensive climatic framework with trend analysis of temperature and precipitation that help to understand long-term climate variability, assess the frequency and intensity of extreme weather events. However, several sources highlight the increasing impact that Italian mountain regions will have to face compared to the rest of the Italian territory (OECD Publishing, 2007). These predictions are supported by the significant temperature increases already observed in the Alpine region, which have been three times the global average for the Northern hemisphere (Alcamo, 2007). Moreover, the area has experienced a shift in its rainfall patterns, characterised by lower rainy days but an increase in intense rainfall events. Climate models predict that, in the coming decades, these trends will intensify, leading to profound changes in the mountain hydrological regime. Such changes are expected to exacerbate hydrogeological risks (Lautenschalger et al., 2008) and threaten the future availability of water resources with decreasing rainfall (Weingartner et al., 2007), shrinking snow cover, and accelerated glacier melting contributing to a significant reduction in water availability. According to the ESPON CLIMATE project the adaptive capacity to climate change is lower in eastern and southern European countries, especially in the Alps that have economic dependency on tourism and agriculture. These changes will have significant consequences for both socio-economic and ecological systems of national importance.

The valley faces a **high level of hydrogeological risk**, a complex threat influenced by multiple factors. These include the valley's geomorphology (a U-shaped glacial valley with steep sides and a wide, flat floor), the presence of numerous water bodies, fires, land abandonment, and heavy rainfall following prolonged periods of drought. In this context, phenomena such as landslides, floods, storms, winds, tornadoes, and fires are having severe consequences on the landscape, posing an ongoing threat to communities, infrastructure, and local economies.

These hazards are affecting the entire territory of Valchiavenna and can potentially impact the population of each municipality. Below are the data on the area and the population of each municipality within the CMV.

Table 2-3. Area and number of inhabitants of the municipalities of Valchiavenna

Municipality of CMV	Inhabitant	Area (Km2)
Gordona	1.900	63,66
San Giacomo Filippo	370	61,67
Chiavenna	7.300	11,08
Madesimo	500	85,25
Samolaco	2.900	45,19
Villa di Chiavenna	950	32,68
Novate Mezzola	1.900	99,70
Piuro	1.900	85,41

To outline the current climate situation, several sources have been consulted, including the Geological Report attached to the PGT (urban planning) of each municipal administration. These sources document past extreme rainfall events that have caused significant damage to infrastructure and posed risks to public safety.

- During the summer of 2017 cumulative precipitation reached 120 mm in 8 hours (estimated RP = 33.4 years), causing the flooding of ground floors in buildings, disruption of road networks, and the evacuation of three families from the municipality of Chiavenna.
- On June 2016, a debris flow from Valle Vallascia caused flooding, with damages to residential buildings and the disruption of the SS 36.
- During 2021-2023 very short and intense rainfall events alternating with long periods of drought caused five major landslides and three severe flash floods which resulted in damage to roads, paths, infrastructures and evacuation of people. In 2018 a 7500 m^3 rockfall heavily damaged Marian Sanctuary of Gallivaggio and damaged the national road, leading to the isolation of the upstream municipalities (Campodolcino and Madesimo), reachable for a few days only on foot. In 2021, in Novate Mezzola 83 people were evacuated as a result of a landslide.

Numerous observed impacts highlight the territory's significant vulnerability to hydraulic and hydrogeological risks (between 2024 and 2025, the Lombardy Region allocated €100,000 to the Mountain Community of Valchiavenna to mitigate these risks). This has prompted Valchiavenna to undertake an in-depth analysis of extreme weather events through the application of the Heavy Rainfall and River Flooding Workflow.

The risk assessment of Valchiavenna therefore will focus on two key hazards:

- **Extreme rainfall events**. These are significant trigger for hydrogeological hazards including landslides and debris flows, as well as flooding in urbanized areas. Given its alpine morphology, Valchiavenna is especially vulnerable to such events, which can rapidly alter the landscape and threaten infrastructures, communities, and ecosystems. *How will this hazard change on Valchiavenna's territory?*

- **River flooding.** Rising rainfall intensity and changes in snowmelt patterns are expected to increase the frequency and severity of river flooding. *Could the rivers in Valchiavenna's territory experience more frequent and intense flooding, posing significant risks to both human settlements and the environment?*

In approaching the assessment of the aforementioned risks for the study area, it is important to note that the context is characterized by:

- a **mature framework of policy instruments for hazard and risk management** (such as Civil Protection Plans, the Hydrogeological Structure Master Plan, the Flood Risk Management Plan, municipal documents on hydraulic risk, the Regional Regulation on Hydraulic Invariance, as well as geological and hydraulic studies supporting urban planning)
- a **well-established knowledge system supporting hazard and risk analysis** (including ARPA meteorological stations, consortium and reservoir operator monitoring stations, experimental university stations, and watershed and forestry studies promoted by the Mountain Community, as well as by the regional administration),
- a **risk and emergency management system** that is integrated into the Civil Protection and land protection framework (such as hydraulic monitoring services and flood monitoring services, early warning systems, and local civil protection systems)

CMV4Clima gives the opportunity to contribute to this context mainly by:

- offering a use case for high-quality European climate datasets and climate services that are not ordinarily utilised in risk assessments
- providing insights about the integration of climate models and scenarios into the same assessments
- pushing forward the effort in the characterization of site and event-specific critical threshold (such as those related to particular urban flooding events or to specific landslides) that are at present generally missing

Data collection

The application of the selected workflows required mainly the acquisition of two categories of data:

- Precipitation events, total amounts, durations, intensities
- River flooding hazard maps

Moreover, the project needed to acquire also knowledge about the characterization of IDF probability curves and about LULC and economic values of the exposed assets.

The **Regional Agency for Environmental Protection** of Lombardy (ARPA Lombardia) represented one of the main sources of data and information. ARPA is a public entity with technical and scientific expertise that carries out data collection and analysis activities to support the environmental policy decisions of Lombardy Region, Provinces, Municipalities, Mountain Communities, Health Protection Agencies (ATS), and other public entities in the regional territory.

From its website, the following data were consulted and downloaded:

- Precipitation datasets from the weather stations of Valchiavenna's territory
- Meteorological reports on extreme weather events on Lombardy Region
- Intensity-Duration-Frequency (IDF) Curves (LSPP). (Carlo De Michele, 2005)

The **Annex 2** "*Aggiornamento della direttiva regionale per la gestione organizzativa e funzionale del sistema di allertamento per i rischi naturali ai fini di protezione civile (d.p.c.m. 27/02/2004)*" part of the D.G.R. n. XI/4114 of 21/12/2020, was consulted to check:

- Homogeneous alert zones of Civil protection that include Valchiavenna's territory (Lombardy Region, 2020)

From the **Geoportale Lombardia** platform (Geoportale Lombardia), which is the geographic information hub of the regional administration and contains all the available regional cartographic data, the **Flood Risk Management Plan for the Po River Basin –** Approved by Legislative Decree No. 49 of 2010 in accordance with Article 7 of Directive 2000/60/EC and Article 7 of Legislative Decree No. 49 of February 23, 2010 - was consulted to download:

- hazard and risk flood maps

ISTAT (ISTAT - Italian National Statistics Institute) was consulted with regards to the:

- value of GDP per capita

2.2.2 Workflow selection

Given the selected risks to be analysed, CMV4Clima chose to take on the respective CLIMAAX workflows for Heavy Rainfall and River Flooding.

Workflow Heavy Rainfall

Valchiavenna is particularly susceptible to intense or prolonged rainfall events due to its orographic setting, where moist air masses from Lake Como and the Po Plain are forced upwards by the mountainous terrain, triggering intense precipitation. Vulnerable groups include both the general population and economic assets (farms, animal farms, factories, as well as infrastructures possibly critical for the supply chain and the business continuity). Furthermore, particularly fragile groups include residents of small, isolated mountain villages and elderly populations living in areas with limited access routes (e.g., hamlets in the municipalities of Piuro, Madesimo, and Novate Mezzola). These events often cause landslides, debris flows, and sudden road closures, disrupting emergency access and isolating communities, particularly in narrow valleys like Valle Spluga and Valle dei Ratti.

Workflow River Flooding

The flood risk is most pronounced along the **Mera River** and its major (Liro) and minor tributaries (the so-called *Merette*), especially during rapid snowmelt combined with rainfall. Populated areas at lower altitudes such as Chiavenna, Prata Camportaccio, and the floodplain of **Pian di Spagna** (a Ramsar wetland near Lake Mezzola) are exposed to overflow events. These zones are critical for agriculture and settlement, and their flat morphology increases vulnerability to prolonged inundation. Particular fragile social groups may include migrant labourers working in agriculture, as well as residents in older flood-prone housing near riverbanks.

Moreover, the territory is characterized by the presence of **minor mountain catchments** with rather **short times of concentration**, that are prone to flash flood events, possibly very dangerous.

2.2.3 Choose Scenario

With regard to socio-economic development, some scenario elements have been elaborated in the course of the study.

1. An outlook of the **demographic development** (total population and distribution into age classes until **2043**) of the area (population sum of the 12 municipalities in the CMV) have been elaborated, based on data available from ISTAT. An overall increment of the total population is expected (although little), but also an **increment of the more fragile groups**, especially the elderly, with a **shrinking population in the class "adults** (15-64)".

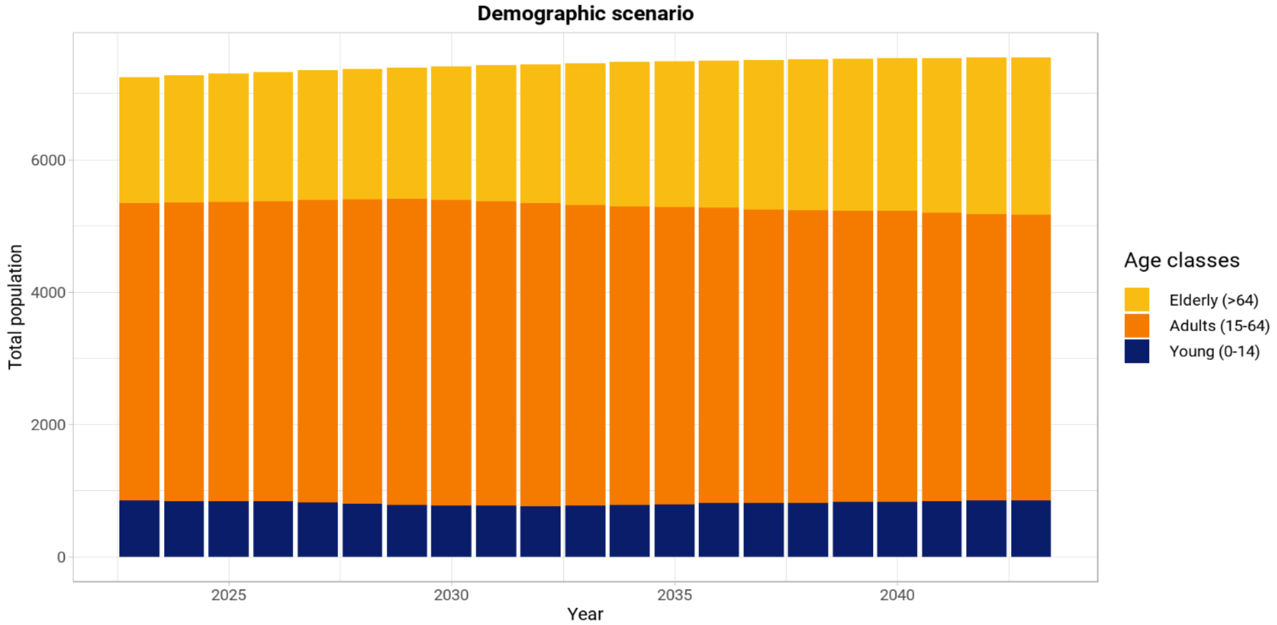

Figure 1 Chart of the demographic scenario for Valchiavenna (2023-2043) (source: ISTAT)

2. Trend in soil consumption (imperviousness) are available from ISPRA (ISPRA - Italian Institute for Environmental Protection and Research) for the 12 municipalities in the valley. It could be noted that in most cases the **sealed soil remains stable**, except for Gordona and Samolaco, where some new areas have grown, mainly still within already developed industrial areas.

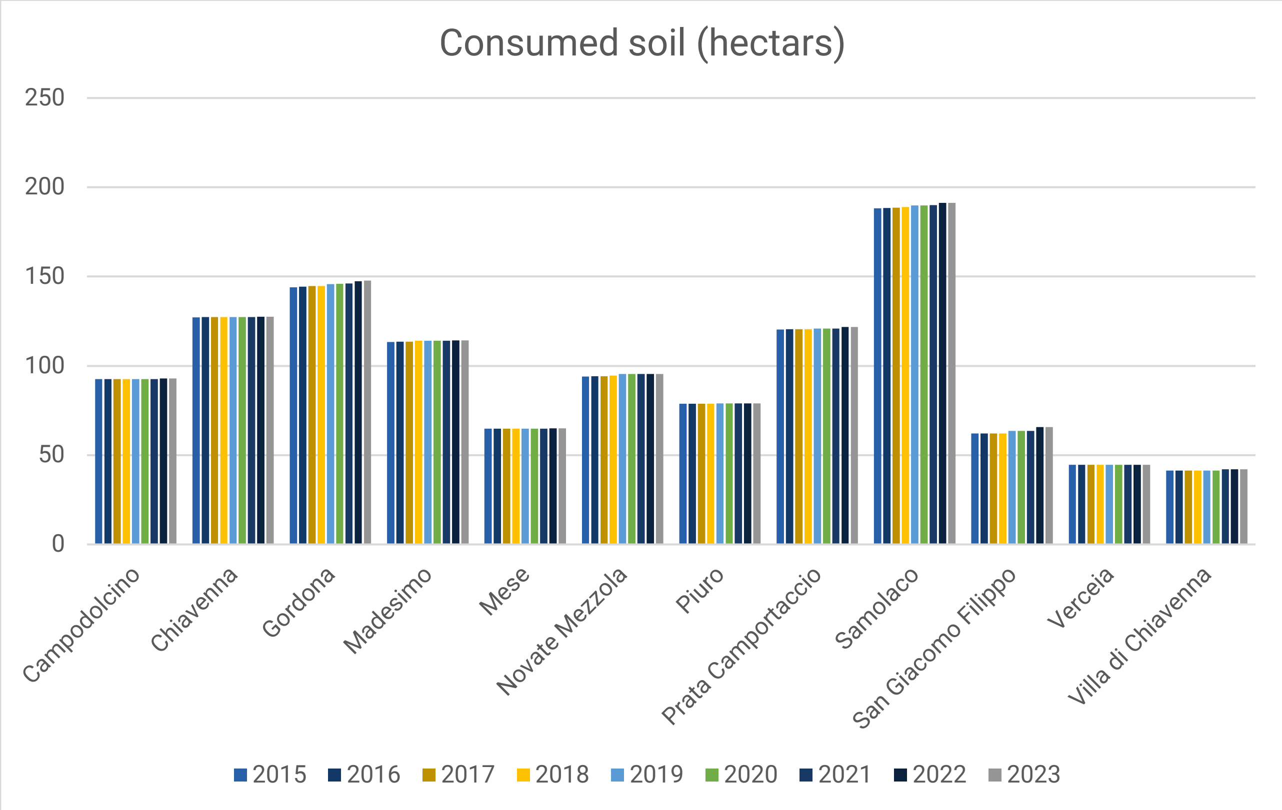

Figure 2 Chart of consumed soil between 2015 and 2023 for the municipalities in CMV (source: ISPRA)

- Regarding the demographic scenario, data is available up to 2050, and it may be useful to analyse data for the short and medium term, as the demographic situation in Valchiavenna is very dynamic.
- About the economic development, there is currently insufficient data to analyse trends across different time horizons.
- Regarding climate scenarios, it is reasonable to align with the choices made at the national level in the NAP, which considers emission scenarios (RCP4.5 and RCP8.5) up to 2050, and at the regional level in the RAS, where the short-term (2040) and medium-term (2070) time horizons are considered.

Available scenarios (RCPs options, combination of GCM and RCM, etc.) utilized in the workflows are going to be discussed in the following sections.

2.3 Risk Analysis

2.3.1 Workflow Heavy Rainfall

In this phase, the Heavy Rainfall workflow was applied in an exploratory mode, with the main objective of testing the usability of selected datasets and methodologies, rather than producing conclusive results

The Heavy Rainfall workflow operates mainly on hazard data; at this time, no data for vulnerability or exposure have been considered.

The application of the workflow that CMV4Ciima envisioned in phase 1 took into account the existing weather forecast and early-warning system, that is in place as a main component of the overall civil protection scheme at the national and regional levels.

In terms of hazard data, in phase 1 CMV4Clima opted for testing different combinations of the available pre-calculated European datasets.

Table 2-4 Data overview workflow Heavy Rainfall

Hazard data	***Vulnerability data***	***Exposure data***	***Risk output***
Combinations of models, emission scenarios and time horizons	Critical thresholds based on Civil Protection early-warning system in place	5 test sites (meteo stations) - Samolaco v.Vignola - Madesimo Spluga - Chiavenna v.Cerletti - San Giacomo Filippo Lago Truzzo - Verceia	RP and magnitude shifts for the single localities (coordinates)
Combinations of models, emission scenarios and time horizons	IDF raster grids based on Rainfall Intensity-Duration-Frequency (IDF) Curves calculated by the Regional Environmental Agency	Areas IM-01 and IM-02, covering the whole CM Valchiavenna territory	RP and magnitude shifts for the two areas in the early-warning system

Hazard assessment

In terms of the hazard assessment, CMV4Clima project decided to test, in phase 1, the datasets offered by the “Path A” in the CLIMAAX platform. Therefore, the Hazard assessment step of the workflow was skipped for the moment and will be possibly undertaken during phase 2, after a more thorough selection of the available input data.

Table 2-5 Combination of parameters defining the datasets tested in CMV4Clima - phase 1

GCM	***RCM***	***RCP***	***BIAS CORR***	***Hist***	***Time_Hor***
ichec-ec-earth	knmi-racmo22e	rcp85	F	1976-2005	2011-2040
ichec-ec-earth	knmi-racmo22e	rcp85	F	1976-2005	2041-2070
mohc-hadgem2-es	knmi-racmo22e	rcp85	F	1976-2005	2011-2040
mohc-hadgem2-es	knmi-racmo22e	rcp85	F	1976-2005	2041-2070
mpi-m-mpi-esm-lr	smhi-rca4	rcp85	F	1976-2005	2011-2040
mpi-m-mpi-esm-lr	smhi-rca4	rcp85	F	1976-2005	2041-2070

Risk assessment

This paragraph elaborates over the choices taken and subsequent analysis performed for what concerns the application of the Heavy Rainfall – Risk Assessment workflow – phase 1.

The Heavy Rainfall Workflow aims to analyse changes in precipitation for specific durations, return periods, and RCP scenarios, Valchiavenna has started assessing its critical impact rainfall thresholds through the following steps:

1. ***Identification of critical thresholds***

According to the Regional Directive for the Organizational and Functional Management of the **Alert System for Natural Risks for Civil Protection** Purposes (Directive PCM 27/02/2004), valid in the

Lombardy Region, where Valchiavenna is located, the regional territory is divided into **homogeneous alert zones**, territorial areas that exhibit uniform ground effects in response to **meteorological forcing**. The distinction into zones arises from the need to activate homogeneous and adequate **responses to address risks** to the population, the social context, and the natural environment, in accordance with the meteorological forcing. The determination of homogeneous zones for Hydro-Meteorological risk takes into account meteorological, topographical, morphological, hydraulic, as well as managerial and administrative aspects, therefore also **vulnerability** and **response capacity** parameters.

Figure 3 represents the boundaries of the two zones IM-01 and IM-02. **IM-01** includes the municipalities of *Madesimo, Campodolcino, Piuro, San Giacomo Filippo, Chiavenna, Villa di Chiavenna, Mese, Gordona* and *Samolaco*. **IM-02** includes the municipalities of *Novate Mezzola* and *Verceia*.

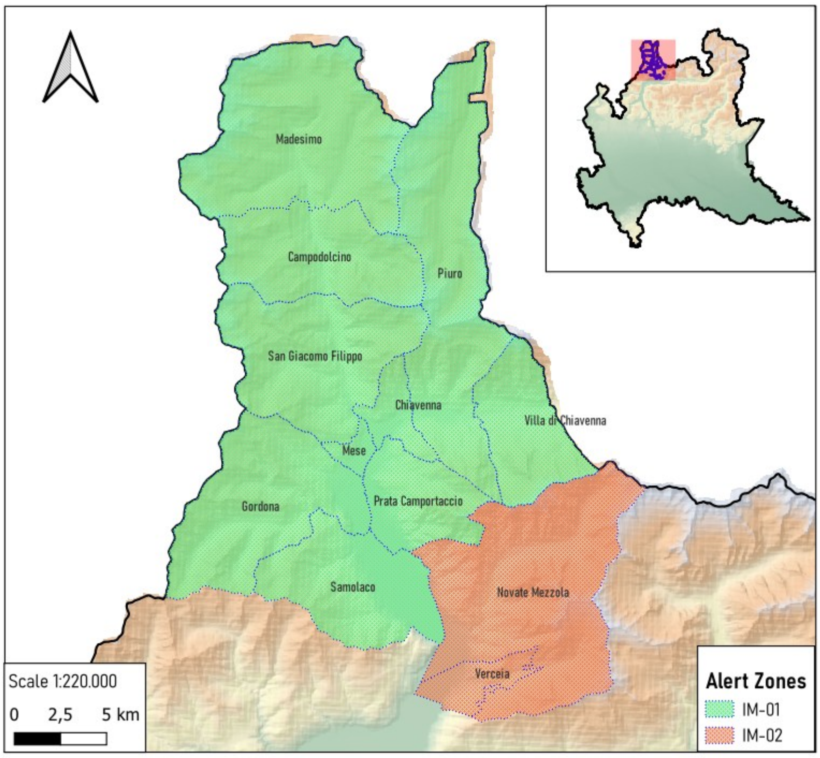

Figure 3 Representation of the homogenous alert zones for Valchiavenna

The zones have been developed by the regional Civil Protection system for various types of hazards (hydraulic, hydro-geological, strong winds, etc.). More specifically, for the purpose of the present investigation, the study will refer to the *homogeneous zones for hydro-meteorological risk: hydrogeological, hydraulic, thunderstorms, and strong winds*.

This particular risk considers, in the definition of the regional civil protection system, "*the consequences induced by the elements that characterize these phenomena: heavy rainfall, hail, lightning, wind gusts, and tornadoes, which can develop even over relatively small areas. When heavy rainfall is abundant and persistent, it can also contribute to hydrogeological and hydraulic risks.*

Lightning, wind gusts, hail, and tornadoes can cause various types of direct and indirect damage to the population and the assets present in the affected territory. The rapid development and limited spatial extent of thunderstorms significantly reduce their predictability within the timeframe defined for the forecasting phase. Thunderstorm risk can cause both localized and widespread damage, potentially severe."

Concerning Storm Risk, the Directive defines different hazard levels for each zone: normality, P1, P2, P3, P4. Table 2-6 explains the meaning of the hazard codes and levels in terms of probability of occurrence of the phenomena, according to the directive. The thresholds are defined based on criteria established by DGR 8753/2008, which analyse the daily alerts issued and the ground effects recorded in each homogeneous zone. The thresholds were set to minimize both missed and false alarms.

Table 2-6 Value key of the hazard codes and levels in terms of general probability of occurrence

Hazard codes (heavy rainfall)	***Hazard level***	***Probability (%) of occurrence of heavy rainfall** (storms = extreme events)*
-	None	0
P1	Very low	1-10 (<2)
P2	Low	10-40 (2-10)
P3	Moderate	40-60 (10-20)
P4	High	>60 (>20)

Table 2-7 General threshold values for the hazard levels in the two homogeneous zones covering Valchiavenna

Zone	**Threshold**	**-**	**P1**	**P2**	**P3**	**P4**
IM-01	6-hours [mm/6h]	0-15	15-35	35-45	45-70	>70
	12-hours [mm/12h]	0-20	20-45	45-55	55-85	>85
	24-hours [mm/24h]	0-25	25-60	60-85	85-110	>110
IM-02	6-hours [mm/6h]	0-15	15-30	30-40	40-65	>65
	12-hours [mm/12h]	0-20	20-40	40-50	50-80	>80
	24-hours [mm/24h]	0-25	25-50	50-80	80-100	>100

Focusing on the relevance of the phenomena to be considered and given the structure of the available datasets, the decision was made to select the values with **duration D = 24 hours** and to test only the boundary values for the most severe alert levels, therefore the **upper limit of level P3** and a value about 30% **higher than the P4** limit.

Table 2-8 Selected critical thresholds and relative parameters Duration and Intensity

Zone	**Alert level**	**D**	**I (mm)**
IM-01	P3 -> P4	24	**110**
	> P4	24	**150**
IM-02	P3 -> P4	24	**100**
	> P4	24	**135**

2. *Testing the thresholds*

The application of the processing to the critical threshold previously identified was carried out with two approaches, one focused on specific locations and one generalized over the area of the two homogeneous zones.

Site-specific risk assessment

<u>Identification of test sites</u>

The choice of the specific locations where to test the risk assessment algorithms was based mainly on three criteria:

- Geographical representativeness over the whole valley
- Presence of a urban area

- Presence of a meteorological station

10 meteorological stations are spread over the territory of Valchiavenna, that belong to the regional network managed by the Regional Environmental Agency (Figure 4): *Gordona, Verceia, Chiavenna v.Cerletti, Samolaco v.Vignola, Val Genasca, San Giacomo Filippo Lago Truzzo, Prata Camportaccio Pratella, Villa di Chiavenna, Campodolcino Alpe Motta, Madesimo Spluga*.

While the station is the only one available for the zone IM-02, hence an obligated choice, more stations are available for IM-02.

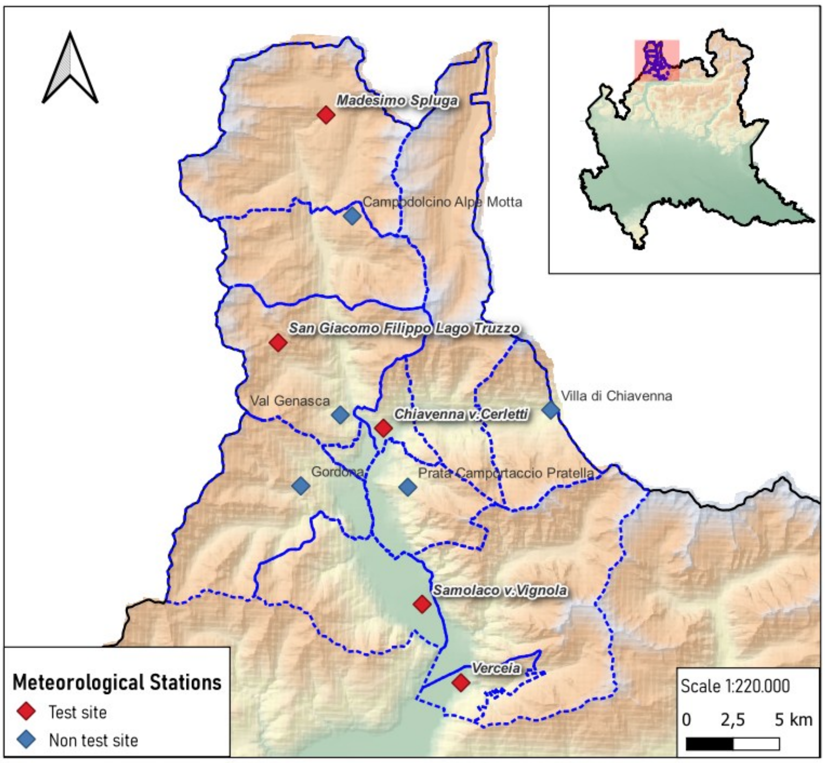

Figure 4 Distribution of the meteorological station in Valchiavenna and selected test sites

The final choice fell on 4 stations, spread from north to south along the valley and covering two different main river catchments, Madesimo and San Giacomo Filippo for the the Liro river: Chiavenna and Samolaco for the Mera river respectively. Moreover, Chiavenna represents the main urban area in the valley.

The decision of choosing sites where meteorological stations are present is also meant to facilitate phase 2, given the availability of measured data on historical storm events.

Calculation of I-D-F triplets

Finally, thanks to the Rainfall Intensity-Duration-Frequency (IDF) Curves calculated by the Regional Environmental Agency, it was possible to estimate the frequencies related to the intensities (Table 2-8) and duration (24 hours) parameters for the specific locations.

For the site-specific risk assessment, CMV4Clima focused on the high-end threshold (higher than P4 hazard level event).

Table 2-9 presents the I-D-F triplets and the coordinates of the sites tested in the workflow. Considering the combinations of parameters, as illustrated in Table 2-5, CMV4Clima operated 30 different runs for the site-specific risk assessment. Results are presented in paragraph 2.4.

Table 2-9 Calculated frequencies (return periods) for the higher critical threshold and the chosen test sites

Station	Zone	I (mm)	D (hours)	F (years)	Coord Y	Coord X
Samolaco v.Vignola	IM-01	**150**	24	**16,5**	46,23611	9,426654
Madesimo Spluga	IM-01	**150**	24	**14,7**	46,47167	9,348123
Chiavenna v.Cerletti	IM-01	**150**	24	**15,4**	46,32081	9,395591
San Giacomo Filippo Lago Truzzo	IM-01	**150**	24	**14,8**	46,36054	9,319988
Verceia	IM-02	**135**	24	**10,8**	46,19868	9,455462

Regional risk assessment

Computing I-D-F raster grids

The Regional Environmental Agency makes available gridded data of all the parameters required to compute Rainfall Intensity-Duration-Frequency (IDF) Curves for the entire region, hence the territory of Valchiavenna as well. The parameters area A1, N, GEV alpha, kappa and epsilon (Figure 5). Cell size is 1.5 by 1.5 km. It should be noted that all the meteorological stations on the territory of CMV fall in different cells of the grid, therefore each of them has a unique set of values for the afore-mentioned parameters.

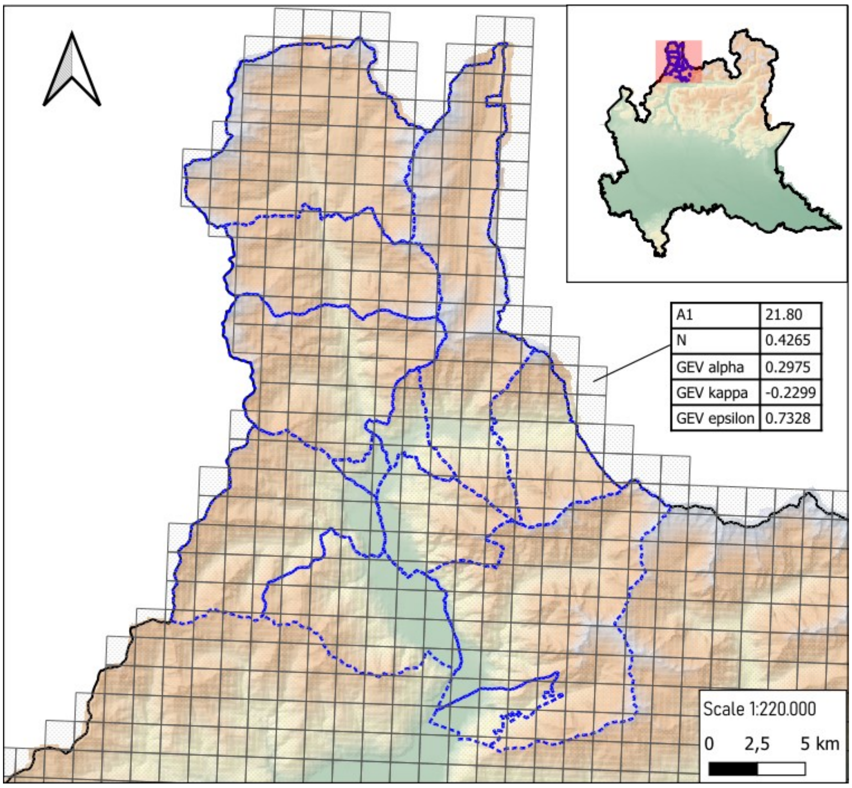

Figure 5 Gridded data for the calculation of Rainfall IDF Curves (source: ARPA Lombardia)

The basic formulas to compute the IDF values are (1) and (2):

$$(1)\ h_T(D) = a_1 w_T D^n$$

$$(2)\ w_T = \varepsilon + \frac{\alpha}{k}\left\{1 - \left[\ln\left(\frac{T}{T-1}\right)\right]^k\right\}$$

where ***h*** is the height of rainfall in mm, ***T*** is the return period in years and ***D*** the considered duration of the rainfall event in hours.

Since in the present case duration *D* and height *h* are given (Table 2-8), inverted formulas were needed to compute *T* (equations (3), (4) and (5)).

$$(3)\ w = \frac{h}{a_1 D^n}$$

$$(4)\ F = exp\left\{-\left[1 - \frac{k}{\alpha}(w - \varepsilon)\right]^{1/k}\right\}$$

$$(5)\ T = \frac{1}{1-F}$$

By applying the formula to the gridded data, it was possible to compute 4 different IDF rasters, this time testing both the P3->P4 boundary and the > P4 thresholds.

Table 2-10 Parameters of the 4 IDF rasters computed for the Regional Risk Assessment

Zone	I (mm)	D (hours)
IM-01	**110**	24
IM-01	**150**	24
IM-02	**100**	24
IM-02	**135**	24

Figure 6 shows an example of a computed raster grid, specifically for the combination of intensity 150 mm and duration 24 hours.

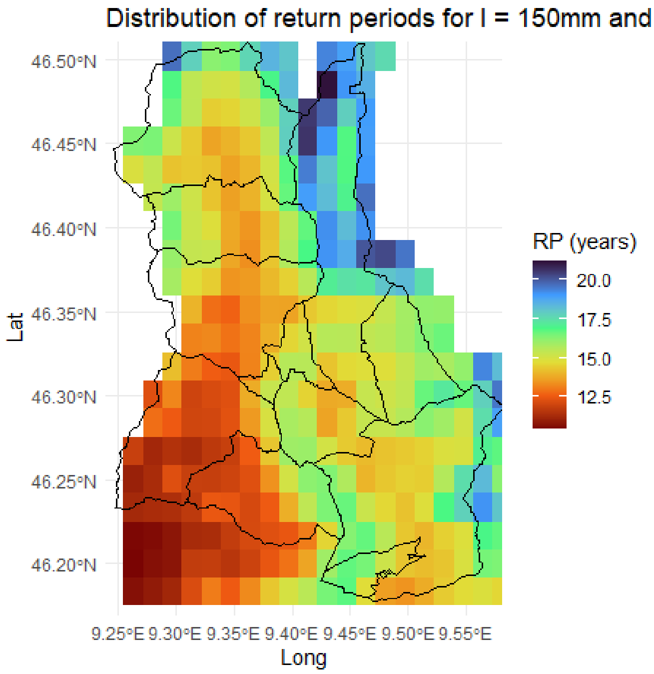

Figure 6 Example of computed IDF raster grids for Valchiavenna (I = 150 mm, D = 24 hours)

2.3.2 Workflow River Flooding

In phase 1 of the project, CMV4Clima has made a preliminary screening of the available data and noted that the scenarios distributed by Acqueduct cannot be considered representative of the area under scrutiny. It chose nevertheless to test the available datasets (JRC Flood depth for different RPs), with a particular interest for the risk assessment and the economic estimation of damages, related to LULC data. It was decided to leave to phase 2 the use of local hazard and risk data, LULC layers and the possibility to develop autonomous scenario data.

Table 2-11 Data overview workflow River Flooding

Hazard data	***Vulnerability data***	***Exposure data***	***Risk output***
JRC Flood Depth maps for Europe	LUISA dataset, damage curves	LUISA dataset, GPD per capita provided by ISTAT	Risk maps, economic damage evaluation over the Mera river area
Aqueduct Flood Risk maps for RCP4.5 and RCP8.5	-	-	Non relevant for the area

Hazard assessment

After an initial attempt to run the workflow over the entire area, CMV4Clima chose to focus on the area of river Mera, where flood risk appears to be more significant, at least in terms of inundated surface and affected urban areas.

Although the workflow was applied to both areas, hereby only the result of this preliminary application to the area of the Mera river are presented.

The **Mera** stream is an important alpine watercourse that flows through the Valchiavenna valley. It originates in **Switzerland**, near the Maloja Pass, and initially flows under the name Maira through the **Upper Engadine**, before entering Italy and **Valchiavenna** around the locality of Castasegna. Once in Italian territory, it is known as the Mera, running at first **east to west** and then turning **south-eastward** through the entire Valchiavenna, until **it joins the Adda River** near the municipality of Piantedo, close to **Lake Mezzola**.

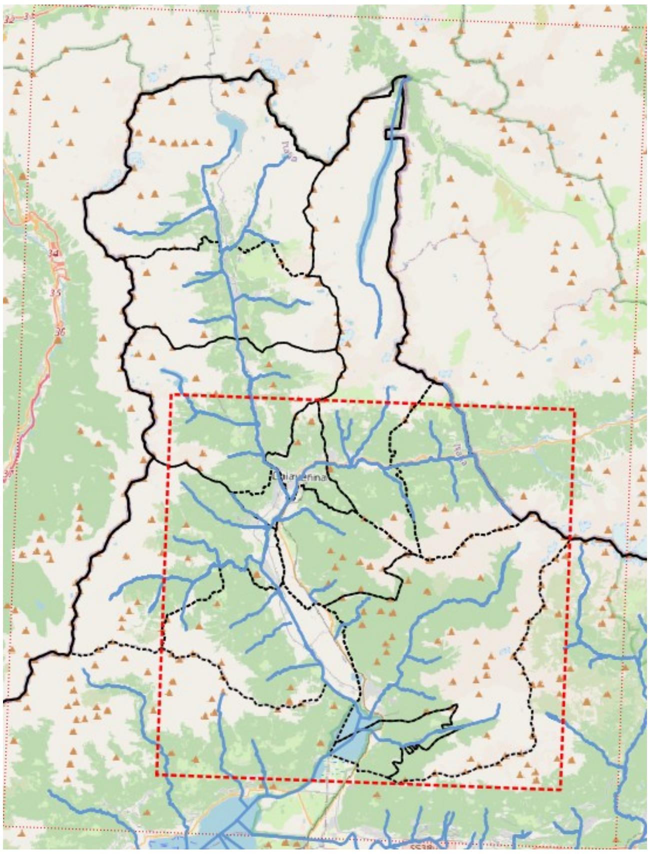

Figure 7 Detail of the Mera river area, focus of the River Flood workflow application in CMV4Clima

The river has a typically **torrential alpine character**, with highly variable discharges and a flow **regime strongly influenced by snowmelt** and intense precipitation, especially during spring and summer. It plays a fundamental hydrological and landscape role in the valley, **serving as the main drainage axis for the entire Valchiavenna watershed**. There **are artificial reservoirs and hydropower infrastructures** associated with the **Mera River system**, although not **directly on the main course** of the Mera in the Italian section. Most of the hydropower activity is linked to its **tributaries** and **diversion systems** that feed into power stations in the **Valchiavenna** area. These are generally **run-of-river** plants or involve **small compensation basins**, not large artificial lakes. The **Lake Mezzola** itself, into which the Mera flows before reaching the Adda, is a **natural lake** but with some **regulated outflow** connected to water level management of **Lake Como** and flood protection systems.

<u>**River flood maps for historical climate**</u>

The high-resolution river flood maps from JRC have been acquired and elaborated thanks to the CLIMAAX python script. An example is shown in Figure 8.

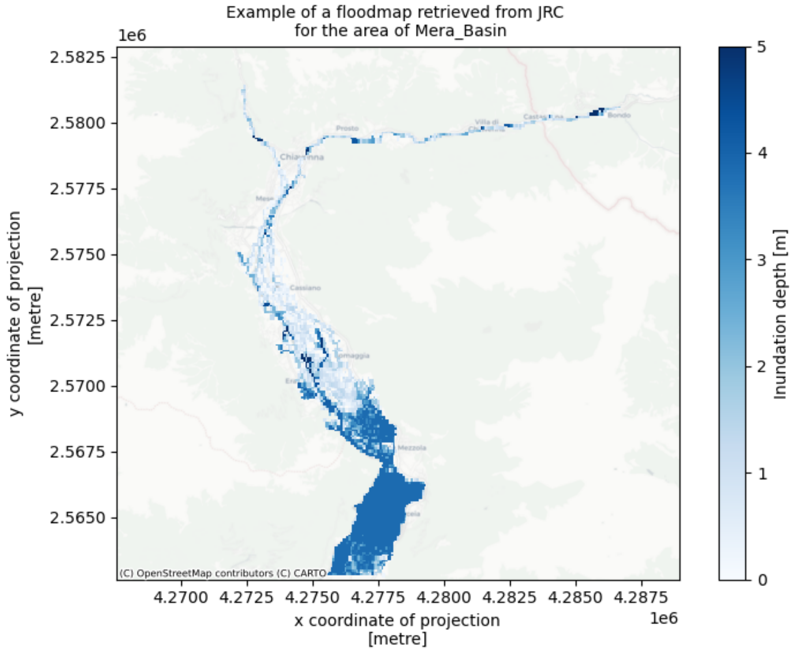

Figure 8 Extraction of a JRC floodmap for the area of river Mera

Return periods of 30, 200 and 500 years have been selected for visualization and further elaboration in order to align to the return period defined by the local Flood Risk Management Plan (PGRA) issued by the Po River Basin District Authority. In the FRMP (PGRA, in Italian) hazard areas are in fact categorized as low hazard P1 (catastrophic event, frequency RP not less than 500 years), medium hazard P2 (RP not less than 200 years) and high hazard P3 (RP not less than 30 years).

River flood maps for future climate scenarios

The flood maps from the **Aqueduct Flood Hazard Maps dataset**, the use of which in the CLIMAAX River Flood workflow is meant to assess qualitatively the change in river flood hazard under climate scenarios do not cover a significant area of the Valchiavenna territory.

In phase 2, CMV4Clima will evaluate the possibility of developing a local hydrologic and hydraulic model based on precipitation and run-off scenario data to overcome the lack of availability from existing sources.

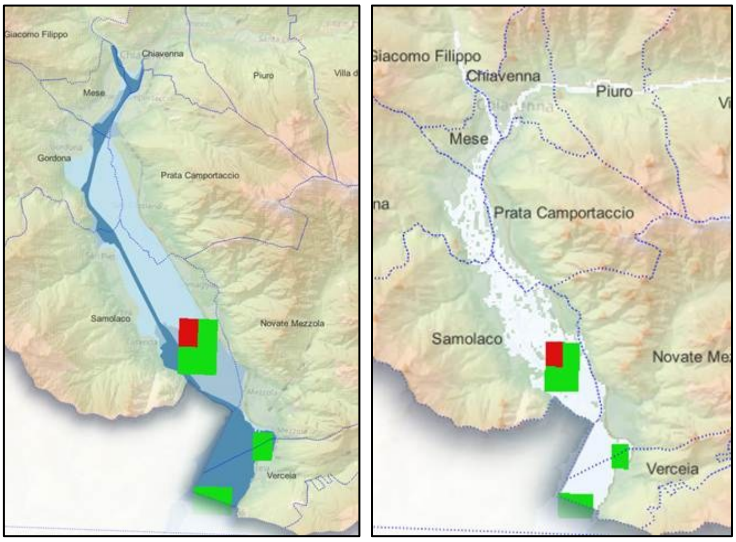

Figure 9 Overlapping of the Aqueduct dataset for Valchiavenna in comparison to (left) the FRMP maps and (right) the JRC Flood depth maps

Risk assessment

Much like with hazard data, also high detail LULC data (exposure) are available at the local level, yet in phase 1 CMV4Clima chose to test the European LUISA dataset and damage curves.

The Land Use data are related to economic values through curves provided by JRC models and the information about local current GDP per capita.
The value of GDP per capita used in the workflow was provided by the national statistics institute ISTAT, is valid for 2022 and for the province of Sondrio, where Valchiavenna is located.
Table 2-12 allows for the comparison of the values in Euro of the GDP per capita in Italy, region Lombardy and the same province of Sondrio.

Table 2-12 GDP per capita for the national, regional and provincial level in the domain of Valchiavenna

Region	***GDP per capita (2022)***
Italy	€ 33 840.53
Lombardy	€ 45 951.69
Sondrio	€ 33.592,00

Figure 10 shows the extraction of the LUISA dataset for the considered area. It is apparent that the majority of the territory belongs to **natural cover classes**, yet the **areas prone to flooding** by the Mera river (in fact the valley floor of the southern portion of Valchiavenna) fall into more **anthropic classes**, from dense and discontinuous urban fabric, to road and rail networks and associated land and agricultural domains.

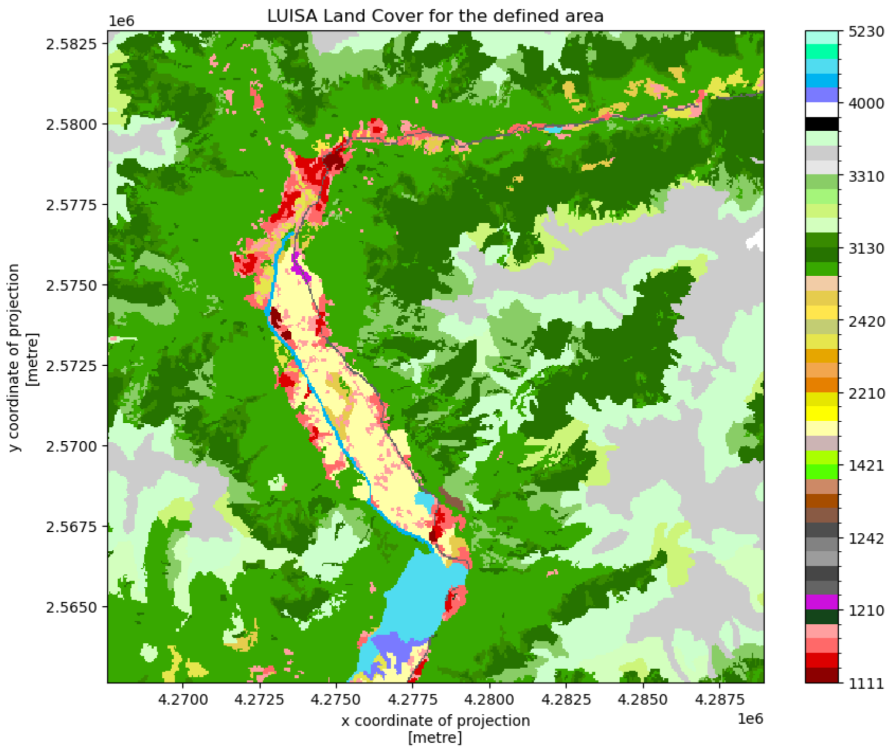

Figure 10 Extraction of the LUISA dataset for the area of the river Mera

The script computes total damage calculations for the affected classes, as shown in Table 2-13.

Table 2-13 Damage calculations (total €/m²) for selected scenarios and return periods (top 10 rows)

	Description	RP30	RP200	RP500
2110	Non irrigated arable land	174.773550	214.922623	227.484970
1122	Low density urban fabric	63.517242	81.126080	86.421861
1123	Isolated or very low density urban fabric	52.409275	67.366464	72.183873
1111	High density urban fabric	51.210022	58.312225	61.769475
4000	Wetlands	39.891170	45.912932	47.414359
1121	Medium density urban fabric	22.697142	28.985503	32.429546
2430	Land principally occupied by agriculture	22.610576	25.984963	27.269072
2310	Pastures	15.821092	19.310932	20.530487
1221	Road and rail networks and associated land	8.366706	10.463673	11.201941
3240	Transitional woodland shrub	1.397142	1.504544	1.548013

2.4 Preliminary Key Risk Assessment Findings

2.4.1 Severity

Heavy Rainfalls

This section presents a synthesis of the results of the application of the workflow, both for the Site-specific assessment and the Regional assessment.

1. ***Site-specific assessment outputs***

Results from the first phase consist in a set of values for:

- 5 sites from 2 different alert zones
- 3 combinations of GCM and RCM
- 2 time horizons (short and mid-term vs historical period 1976-2005)

A brief descriptive statistic analysis was performed to offer an insight into the uncertainty of the results, yet at this time too few outputs area available to produce significant answers. Figure 11 presents the outcome of this preliminary analysis, whereas Table 2-14 intends to help the legibility of the same charts.

Table 2-14 Correspondence between site/station names and the codes used in the charts

Site/Station	Abbreviation	Alert Zone
Samolaco v.Vignola	**SAM**	IM-01
Madesimo Spluga	**MAD**	IM-01
Chiavenna v.Cerletti	**CHI**	IM-01
San Giacomo Filippo Lago Truzzo	**SGF**	IM-01
Verceia	**VER**	IM-02

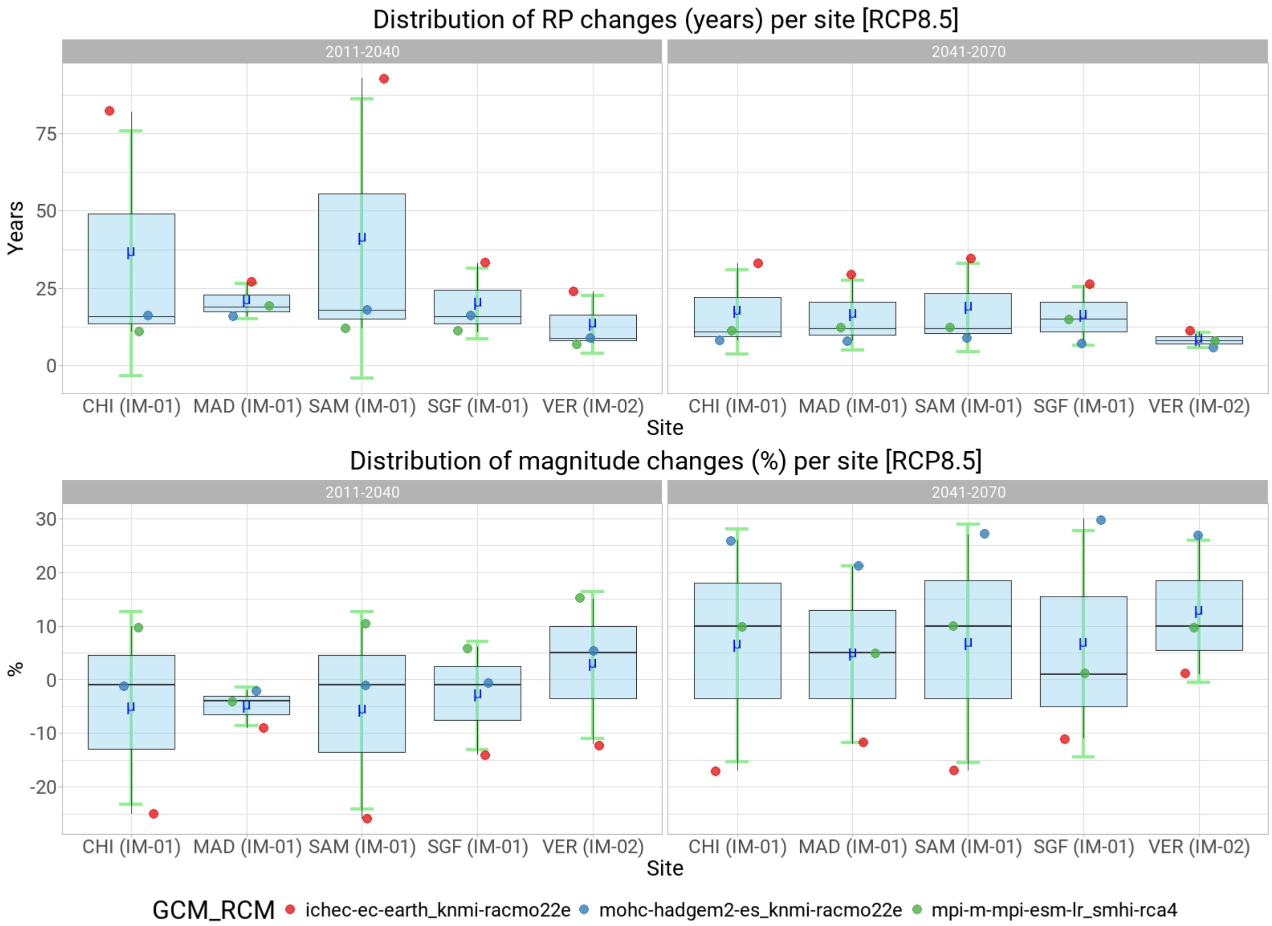

Figure 11 Brief descriptive statistics on the results of the site-specific risk assessment workflow

These results, although preliminary, seem to show **some important limits** in the application of the modelled Mean precipitation flux data, particularly for the near term scenario. Particularly, the *ichec-ec-earth/knmi-racmo22e* GCM-RCM combination shows results of **opposite sign** compared to the other two combinations of models. It should be noted again that there are two few samples for a relevant statistical analysis at this time.

2. *Regional risk assessment*

The application of the River Flooding workflow in Regional Assessment mode produced 24 different combinations, resulting in a total of 72 rasters (including Precipitation factors, Precipitation shifts and Return Period shifts).

More thorough analysis is needed to evaluate the quality of these results. Qualitatively, the outputs appear consistent with the site-specific analysis, but also sharing the same level of roughly estimated uncertainty.

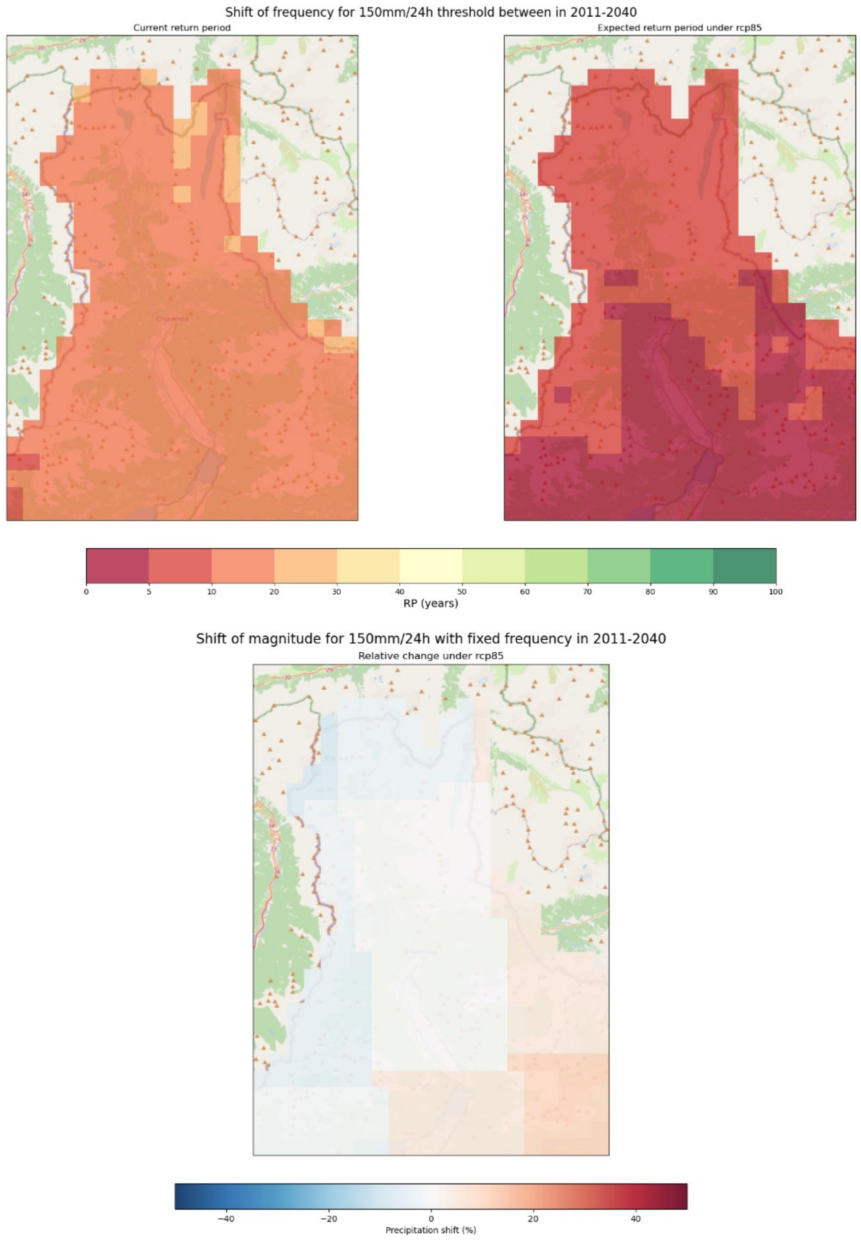

Figure 12 Example of outputs (mpi-m-mpi-esm-lr/smhi-rca4) for the 150mm/24h thresholds and near-term period

Further investigation is deemed necessary in phase 2, along with the identification of more specific thresholds related to registered historic events.

River flooding

Figure 13 shows two main findings:

- over the whole considered area, three most impacted areas could be isolated (highlighted in Figure 14)
- in a general sense, the three RP period scenarios do not differ substantially, in terms of the localization of the most impacted areas

There is a substantial difference in the total damage values among different RP scenarios, as highlighted in Table 2-15.

Table 2-15 Distribution of total estimated damages among LULC classes and differences among RP flood events

	Description	RP30	RP200	RP500	D200-30	D200-30 (%)	D500-30	D500-30 (%)
2110	Non irrigated arable land	174.773.550,00 €	214.922.623,00 €	227.484.970,00 €	40.149.073,00 €	23,0	52.711.420,00 €	30,2
1122	Low density urban fabric	63.517.242,00 €	81.126.080,00 €	86.421.861,00 €	17.608.838,00 €	27,7	22.904.619,00 €	36,1
1123	Isolated or very low density urban fabric	52.409.275,00 €	67.366.464,00 €	72.183.873,00 €	14.957.189,00 €	28,5	19.774.598,00 €	37,7
1111	High density urban fabric	51.210.022,00 €	58.312.225,00 €	61.769.475,00 €	7.102.203,00 €	13,9	10.559.453,00 €	20,6
4000	Wetlands	39.891.170,00 €	45.912.932,00 €	47.414.359,00 €	6.021.762,00 €	15,1	7.523.189,00 €	18,9
1121	Medium density urban fabric	22.697.142,00 €	28.985.503,00 €	32.429.546,00 €	6.288.361,00 €	27,7	9.732.404,00 €	42,9
2430	Land principally occupied by agriculture	22.610.576,00 €	25.984.963,00 €	27.269.072,00 €	3.374.387,00 €	14,9	4.658.496,00 €	20,6
2310	Pastures	15.821.092,00 €	19.310.932,00 €	20.530.487,00 €	3.489.840,00 €	22,1	4.709.395,00 €	29,8
1221	Road and rail networks and associated land	8.366.706,00 €	10.463.673,00 €	11.201.941,00 €	2.096.967,00 €	25,1	2.835.235,00 €	33,9
3240	Transitional woodland shrub	1.397.142,00 €	1.504.544,00 €	1.548.013,00 €	107.402,00 €	7,7	150.871,00 €	10,8

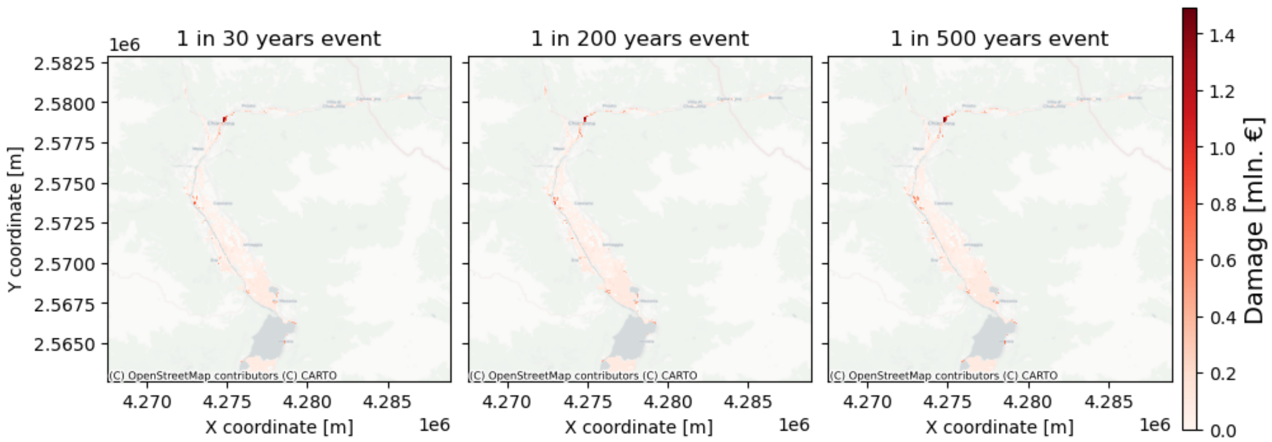

Figure 13 River flood damages for selected river flow scenarios in current day climate

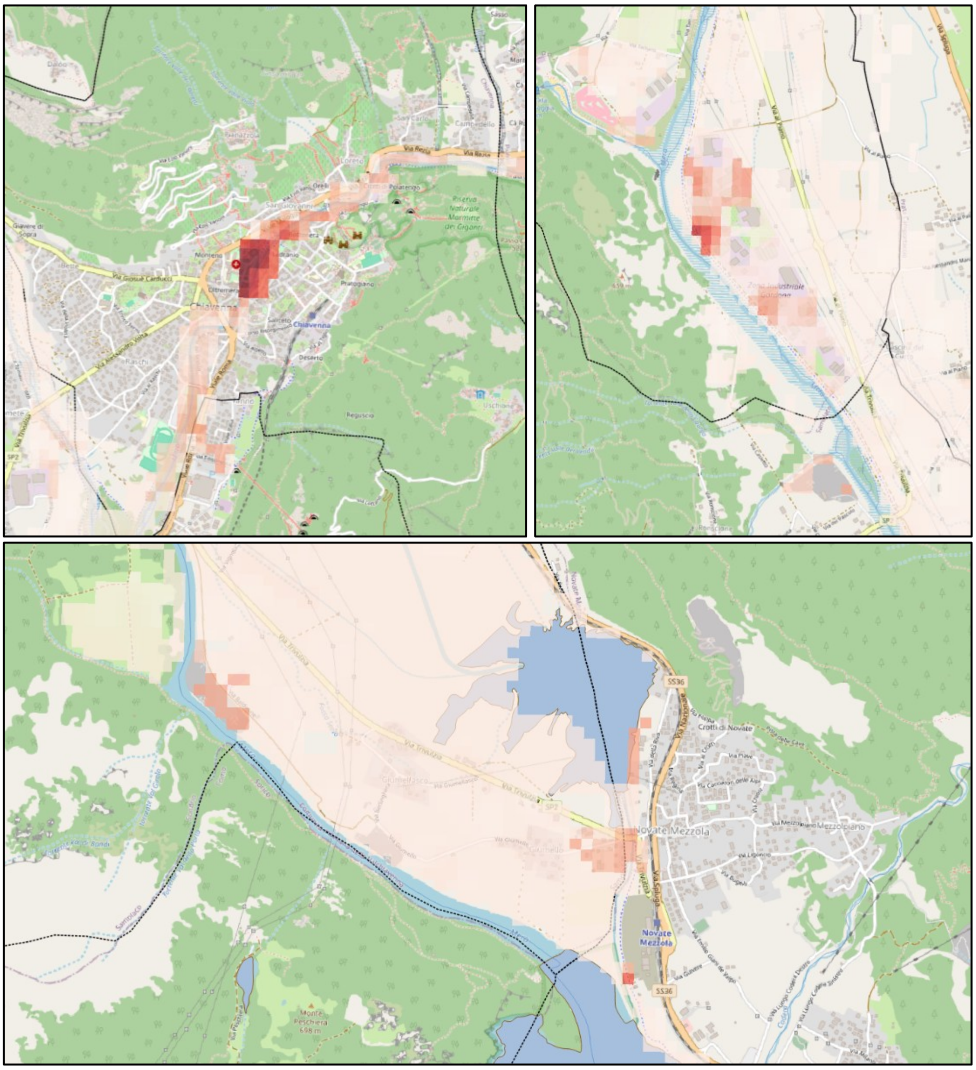

Figure 14 Most impacted areas: (upper left) urban area of Chiavenna, (upper right) industrial zone of Gordona, (lower) urban and industrial zone of Novate Mezzola

2.4.2 Urgency

Although the attribution is still not totally confirmed, extreme meteorological events are perceived as more and more frequent over the territory of Valchiavenna as well. In terms of heavy rainfalls and the related cascading effects (urban flooding, landslides and flash floods), in the last 5-10 years several events have been observed and some are being more thoroughly investigated (es. Gallivaggio, Val Genasca, etc.). Given a general trend of depopulation of mountain areas and consequent decreasing capacity in land maintenance on one side, and increasing demand of urban areas to take in the shifting population, the topic appears particularly urgent also in the very short period.

2.4.3 Capacity

The Valchiavenna territory's capacity to address climate risks related to heavy rainfall and river flooding relies on a combination of institutional tools, technical expertise, monitoring systems, and a well-established regulatory and planning framework. The area benefits from a network of institutional and operational actors (Mountain Community, Municipalities, ARPA, Lombardy Region, Civil Protection) actively involved in risk management through the implementation of plans such as the Civil Protection Plan, the Flood Risk Management Plan (PGRA), local urban development plans

(PGT), and river contracts. Moreover, the strong presence of artificial reservoirs and infrastructures for hydro-power generation contributes on the one hand to the regulation of the general water regime in the area, on the other hand to keep the interests on the topic of hydraulic and hydrological risk high.

Nonetheless, response capacity could be furtherly improved by adapting on different aspects. First, the fragmentation of responsibilities in managing critical infrastructures (e.g., roads, dams, water networks) may hinder a coordinated approach. Additionally, limited financial and human resources, especially in smaller municipalities, constrain the updating of infrastructure and the adoption of risk management, risk mitigation and adaptation measures.

The Valchiavenna region must strengthen risk governance, making it less fragmented and more integrated across different levels to improve emergency planning, ensuring greater preparedness and effectiveness. The increasing intensity and frequency of extreme events, along with their unpredictable cascading effects, may further elevate residual risk—defined as "the risk that remains after risk adaptation measures have been taken into account."

In terms of knowledge, data availability is relatively good thanks to local hydro-meteorological monitoring networks and access to European datasets. However, the systematic use of climate projections in decision-making processes is still limited, and specific risk thresholds for local events should be furtherly investigated. Technical capacity at the local level is gradually improving, also driven by the Mountain Community's participation in cross-border projects and European initiatives (e.g., CLIMAAX, AMALPI MORE, EURADAPT), which contribute to capacity building, the sharing of best practices, and the development of innovative tools.

Moreover, addressing territorial risks and understanding its dynamics and geography involves implementing maintenance and preservation measures that can simultaneously help slow down the trend of depopulation in the lateral valleys.

2.5 Preliminary Monitoring and Evaluation

The first phase of the CMV4Clima project provided a valuable learning experience in developing a climate risk assessment tailored to a complex Alpine context. One of the main takeaways was the importance of producing data and outputs that are meaningful and usable across different levels of decision-making. While the preliminary workflows helped identify key risk areas and test available datasets, the need for the use of a broader range of input datasets and a more structured and statistically sound analysis emerged as a priority for the next phases. In particular, greater clarity is needed regarding the differences among the various data sources, especially in terms of scale, resolution, and underlying assumptions.

The first key element is the integration of existing monitoring systems into the CRA process. This includes the regional civil protection early-warning system, ARPA Lombardia's meteorological and hydrological stations, and the regional damage reporting database (RASDA). These systems already provide a valuable baseline for observing hazard frequency and intensity, as well as the impacts of past events.

Secondly, the availability of European datasets such as LUISA, IDF grids, and flood risk maps from JRC enables a broader and more harmonized approach to long-term monitoring, in line with the CLIMAAX methodology. Their use in Phase 1 has demonstrated the potential for integrating local and European data to assess changes in hazard scenarios and exposure patterns. Nevertheless, there is a growing need for more granular and site-specific data, particularly related to vulnerability and exposure. Additional resources will be needed to enhance data processing capacities, develop new indicators, and deepen the understanding of cascading effects and compound risks. Future efforts should also focus on building institutional competencies to interpret and act upon the results, ensuring that the assessment process evolves into a permanent capacity for adaptive risk management.

A central challenge was the management and communication of uncertainty. The outputs of Phase 1 reflect a significant range of variability across scenarios and models. Understanding the implications of these uncertainties—especially when translating scientific results into planning tools—will be critical moving forward. This requires both technical improvements in the statistical treatment of data and the development of communication strategies that make uncertainties comprehensible to different audiences.

Stakeholders involved so far—primarily public institutions and service providers—have shown strong interest in the risk assessment process and actively contributed data and contextual information. However, it is clear that stakeholder involvement must be both broadened and deepened in the next phases. The insights from Phase 1 highlight the need to strengthen co-design mechanisms and to engage additional actors such as utility companies, economic sectors, and vulnerable community groups. This will ensure that the analysis becomes increasingly inclusive, relevant, and action-oriented.

3 Conclusions Phase 1- Climate risk assessment

The first phase of the CMV4Clima project has laid the foundations for a structured, evidence-based approach to assessing climate risks in the Valchiavenna territory. Through the application of the CLIMAAX methodology, the project has initiated a systematic analysis of heavy rainfall and river flooding risks—identified as key hazards for the area—while beginning to incorporate climate change projections and socio-economic scenarios into the local risk management framework.

This initial phase allowed the project team to explore the quality and applicability of multiple data sources, to estimate critical thresholds based on local early-warning systems, and to begin testing quantitative workflows to evaluate hazard trends under different climate scenarios. Preliminary results demonstrated both the potential and limitations of existing datasets and modeling approaches, especially when used in complex Alpine contexts characterized by spatial fragmentation, cross-border dependencies, and limited planning capacity.

Some important achievements emerged from phase 1:

- A clearer understanding of the main hazards affecting the territory, their spatial distribution, and the associated vulnerabilities;
- The preliminary application of two CLIMAAX workflows (Heavy Rainfall and River Flooding), allowing for both site-specific and regional-scale assessments using available European datasets;
- The identification of critical precipitation thresholds relevant for the territory and anchored in the regional early-warning system, which could allow for consideration about the future impact on the frequency of activation of the Civil Protection system at local level;
- An exploration of local capacities and institutional frameworks for climate risk governance, highlighting strengths and gaps
- The set-up of a wide engagement process for local and regional stakeholders

Moreover, the approach to economic estimation of exposed assets adds a new and very rich in potential information layer on the ordinary risk (exposure and vulnerability) assessment used in emergency planning. The application of the River Flood workflow in phase 1 allowed for preliminary identification of risk “hot-spots” on the territory and laid foundation for further investigation on the matter.

A key achievement of Phase 1 lies in the growing awareness of the need to bridge scientific assessments with policy and planning tools. The analysis highlighted the critical role of stakeholder engagement, the relevance of local contextual knowledge, and the necessity to manage and communicate uncertainty in a transparent manner. In particular, the importance of producing actionable and meaningful outputs—adapted to the operational needs of local institutions—emerged as a guiding principle for the next phases.

At the same time, several gaps were identified that will guide future efforts:

- Data fragmentation and the limited use of climate projections in existing planning tools represent barriers to fully climate-proof decision-making
- There is need for improved statistical treatment of the outputs, enhanced data granularity, and deeper analysis of vulnerability and exposure
- Moreover, although risk ownership is partially defined, a more integrated and coordinated governance framework will be needed to translate risk assessments into concrete actions. Strengthening stakeholder involvement and institutional capacity will be essential to ensure that the climate risk assessment evolves from a technical exercise into a shared, co-owned process.

Despite these challenges, Phase 1 provided valuable insights and created momentum for further engagement with stakeholders and institutional actors. It also demonstrated the relevance of combining local knowledge with European-level tools and methodologies. The groundwork was set for Phase 2, where a deeper risk quantification, stakeholder co-design, and the definition of adaptation measures will be pursued.

Ultimately, CMV4Clima Phase 1 has provided a contribution (together with other European projects) toward aligning Valchiavenna’s climate adaptation efforts with broader regional, national, and European objectives.

As Phase 2 begins, CMV4Clima is well positioned to build on these initial results. The groundwork was laid for a more advanced risk quantification, the co-development of adaptation strategies, and the establishment of a robust monitoring and evaluation framework that will support long-term resilience building in Valchiavenna.

4 Progress evaluation and contribution to future phases

As a follow-up and integration to the analysis carried out in phase 1, CMV4Clima intends to:

- Include the site of Villa di Chiavenna in the site-specific assessment for Heavy Rainfalls, given its representativity for the area nearby the headwaters of the basing of river Mera
- Elaborate a wider range of datasets, including the bias-corrected ones, made available by CLIMAAX (path A) and further investigate the possibility of testing different original combinations (path B)
- Completing the process of identifying event-related thresholds, which are more representative of extreme events (whereas the alert system thresholds are generally very precautionary)
- Evaluating the opportunity of producing a local hydrological and hydraulic model to be fed with rainfall and run-off scenario data for application in the River Flooding workflow

Moving into phase 2, outputs of phase 1 are going to be shared and presented to key stakeholders. In particular, a stronger dialogue will be established with municipal technical offices, regional technical representatives, technicians from the Integrated Water Service operator, those responsible for reservoirs used for hydroelectric power generation, and with representatives of the Geological Experimental Station of the University of Milan, in order to further investigate the study of critical thresholds related to the possible triggering of hazardous events, both from a hydraulic perspective and in terms of hydrogeological instability.

In this regards, some steps have been already carried out in phase 1, in terms of:

- **Data collection:** ten years of cumulative precipitation data (2014–2024) were downloaded from the ARPA Lombardia weather stations database, which is freely available on its website. Data were collected from eight weather station located within the Valchiavenna territory.
- **Meteorological reports analysis:** ARPA Lombardia publishes annual reports on significant meteorological events occurred in Lombardia. Some of these reports were consulted to identify periods between 2014 and 2024 when extreme weather phenomena may have affected the Valchiavenna region.
- **Impact analysis:** for each identified meteorological event, an online search was conducted to assess its impacts on community, infrastructure, and environment of Valchiavenna territory. Sources included local newspapers, online journals, and social media posts. However, this phase was, at this time, only partially successful, identifying approximately 15 significant events. To enhance the dataset and obtain a more comprehensive record of past impact events, the Community of Valchiavenna collected additional information from the municipalities, requesting access to RASDA reports. RASDA are forms used by local authorities to record and quantify damages resulting from natural disasters that have occurred in their territory. Although the RASDA reports were consulted, limited information was available regarding the severity of the events.
- **Critical thresholds:** for each rainfall event, the cumulative precipitation was recorded from the closest available weather station. Based on this methodology, a hazard-impact database was created for event-related thresholds, which needs further investigation.

Moreover, in phase 2 CMV4Clima will

- implement and improve the loss and damage estimates with regard to the flood risk
- further investigate the interplay with
    - the risk mitigation works already in place or planned on the territory

- the overall civil protection system, including the early-warning system and the several hydraulic monitoring and surveillance posts and flood emergency services on the territory
- the water regulation systems in place, associated with the hydro-power generation purpose

Table 4-1 Overview key performance indicators

Key performance indicators	***Progress***
At least [2] workflows successfully applied on Deliverable 1	Completed (2/2)

Table 4-2 Overview milestones

Milestones	***Progress***
M1: Test of CLIMAAX workflow River Flood	Completed
M2: All CLIMAAX workflows applied	Completed
M3: First level stakeholder mapping	Completed

5 Supporting documentation

1. HEAVY_RAIN_INPUTS_OUTPUTS

```
├──── Spreadsheet
│    └──── CMV4Clima_WF_HR_GEN_INPUT_OUTPUT.xlsx
├──── IDF_RASTER_INPUTS
│    └──── Raster files of precipitation thresholds (e.g., CMV_raster_h100_D24.tif)
├──── OUTPUT_AREA
│    ├──── Time Horizon: 2011−2040
│    │    └──── Multiple model folders (e.g., IM-01_110_24_'ichec-ec-earth'_'knmi-racmo22e'_2011-2040)
│    │         ├──── PLOTS folder: PNG images of threshold shifts
│    │         └──── RASTER folder: TIFF and XML files with precipitation/flood modeling outputs
│    ├──── Time Horizon: 2041–2070
│    │    └──── Same structure as 2011−2040 with updated time span and models
├──── Notes:
│    • Each model folder is named according to intensity-duration thresholds and GCM/RCM pairing
│    • Raster files include factor and shift maps for precipitation and return periods
│    • Plot files are visual outputs of model calculations
```

[Only representative folders and file types are shown. The full dataset includes multiple models, thresholds, and emission scenarios]

2. RIVER_FLOODING_INPUTS_OUTPUTS

```
├──── Base Data
│    ├──── JRC_damage_curves.csv
│    └──── maxdam_luisa.csv
├──── MERA
│    └──── LUISA_damage_info_curves_Mera_Basin.xlsx
├──── OUTPUT
│    ├──── PLOT
│    │    ├──── Result_map_Mera_Basin_damages_overview.png
│    │    ├──── Result_map_Mera_Basin_rp100.png
│    │    ├──── Result_map_Mera_Basin_rp200.png
│    │    └──── Result_map_Mera_Basin_rp500.png
│    └──── RASTER
│        ├──── flood_Mera_Basin_RP10_damagemap.tiff
│        ├──── flood_Mera_Basin_RP10_damages.csv
│        ├──── flood_Mera_Basin_RP50_damagemap.tiff
│        ├──── flood_Mera_Basin_RP50_damages.csv
│        ├──── flood_Mera_Basin_RP100_damagemap.tiff
│        ├──── flood_Mera_Basin_RP100_damages.csv
```

```
│       ├──── flood_Mera_Basin_RP200_damagemap.tiff
│       ├──── flood_Mera_Basin_RP200_damages.csv
│       ├──── flood_Mera_Basin_RP200_damagemap.qml
│       ├──── flood_Mera_Basin_RP200_damagemap.tiff.aux.xml
│       ├──── flood_Mera_Basin_RP500_damagemap.tiff
│       ├──── flood_Mera_Basin_RP500_damages.csv
│       ├──── flood_Mera_Basin_RP500_damagemap.tiff.aux.xml
│       ├─── curves.csv
│       └──── land_use_Mera_Basin.tiff
```

Notes:

• Raster folder includes TIFF maps and CSVs representing damage estimations at different return periods (RP10, RP50, RP100, RP200, RP500).

• Plot folder contains visual overviews of flood impact scenarios.

• LUISA and JRC data inform the damage modelling in the Mera Basin.

3. SOIL_SEALING
    a. CONSUMO_SUOLO_ISPRA.xlsx
4. COMMUNICATION_DISSEMINATION_PARTICIPATION
    a. COMMUNICATION_MATERIALS
        i. Leaflet V8.pdf
        ii. Roll-Up V7_DEFINITIVO.pdf
        iii. List_Stakeholders_meetings_and_Dissemination.docx
    b. MEETINGS
        i. Incontro 13-03-25.jpg
        ii. KOM_December_2024_Agenda.pdf
    c. NEWSPAPERS
        i. Centrovalle_10_08_2024.jpg
        ii. Centrovalle_21_12_2024_kickoff_CMV4Clima.jpg
        iii. Valchiavenna_marzo2025.PNG
    d. Report_Com&Dis_Activities_CLIMAAX_upFeb2025.pdf

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