2ND TEHMATIC POLICY AREA

MOBILITY AND CONNECTIVITY

ACTION GROUP 5

Connecting people electronically and promoting accessibility to public services

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80 million people, 7 countries, 48 regions, mountains and plains addressing together common challenges and opportunities

Interreg Alpine Space
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1 The Shaping of the Alpine Region Through Artificial Intelligence

1.1 Executive Summary

Artificial Intelligence (AI) is increasingly recognized as a transformative technology with the potential to address critical challenges and unlock new opportunities within the European Alpine region. This report examines the current landscape of AI applications in the Alps, focusing on three key themes: (i) tourism and sport, (ii) water management, and (iii) natural hazards risk management and climate change monitoring. Across these domains, AI is being explored and implemented through various EU-funded projects, demonstrating its capacity to enhance sustainability, improve efficiency, and provide valuable insights for decision-making. While the adoption of AI in the Alpine region is still in the relatively early stages, numerous projects are showcasing promising use cases and potential benefits. However, challenges related to data availability, technical expertise, ethical considerations, and integration with existing systems need to be addressed to ensure the responsible and effective implementation of AI initiatives. This report concludes by highlighting key findings and offering recommendations for policymakers and stakeholders to foster a future where AI contributes significantly to the resilience and prosperity of the Alpine region.

Summary

2 Table of Acronyms

The following table lists all acronyms used in the report “The Shaping of the Alpine Region Through Artificial Intelligence” together with their full meanings.

Acronym	Full Meaning
ADAPTNOW	Adaptation to Climate Change in Alpine Regions (EU project)
AG1	EUSALP Action Group 1 – Research and Innovation
AG2	EUSALP Action Group 2 – Economic Development
AG3	EUSALP Action Group 3 – Labour Market, Education, and Training
AG5	EUSALP Action Group 5 – Connectivity and Digitization
AG9	EUSALP Action Group 9 – Energy
AI	Artificial Intelligence
AI Act	Artificial Intelligence Act (EU) 2024/1689
AI4FLOOD	Artificial Intelligence for Flood Preparedness (EU project)
B2B	Business-to-Business
CCP1	Cross-Cutting Priority 1 – Promoting the Digitalization of the Alps
CLINT	Climate Intelligence Project (EU programme)
CLISP-ALP	Climate Change Adaptation by Spatial Planning in the Alpine Space
Crowd in Motion (CiMo)	European Digital Innovation Hub for Tourism and Sport in the Alps
DAC	Digital Alps Conference
DAC 2025	Digital Alps Conference 2025 (Lienz, Austria)
DARROW	Data and AI for River and Water Optimization (project)
DGA	Data Governance Act (EU) 2022/868
DMA	Digital Markets Act (EU) 2022/1925
DSA	Digital Services Act (EU) 2022/2065
DSDS	Decision Support and Data Services (MedEWSa component)
Data Act	Data Act (EU) 2023/2854
DiMark	Digital Marketplace for Water Data (EU project)
EDIH	European Digital Innovation Hub
EIF	European Interoperability Framework
EO	Earth Observation
EO4ALPS-Snow	Earth Observation for Alpine Snow Monitoring (project)
ETDS	European Tourism Data Space
EU	European Union
EU GDP	Gross Domestic Product of the European Union
EUSALP	EU Strategy for the Alpine Region
EYOF	European Youth Olympic Festival
FARMWISE	Farm Water Intelligence System for Efficiency (project)
GDPR	General Data Protection Regulation (EU) 2016/679
HPC	High-Performance Computing
ICT4Water	Information and Communication Technologies for Water (EU Cluster)
IEA	Interoperable Europe Act (EU) 2024/903
INTERTWIN	Integrated Twin for Alpine Water Systems (project)

IoT	Internet of Things
ML	Machine Learning
MountAIn	AI-based Human Motion Analytics Testbed in Mountain Scenarios (project)
OGC	Open Geospatial Consortium
PARATUS	Preparedness and Resilience Against Natural Disasters Using AI (project)
R&I	Research and Innovation
RDMDT	Resilience Decision-Making Digital Tool
RESPOnD	Resilient and Smart Policy for Natural Disasters (EU project)
SME	Small and Medium-sized Enterprise
SMEs	Small and Medium-sized Enterprises
SUMMER Project	Smart Urban Monitoring for Environmental Resilience (project)
SmartCommUnity	Smart Communities in the Alpine Space (Interreg project)
SmartVillages	Smart Villages (Interreg Alpine Space project)
THMT	Tourism and Health Management Tools (project)
VLOP	Very Large Online Platform
VLOSE	Very Large Online Search Engine
VisionAlps	Business-to-Business Initiative for Digital Transformation of the Alps
WOLL	Water-Oriented Living Lab
X-RISK-CC	Cross-Risk Climate Change (project for hazard assessment)
XAI	Explainable Artificial Intelligence

3 Introduction: The Rise of AI in the Alpine Region

3.1 Importance of the Alpine Region

The Alpine region of Europe holds significant ecological, economic, and social importance, serving as a crucial biodiversity hotspot, a vital source of freshwater, and a popular destination for tourism and recreation. This area is characterized by its unique and often fragile ecosystems, which are particularly vulnerable to the impacts of climate change and natural hazards. The European Union (EU) and the EU Strategy for the Alpine Region (EUSALP) play a crucial role in promoting sustainable development within this diverse and interconnected territory. Recognizing the need for innovative solutions to address the region's specific challenges, stakeholders are increasingly looking towards advanced technologies like Artificial Intelligence (AI).

3.2 Potential of Artificial Intelligence

Artificial Intelligence has emerged as a transformative technology with the capacity to analyze vast amounts of data, generate predictions, optimize complex systems, and automate various processes across numerous sectors. Its capabilities in pattern recognition, forecasting, and decision support offer significant potential for addressing the unique challenges and opportunities present in the Alpine region **Errore. L'origine riferimento non è stata trovata.**. From enhancing the efficiency of tourism operations to improving the management of water resources and strengthening resilience against natural hazards, AI presents a powerful toolkit for sustainable development in this sensitive environment.

3.3 Report Objectives and Structure

This report aims to provide a comprehensive analysis of how AI is currently shaping the Alpine areas, with a specific focus on EU-funded projects addressing tourism and sport, water management, natural hazards risk management, and climate change monitoring. The objectives include identifying use cases and potential benefits, recognizing best practices at the EU and EUSALP levels, and assessing the status of AI initiative implementation, including governance, sustainability, and adoption challenges. The report is structured to first analyze AI applications within each of the three thematic areas, followed by a cross-cutting analysis of ethical considerations and adoption challenges, and finally, a conclusion summarizing key findings and offering recommendations.

4 Context Analysis on EU and EUSALP Levels: Exploration of the Framework at the European Level for Developing New Initiatives Related to Artificial Intelligence

4.1 Introduction: The European Union's Vision for a Data-Driven and AI-Powered Economy

The European Union (EU) has positioned itself as a global leader in regulating and fostering a digital economy that is fair, innovative, and human-centric. At the heart of this ambition is the European Data Strategy, launched in 2020, which seeks to create a single market for data where information flows freely across borders and sectors, benefiting businesses, researchers, public administrations, and citizens. This strategy emphasizes respect for European values, including privacy, data protection under the General Data Protection Regulation (GDPR) (EU) 2016/679, and competition law, while promoting investments in data infrastructures and the development of common European data spaces. By 2025, the EU data economy is projected to reach €829 billion, up from €301 billion in 2018, representing 5.8% of EU GDP, with 10.9 million data professionals and 65% of the population possessing basic digital skills. The strategy integrates with broader digital goals under the Europe's Digital Decade program, aiming for 100% online accessibility of key public services by 2030 and widespread adoption of technologies like AI, cloud computing, and high-performance computing. Central to this are the "Big Five" regulations: the Digital Markets Act (DMA) (EU) 2022/1925, Digital Services Act (DSA) (EU) 2022/2065, Data Governance Act (DGA) (EU) 2022/868, Data Act (EU) 2023/2854, and AI Act (EU) 2024/1689. These laws collectively shape the European data economy by addressing market fairness, service safety, data sharing, and AI governance. Complementing them are the Interoperable Europe Act (IEA) (EU) 2024/903 and the European Interoperability Framework (EIF), which ensure seamless data exchanges and interoperability across regions and sectors.

In the context of the EU Strategy for the Alpine Region (EUSALP), established in 2015, these frameworks are particularly relevant. EUSALP, involving seven countries and 48 regions, focuses on economic growth, mobility, and environmental sustainability. Action Group 5 (AG5) leads efforts in digitization and connectivity, coordinating the cross-cutting priority CCP1: "Promoting the Digitalization of the Alps." This involves collaboration with AG1 (research and innovation), AG2 (economic development), AG3 (labor market), and AG9 (energy) to advance digital transitions, including AI applications in tourism, water management, natural hazards risk management, and climate change monitoring. The proposed study on AI for local communities aligns with CCP1 by providing concrete cases to feed into AG5's strategy and AG2's work on data spaces for SMEs.

This analysis explores the EU framework, detailing the Big Five regulations, IEA, EIF, and other initiatives, while examining their implications for EUSALP. It highlights how these enable new AI initiatives, addressing challenges like data access, infrastructure limitations, and workforce upskilling in Alpine regions. The framework not only regulates but also empowers stakeholders to harness AI for sustainable growth, with potential economic benefits like €270 billion added to EU GDP by 2028 from enhanced data sharing.

4.2 The Digital Markets Act (DMA): Fostering Fair Competition in Digital Markets

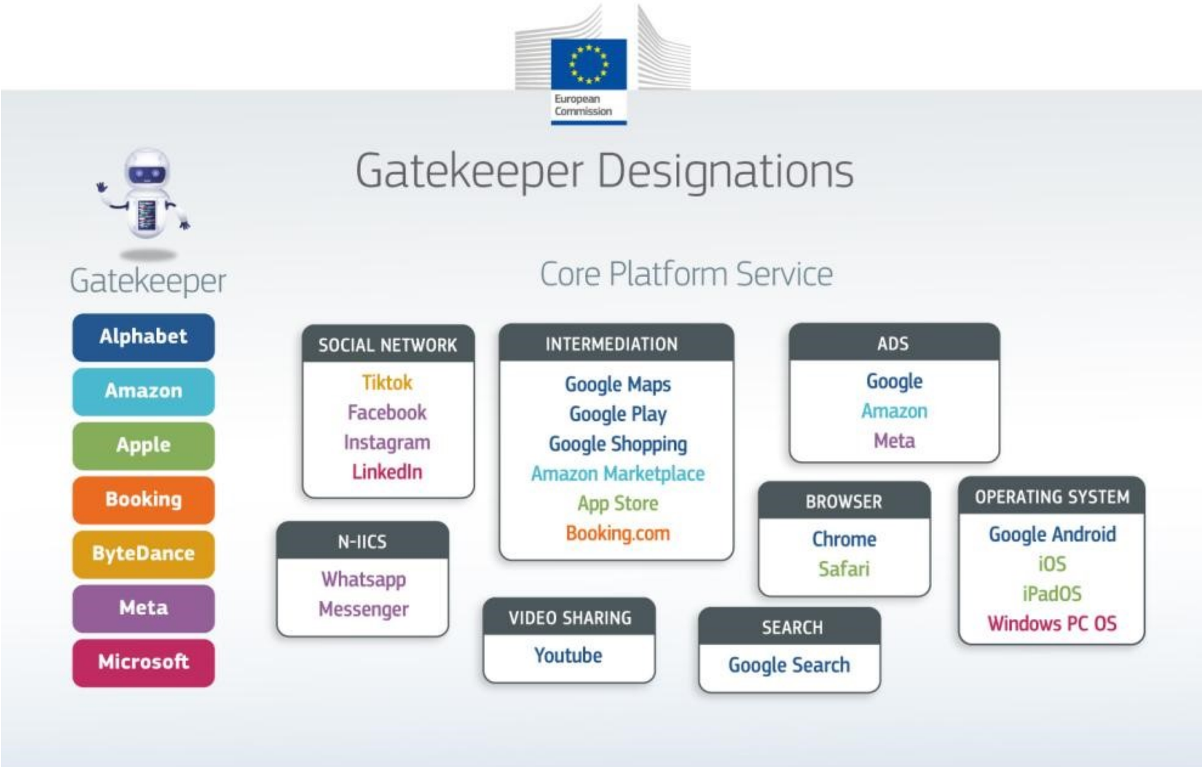

Figure 1 - DMA Gatekeepers Designations

The DMA, effective from May 2023, targets "gatekeepers"—large digital platforms with significant market power—to ensure contestable and fair digital markets (see Figure 1). Gatekeepers are designated based on quantitative thresholds: €7.5 billion EU turnover, €75 billion market capitalization, 45 million monthly active end users, and 10,000 yearly active business users in at least three Member States. Qualitative criteria apply via market investigations if thresholds are unmet but power is evident. Objectives include preventing unfair practices that hinder innovation and consumer choice, such as self-preferencing or data silos. Key provisions (Articles 5-7) impose obligations like data portability (Article 6(9)), interoperability for communication services (Article 7), and prohibiting tying practices (Article 5(7)). Gatekeepers must allow business users access to generated data, fostering data sharing crucial for AI development.

Enforcement is centralized with the European Commission, which can impose fines up to 10% of global turnover (20% for repeated violations) and structural remedies like divestitures (Article 29). This complements competition law under Articles 101-102 TFEU without replacing it.

In relation to AI and the data economy, the DMA indirectly supports AI adoption by breaking data monopolies, enabling SMEs and startups to access datasets for training models. For EUSALP, this is vital in Alpine regions where SMEs dominate sectors like tourism. Gatekeepers' data obligations can fuel AI-

driven personalized experiences, such as recommendation systems for Alpine sports, while promoting innovation in remote areas. However, challenges include ensuring Alpine businesses, often small, can leverage these without high compliance costs. The DMA's impact on regional development lies in leveling the playing field, potentially boosting economic growth by facilitating AI integration in local economies.
The DMA aligns with the European Data Strategy by promoting fair data access, estimated to unlock €270 billion in value. In EUSALP's CCP1, it supports networking on digital priorities, enabling AI initiatives like predictive analytics for natural hazards by ensuring data flows from platforms to public authorities.

4.3 The Digital Services Act (DSA): Enhancing Safety and Transparency in Digital Services

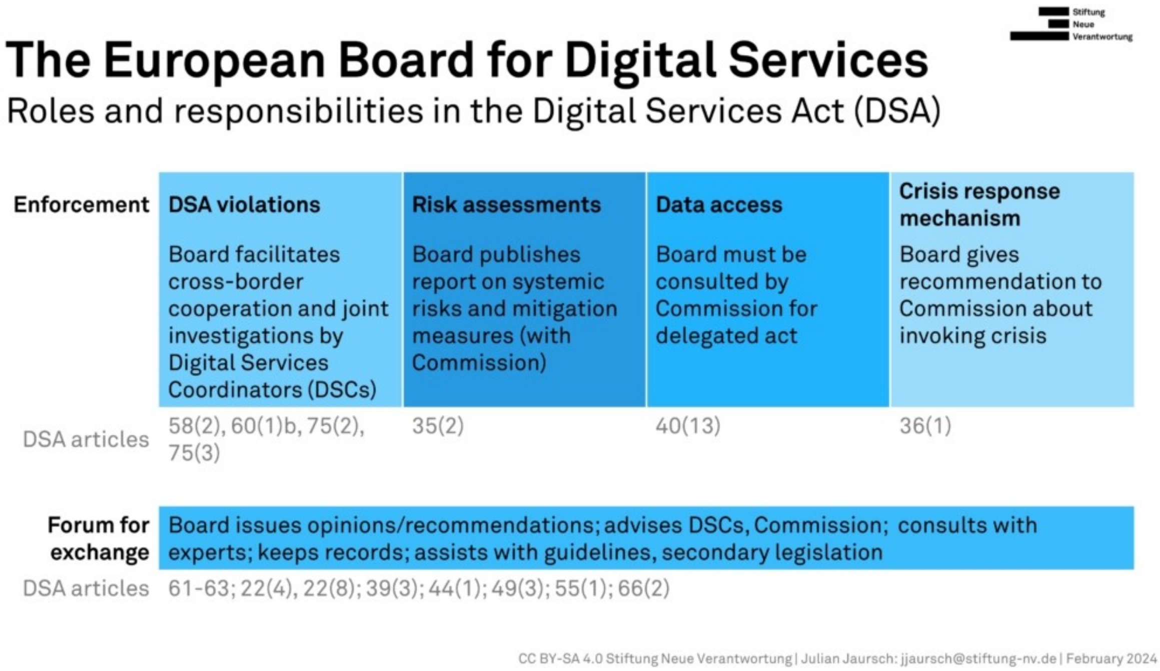

Figure 2 - DSA Role and responsibilities [https://dsa-observatory.eu]

The DSA (Figure 2), effective from February 2024, modernizes the e-Commerce Directive to create a safer online environment, protecting fundamental rights while addressing illegal content and systemic risks. It applies to intermediary services, including hosting, caching, and online platforms, with stricter rules for Very Large Online Platforms (VLOPs) and Search Engines (VLOSEs) exceeding 45 million users (10% of EU population).
Objectives focus on harmonizing rules to prevent market fragmentation, ensuring transparency, and mitigating risks like disinformation and harm to minors. Key provisions include liability exemptions for neutral intermediaries (Articles 4-8), due diligence obligations like notice-and-action mechanisms (Article 16), and transparency in content moderation (Article 15). VLOPs must conduct risk assessments for systemic issues, including AI-driven content amplification, and implement mitigations like algorithmic adaptations (Article 34-35).
Transparency requirements mandate annual reports on moderation (Article 42) and advertisement repositories (Article 39). Enforcement involves Digital Services Coordinators per Member State and Commission oversight for VLOPs, with fines up to 6% of global turnover.

Regarding AI, the DSA regulates AI in content moderation and recommender systems, requiring disclosure of prioritization criteria and alternatives not based on profiling (Article 27). It prohibits profiling-based advertisements for minors (Article 28), aligning with ethical AI principles. For data protection, it complements GDPR by ensuring data minimization in moderation.
In the data economy, the DSA promotes trust by addressing illegal data practices, facilitating secure data sharing. For EUSALP, it enhances digital services accessibility in Alpine communities, supporting AI in tourism (e.g., safe online booking platforms) and environmental monitoring (e.g., moderating disinformation on climate change). Regional implications include improved user safety in remote areas, where digital reliance is high for services like hazard alerts. The DSA's crisis response mechanisms (Article 36) can aid natural hazards management, integrating AI for real-time warnings.

4.4 The Data Governance Act (DGA): Building Trust in Data Sharing and Altruism

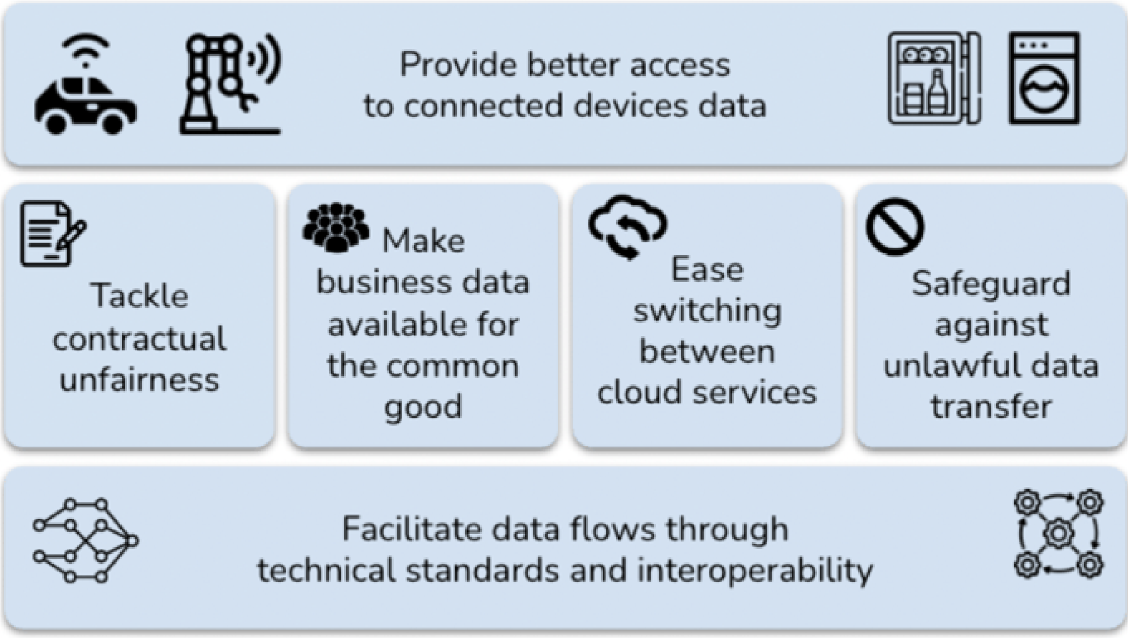

Figure 3 - Data Act Pillars [https://www.dawex.com]

The DGA, applicable from September 2023, establishes a framework for trustworthy data sharing, focusing on public sector data re-use, data intermediation services, and data altruism (see Figure 3). It complements the Open Data Directive by covering protected data like personal or commercially confidential information.
Objectives include increasing data availability for innovation, particularly AI, while ensuring trust through neutrality and security. Scope excludes security-sensitive data but applies to public bodies, intermediaries, and altruistic organizations.
Key provisions: Public sector data re-use requires non-exclusive arrangements (Article 4), secure processing environments (Article 7), and single information points (Article 8). Data intermediaries must notify authorities, maintain neutrality (Article 12), and use a common logo (Article 43). Data altruism allows voluntary sharing for public interest (e.g., healthcare, climate), with recognized organizations registering for a label (Articles 16-25).

The European Data Innovation Board coordinates implementation (Article 26). Significance lies in fostering FAIR data principles, enabling AI training on diverse datasets.
For AI, the DGA supports ecosystems by facilitating altruistic data pools for machine learning in public interest areas like climate monitoring. In the data economy, it boosts innovation for SMEs via intermediaries.
In EUSALP, it aligns with AG5's digitization strategy, enabling data sharing for AI in water management (e.g., altruistic sensor data) and tourism (e.g., re-using public mobility data). Implications for Alpine regions include overcoming data silos in remote areas, promoting sustainable growth through AI-driven resource optimization.

4.5 The Data Act: Unlocking Fair Access to IoT and Generated Data

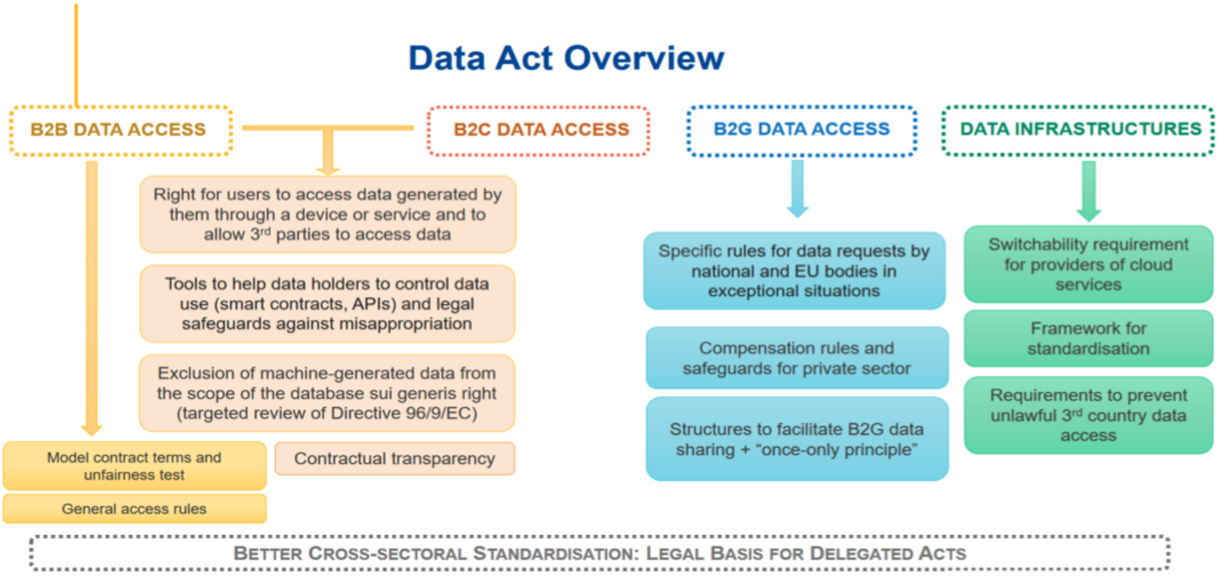

Figure 4 - The Data Act overview

The Data Act (Figure 4), effective from September 2025, ensures fair data access from connected products and services, addressing IoT data silos. It applies to manufacturers, users, and data holders, excluding small enterprises in some cases.
Objectives: Empower users with data rights, facilitate switching between services, and prevent unfair practices. Scope covers product and service data, excluding inferred data unless agreed.
Key provisions: Users access generated data free and in machine-readable formats (Article 4), share with third parties (Article 5), under fair terms (Article 8). Switching obligations eliminate barriers (Articles 23-31), with charges phased out by 2027. Public sector access in emergencies (Article 14).
For AI, it provides raw IoT data for training models, supporting decision-making in sectors like agriculture. Fair practices (Article 13) enhance competition, excluding gatekeepers from certain benefits.
In EUSALP, it enables AI for natural hazards (e.g., sensor data from infrastructure) and tourism (e.g., smart devices for visitor tracking). Alpine implications: Improved water management via IoT data, fostering innovation in isolated communities.

4.6 The AI Act

Objectives: Ensure safe, ethical AI respecting rights, while promoting innovation via sandboxes (Article 57). Risk-based classification: Prohibited (e.g., social scoring, Article 5), high-risk (e.g., biometrics, Article 6), limited-risk (transparency, Article 50), minimal-risk. High-risk requirements: Risk management (Article 9), data quality (Article 10), transparency (Article 13), human oversight (Article 14). For data governance, it mandates bias-free datasets, aligning with GDPR. Ethical AI is promoted through codes of conduct. In EUSALP, it enables AI for public administrations (e.g., hazard prediction) and communities (e.g., tourism personalization), with sandboxes testing Alpine-specific applications. Implications: Balanced innovation in sensitive sectors like climate monitoring.

The AI Act's risk-based approach has direct and critical implications for EUSALP’s key sectors, ensuring safety and trust while fostering cross-border digital innovation in the Alps.

AI applications in tourism and sport, such as systems for personalizing tourist offerings or optimizing lift operations, generally fall under minimal-risk. However, if AI is used in safety-critical applications for high-risk sports or mountain rescue operations (e.g., classifying risk levels on ski slopes), it may be deemed high-risk. This would trigger mandates for human oversight (Article 14) and ensure data quality (Article 10) for reliable input like real-time snowpack data, crucial for regional cooperation on safe Alpine leisure. Regulatory sandboxes are key here for testing new, localized multilingual tourism models.

AI is essential for optimizing irrigation networks or predicting water stress in mountain valleys. Systems controlling critical public infrastructure, such as water flow regulation in large dams or major regional purification plants, are likely classified as high-risk. These systems must comply with rigorous risk management (Article 9) to prevent catastrophic failure and ensure bias-free data is used, guaranteeing equitable water distribution across communities and Member States.

AI models for real-time prediction of hazards like avalanches, landslides, or glacial lake outbursts directly impact public life and property, classifying them as high-risk. This mandates strict transparency (Article 13): authorities must understand how the model reaches a “high alert” decision, allowing human experts to validate and override outputs. The use of sandboxes (Article 57) is vital to safely test new predictive algorithms against historical Alpine data before deployment in volatile cross-border areas.

AI facilitates the analysis of vast datasets from satellite imagery, enabling precise monitoring of glacier melt rates and micro-climate shifts. While generally lower risk, the AI Act's requirements for bias-free datasets and data quality are crucial to ensure that climate models accurately capture localized Alpine vulnerabilities without systemic distortion. By promoting ethical AI, the Act guarantees that monitoring systems provide a reliable, politically neutral basis for EUSALP policy and adaptation strategies across the Alpine region.

Figure 5 - The Risk scale defined in the AI-Act

4.7 The Interoperable Europe Act and European Interoperability Framework: Enabling Seamless Data Flows

The IEA, adopted in March 2024, mandates interoperability assessments for digital public services (Article 3), solution sharing via a portal (Article 4), and governance through the Interoperable Europe Board (Article 15). It includes AI as solutions, promoting open code.
The EIF provides principles (e.g., openness, reusability), layers (legal, organizational, semantic, technical), and 47 recommendations for interoperability.
In AI and data sharing, they facilitate cross-border exchanges, supporting AI integration in services. For EUSALP, they align with CCP1, enhancing AI in trans-Alpine initiatives like hazard management.

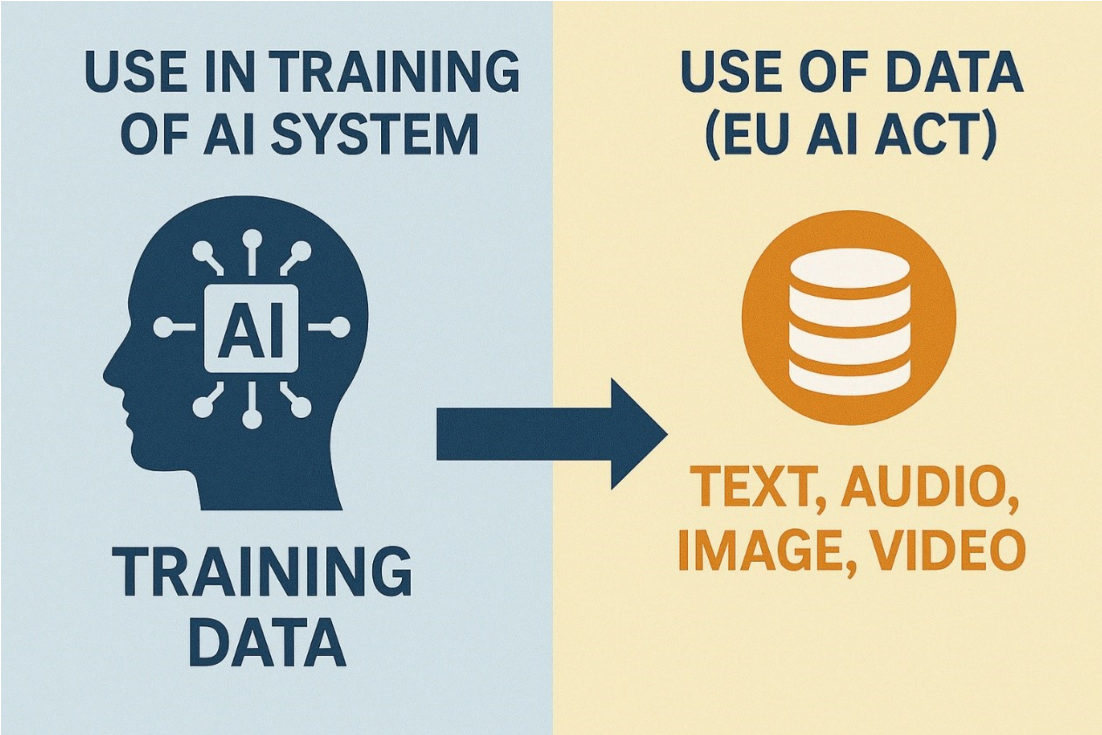

Figure 6 - Necessity of cross-references with the data management and services acts.

4.8 Other Initiatives: Common Data Spaces and Digital Decade

Alongside major regulations, the EU promotes common European data spaces in areas like health, energy, and agriculture. These are designed to provide shared, high-quality datasets for AI training and innovation.

The Digital Decade targets 75% enterprise AI adoption by 2030. Within EUSALP, initiatives such as the Digital Alps Conference 2025 and projects like SmartCommUnity focus on advancing AI in rural and mountainous regions, ensuring no community is left behind in the digital transition.

4.9 Developing AI Projects for the Alpine Area

AI initiatives in the Alpine region must adhere to the broader EU regulatory framework while addressing the region's unique geographical, environmental, and economic challenges.

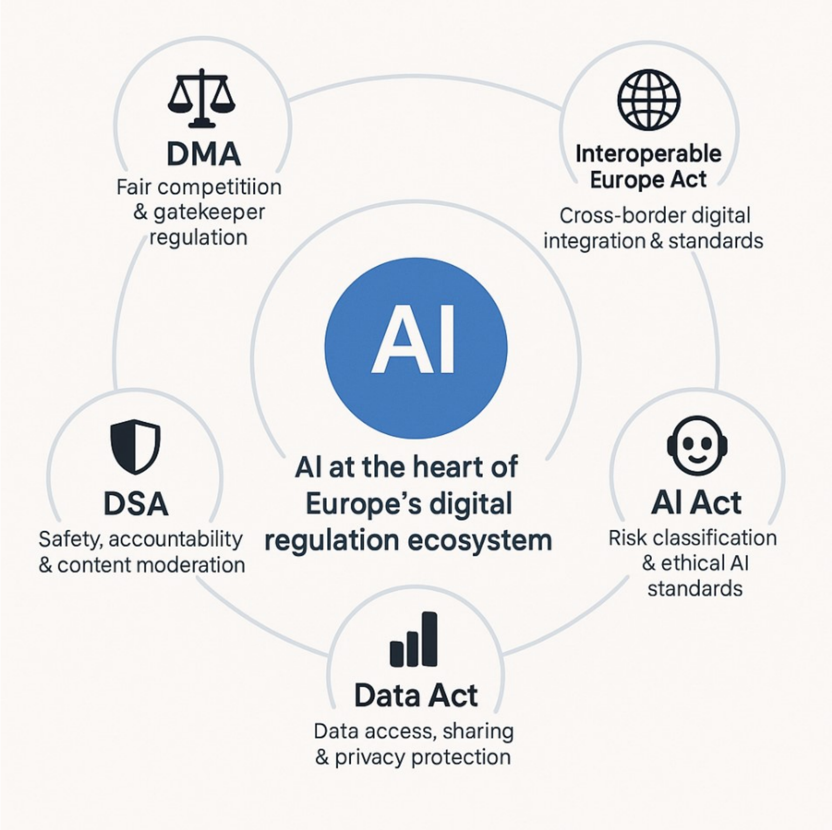

Figure 7 - The AI interactions within the EU regulatory Acts

The development of AI solutions must take into consideration the following key considerations:

a) GDPR Compliance and Data Governance
   - Ensuring AI projects handle personal and location-based data in line with GDPR principles, including data minimization, purpose limitation, and explicit user consent.
   - Establishing secure data-sharing agreements between Alpine states to maintain compliance while fostering innovation.
   - Implementing privacy-preserving AI techniques, such as federated learning, to enable cross-border AI model training without exposing sensitive data.

b) Interoperability and Cross-Border Collaboration
   - Aligning AI initiatives with the Interoperable Europe Act to facilitate seamless data exchange and cooperation across different national and regional administrations.
   - Developing common technical standards for AI applications in areas such as environmental monitoring, smart tourism, and sustainable mobility to enhance cross-border efficiency.
   - Integrating AI-driven systems with existing digital infrastructure, including smart grids, IoT networks, and public-sector data platforms, to ensure seamless interoperability.

c) Sustainable and Ethical AI Development
   - Encouraging AI solutions that support environmental sustainability, such as climate change prediction models, renewable energy optimization, and disaster risk management.
   - Ensuring AI-driven decision-making in tourism, transport, and agriculture aligns with local socio-economic priorities and cultural heritage preservation.

- Promoting AI literacy and capacity-building among local stakeholders to facilitate informed adoption and governance of AI technologies.

The European regulatory framework for AI development is designed to balance innovation with accountability, fostering an ecosystem where AI-driven solutions can flourish while ensuring compliance with ethical and legal standards. By aligning AI initiatives with the DMA, DSA, Data Act, AI Act, and Interoperable Europe Act, businesses and policymakers can create sustainable, competitive, and responsible AI solutions that enhance economic growth and societal well-being in the EU.
For AI projects specific to the Alpine region, additional considerations such as GDPR compliance, interoperability, and sustainability must be incorporated to support a resilient and efficient digital landscape. These legislative measures collectively establish a structured pathway for AI innovation, ensuring a secure, fair, and dynamic digital environment across Europe and within its unique regional contexts.

4.10 Implications for EUSALP and Alpine AI Initiatives: Bottlenecks, Challenges, Possibilities, and Impacts in Rural Areas

The EU framework outlined in the preceding sections—encompassing the Big Five regulations (DMA, DSA, DGA, Data Act, and AI Act), the Interoperable Europe Act (IEA), and the European Interoperability Framework (EIF)—provides a robust foundation for advancing AI initiatives within the EU Strategy for the Alpine Region (EUSALP). This framework not only regulates data flows, ensures ethical AI deployment, and promotes interoperability but also directly supports EUSALP's cross-cutting priority CCP1: "Promoting the Digitalisation of the Alps," coordinated by Action Group 5 (AG5) in collaboration with AG1, AG2, AG3, and AG9. As of August 2025, recent developments, such as the Digital Alps Conference (DAC) 2025 held in Lienz, Austria, underscore the momentum, with themes centered on AI innovation, dataspaces, and sustainable connectivity for mountain communities. The conference highlighted workshops on smart communities and SMEs, emphasizing AI's role in addressing Alpine-specific challenges like remoteness and environmental vulnerability.
However, adopting AI in rural Alpine areas—characterized by sparse populations, rugged terrain, limited infrastructure, and economic reliance on sectors like agriculture and tourism—presents unique bottlenecks and challenges. These include data scarcity due to low digital maturity, high costs of broadband deployment in mountainous regions, skills gaps in local workforces, and regulatory compliance burdens for small entities. Possibilities arise from the framework's emphasis on data sharing (via DGA and Data Act) and AI sandboxes (under the AI Act), enabling tailored solutions that leverage IoT, machine learning, and predictive analytics. Impacts could be transformative, boosting economic resilience, enhancing environmental sustainability, and improving quality of life, potentially adding billions to regional GDP through optimized resource use and innovation. Yet, uneven adoption risks widening urban-rural divides, with remote communities lagging if infrastructure bottlenecks persist. EUSALP's work plans for 2023-2025 align closely, promoting research on climate adaptation, water reservoirs, and digitalization, while stimulating sustainable tourism and local goods production. Initiatives like the SmartCommUnity project support rural AI adoption, fostering ecosystems for data-driven decision-making. Below, we delve into the three focal topics: tourism and sport, water

management, and natural hazards risk management and climate change monitoring. For each, we analyze bottlenecks and challenges, possibilities enabled by the EU framework, and potential impacts, drawing on recent projects and studies as of 2025.

4.10.1 Tourism and Sport: Navigating Digital Transformation in Seasonal Economies

Bottlenecks and Challenges:

Rural Alpine tourism and sport sectors, which contribute over €50 billion annually to the regional economy, face significant hurdles in AI adoption. Key bottlenecks include inadequate digital infrastructure, with broadband coverage below 50% in some remote valleys, hindering real-time data collection from IoT sensors in ski resorts or hiking trails. Data scarcity is acute; small operators often lack the volume or quality of data needed for AI training, exacerbated by privacy concerns under GDPR and the DSA's transparency requirements for online platforms. Challenges also encompass workforce upskilling—many local businesses employ seasonal workers with limited tech literacy—and high initial costs for AI tools, which can strain SMEs comprising 90% of the sector. Climate variability adds complexity, as warming reduces snow cover, forcing diversification into year-round activities without sufficient predictive tools. Regulatory compliance, such as AI Act classifications for high-risk systems in personalized recommendations, may overwhelm small entities, potentially delaying adoption.

Possibilities:

The EU framework unlocks opportunities by facilitating data access and interoperability. The Data Act's provisions for IoT-generated data sharing enable tourism apps to integrate sensor data from wearables or drones for personalized experiences, like AI-optimized hiking routes. DGA-supported data altruism could pool visitor data for communal AI models, while the DMA ensures fair access from gatekeeper platforms, allowing Alpine SMEs to compete in digital marketing. The AI Act's sandboxes, combined with IEA's interoperability standards, support pilot projects like those discussed at DAC 2025, where AI and dataspaces were explored for smart tourism. EUSALP's AG2 collaboration on data spaces for SMEs could extend to tourism, enabling AI-driven demand forecasting. Recent initiatives, such as the Interreg Alpine Space Programme's calls for digital projects, promote AI for sustainable year-round tourism, including virtual reality simulations for off-season promotion.

Impacts:

Successful AI integration could boost visitor numbers by 20-30% through personalized, sustainable offerings, such as AI chatbots for eco-friendly sport recommendations, enhancing economic resilience in rural areas. Positive impacts include reduced environmental footprints via optimized transport routes, aligning with EUSALP's green goals, and job creation in tech-maintenance roles. However, if challenges persist, impacts might be negative, with AI exacerbating inequalities—larger resorts adopting faster, marginalizing small operators—and over-reliance on algorithms risking data biases in diverse Alpine cultures. Overall, for EUSALP, this could feed into CCP1 by showcasing AI success stories, inspiring cross-regional networking and potentially increasing GDP contributions from tourism by €10-15 billion by 2030.

4.10.2 Water Management: Addressing Scarcity in Fragile Ecosystems

Bottlenecks and Challenges:

Alpine water management is critical, supplying 40% of Europe's freshwater, yet rural areas grapple with AI adoption amid climate-induced droughts and floods. Bottlenecks include fragmented data ecosystems; sensors in remote watersheds are sparse, leading to incomplete datasets for AI models, compounded by infrastructure limitations like poor connectivity for real-time monitoring. Challenges involve regulatory hurdles—the Data Governance Act requires secure environments for sharing sensitive hydrological data, but small public authorities lack resources for compliance. Workforce skills gaps persist, with local engineers untrained in AI, and ethical issues arise under the AI Act for high-risk systems predicting water allocation. Economic constraints in rural communities, where water utilities are often underfunded, amplify costs for AI deployment, while transboundary rivers complicate data sovereignty across EUSALP countries.

Possibilities:

The framework offers pathways through enhanced data sharing and innovation. The Data Act mandates access to IoT data from smart meters, enabling AI predictive models for leak detection and demand forecasting, as seen in the SUMMER Project, which integrates smart tech for water management. DGA's intermediaries could facilitate Alpine-wide data pools for AI training, while EIF guidelines ensure interoperability across borders. Recent projects like WATERWISE (2024-2027) co-design sustainable solutions, incorporating AI for vulnerability assessments. Deltares' 2025 report highlights AI's role in groundwater modeling and flood prediction, aligning with EUSALP's open data promotion in work plans. AG5's focus on AI in DAC 2025 workshops explored dataspaces for resilient water systems. Possibilities extend to collaborative initiatives, like using AI Act-compliant tools for optimizing irrigation in agriculture-dependent rural areas.

Impacts:

AI could reduce water losses by 15-25% through predictive maintenance, enhancing sustainability and supporting biodiversity in Alpine ecosystems. Positive impacts include cost savings for rural municipalities—potentially €500 million annually region-wide—and improved resilience to climate extremes, fostering food security. However, mismanaged AI might lead to over-allocation biases, disadvantaging downstream communities, or privacy breaches in data sharing. For EUSALP, impacts reinforce AG5's strategy, contributing to CCP1 by providing case studies that promote cross-sectoral partnerships, ultimately aiding the transition to a data-driven, sustainable water economy in rural Alps.

4.10.3 Natural Hazards Risk Management and Climate Change Monitoring: Building Resilience Against Mounting Threats

Bottlenecks and Challenges:

Alpine regions face escalating hazards like avalanches, landslides, and floods due to climate change, with rural areas particularly vulnerable owing to isolation. Bottlenecks include data gaps from sparse monitoring networks in high-altitude zones, where extreme weather disrupts sensors, limiting AI's predictive accuracy. Challenges encompass high computational demands for multi-hazard models, straining rural infrastructure, and skills shortages in local administrations for interpreting AI outputs. The AI Act's risk-based approach classifies hazard prediction as high-risk, requiring rigorous testing that small entities may find burdensome. Transboundary hazards add complexity, with varying data standards across EUSALP states hindering interoperability.

Possibilities:

The EU framework enables advanced monitoring via integrated data flows. The Data Act supports IoT sensor data sharing for real-time AI analytics, as in the PARATUS project for disaster preparedness.

DGA's altruism mechanisms could aggregate climate data for machine learning models, while IEA ensures cross-border compatibility. Recent advancements include GMD GmbH's AI for hazard prevention (2025) and studies integrating AI with climate scenarios for multi-risk assessment in Alps. The CERC research center develops AI-based solutions for mountain challenges, and the OGC Climate and Disaster Resilience Pilot 2024 addresses ARD gaps for landslides. EUSALP's work plans emphasize R&I on climate adaptation, with DAC 2025 discussing AI for resilient communities. Explainable AI (XAI) tools enhance trust in hazard models.

Impacts:

AI could cut disaster damages by 20-40% through early warnings, saving lives and €1-2 billion yearly in rural infrastructure. Impacts include empowered communities via mobile alerts, reduced health risks from climate events, and informed spatial planning under CLISP-ALP. Negative potentials involve algorithmic biases amplifying vulnerabilities in underrepresented areas or over-dependence eroding traditional knowledge. For EUSALP, this bolsters CCP1, feeding AG5's catalogue with success stories that drive collaborative risk reduction, enhancing overall Alpine resilience.

In summary, while bottlenecks like infrastructure and skills persist, the EU framework's tools offer scalable possibilities, promising profound impacts on rural Alpine sustainability. EUSALP must prioritize targeted funding and training to maximize these, ensuring equitable AI adoption across its territories.

5 Use Cases and Possible Benefits for the Alpine Area

The Alpine region stands as a unique geographic and socio-economic entity where the convergence of artificial intelligence technologies with traditional mountain activities creates distinct opportunities that differ fundamentally from standard AI applications in urban or lowland contexts. While AI implementation in sectors such as public administration, transportation, and education typically follows well-established patterns that can be replicated across various geographical settings, the Alpine environment demands specialized applications that respond to the region's specific challenges, opportunities, and constraints.

5.1 The Alpine Specificity: Beyond Generic AI Applications

The mountainous terrain, extreme weather variability, seasonal tourism patterns, and fragile ecosystems of the Alpine region create a context where generic AI solutions prove insufficient. Unlike standard AI deployments in public administration that focus primarily on process automation and citizen services, or transportation systems that optimize urban mobility, Alpine AI applications must account for the unique interplay between human activities and mountain environments. The region's characteristics—including elevation-dependent climate variations, avalanche risks, seasonal accessibility challenges, and the critical role of water resources—necessitate AI solutions that are deeply embedded in understanding mountain-specific dynamics[1] [2] [3] [4] [5] [6].

The AI Applications in Alpine Tourism and Sport theme represents a departure from conventional tourism technology implementations. While urban tourism relies on standardized recommendation systems and booking platforms, Alpine tourism AI must integrate real-time environmental data, safety considerations, and the unique characteristics of mountain sports. The technology addresses the specific challenge of personalizing experiences within an environment where weather conditions, snow quality, and natural hazards can change rapidly, requiring AI systems that can process multimodal data streams including meteorological forecasts, terrain conditions, and individual skill assessments[7] [8] [9].

Mountain tourism presents unique data challenges that distinguish it from other sectors. The integration of IoT sensors across varied altitudes, the need for real-time safety monitoring, and the seasonal nature of many Alpine activities create datasets and analytical requirements that differ substantially from

[1] https://www.mountain-planet.com/en/artificial-intelligence-enhancing-the-mountain-customer-experience/
[2] https://eo4society.esa.int/projects/dta/
[3] https://www.gmd.care/en/natural-hazards
[4] https://digitalalps.eu
[5] https://www.gmd.care/en/press-en-eintrag/innovative-early-warning-systems-for-alpine-natural-hazards-gmd-gmbh-in-the-media-spotlight
[6] https://www.alpine-region.eu/fileadmin/user_upload/ACTION_GROUPS/AG5/EUSALP_Work_plans_23-25_AG5.pdf
[7] https://www.simagazin.com/en/si-alpin/topics/digitalisation-innovation/the-digital-mountain/
[8] https://www.salzburgresearch.at/en/projekt/mountain/
[9] https://machinelearning.uniud.it/projects/eyof2023/

conventional tourism applications. AI systems must balance performance optimization with safety considerations, incorporating avalanche forecasting, weather pattern recognition, and crowd management in ways that are specifically calibrated to mountain environments[10 11].

5.2 Water as the Alpine Lifeline: AI for Sustainable Resource Management

The AI for Sustainable Water Management in the Alps theme addresses challenges that are fundamentally different from water management in other geographical contexts. Alpine water systems serve multiple critical functions: they provide drinking water to downstream populations, support hydroelectric power generation, maintain ecosystem balance, and sustain tourism activities. The complex interdependencies between snowpack dynamics, glacial melt, precipitation patterns, and human demand create a management challenge that requires AI applications specifically designed for mountain hydrology[12 13 14 15 16].

Unlike urban water management systems that focus primarily on distribution efficiency and quality control, Alpine water management AI must integrate predictive modeling for seasonal variations, climate change impacts on glacial resources, and the optimization of hydroelectric generation while maintaining ecological flows. The technology must account for the unique temporal dynamics of mountain water systems, where winter snow accumulation determines summer water availability, and where climate change is altering traditional patterns in ways that require continuous model adaptation[17 18 19].

The hydropower sector in the Alps exemplifies the specificity of mountain applications, where AI systems must optimize energy production while considering environmental constraints, seasonal variations in water availability, and the increasing frequency of extreme weather events. These challenges are markedly different from AI applications in other energy sectors, requiring specialized algorithms that can handle the non-linear relationships between meteorological conditions, water flow, and energy demand[20 21 22 23].

5.3 Natural Hazards and Climate Monitoring: AI for Mountain Safety

The AI in Natural Hazard Risk Management and Climate Change Monitoring in the Alps theme addresses risks and monitoring challenges that are unique to mountain environments. While AI applications in emergency management in other contexts often focus on urban disasters or coastal flooding, Alpine

[10] https://seniorsskiing.com/ai-is-already-bringing-changes-to-ski-resorts/
[11] https://ceur-ws.org/Vol-4031/10_short.pdf
[12] https://ecs-nodes.eu/en/4-digital-and-sustainable-mountain/spoke-4-flagship-projects/summer-project
[13] https://flore.unifi.it/bitstream/2158/1429254/1/UNESCO%202025.pdf
[14] https://www.waterpowermagazine.com/analysis/ai-driven-water-forecasting-enhancing-hydropower-resilience/
[15] https://www.alpconv.org/fileadmin/user_upload/Publications/RSA/RSA2_long_EN.pdf
[16] https://www.sciencedirect.com/science/article/pii/S0022169421011756
[17] https://www.cimafoundation.org/en/news/snow-artificial-intelligence-and-future-visions-a-researchers-journey-from-the-alps-to-oslo/
[18] https://www.sciencedirect.com/science/article/pii/S2214581824004051
[19] https://energy.sustainability-directory.com/area/alpine-water-scarcity/
[20] https://www.sciencedirect.com/science/article/pii/S0952197625014368
[21] https://energy.sustainability-directory.com/question/what-are-the-challenges-of-integrating-ai-with-hydropower-plants/
[22] https://www.sciencedirect.com/science/article/pii/S004896972302555X
[23] https://unesdoc.unesco.org/ark:/48223/pf0000393243

hazard management must contend with avalanches, rockfalls, debris flows, and glacier-related hazards that are specific to high-elevation environments[24] [25] [26] [27].

The complexity of Alpine natural hazard systems requires AI approaches that can integrate multiple data sources—from seismic monitoring to meteorological forecasting—to predict events that often occur with little warning and can have cascading effects across mountain communities. Unlike standard emergency response systems, Alpine hazard AI must account for the isolated nature of many mountain communities, the challenges of evacuation in difficult terrain, and the seasonal variations in risk exposure[28] [29] [30] [31].

Climate change monitoring in the Alps presents unique challenges that distinguish it from climate monitoring in other regions. The rapid changes occurring in high-elevation environments, including permafrost degradation, glacial retreat, and shifting precipitation patterns, require AI systems capable of processing high-resolution spatial and temporal data to detect changes that may not be apparent in broader climate datasets. The technology must be sensitive to elevation-dependent variations and capable of providing early warning systems for climate-related hazards that are specific to mountain environments[32] [33] [34] [35].

5.4 Integration and Interdisciplinary Approach

These three themes are interconnected in ways that reflect the integrated nature of Alpine systems. Tourism activities depend on water resources and are constrained by natural hazard risks; water management must account for tourism demand and climate change impacts; and natural hazard management affects both tourism safety and water resource infrastructure. This interconnectedness requires AI approaches that can operate across traditional sectoral boundaries, providing integrated solutions that recognize the systemic nature of Alpine challenges[36].

The development of AI applications for the Alpine region also reflects broader trends in digital transformation of mountain communities, where technology serves not only to optimize individual sectors but to support the overall sustainability and resilience of mountain territories. Unlike AI implementations in other contexts that may focus on single-sector optimization, Alpine AI applications

[24] https://www.gmd.care/en/natural-hazards
[25] https://www.mci.edu/en/news-filter-en/228-researchnews/5785-can-ai-predict-natural-hazards-better
[26] https://www.cmcc.it/projects/arca-artificial-intelligence-platform-to-prevent-climate-change-natural-hazards
[27] https://associazionegeotecnica.it/wp-content/uploads/2020/01/rig_2_2017_063_calvello.pdf
[28] https://www.gmd.care/en/press-en-eintrag/innovative-early-warning-systems-for-alpine-natural-hazards-gmd-gmbh-in-the-media-spotlight
[29] https://www.sciencedirect.com/science/article/pii/S0012825219304635
[30] https://www.swissinfo.ch/eng/climate-solutions/how-to-protect-people-and-places-from-landslides-in-switzerland/85470970
[31] https://boa.unimib.it/retrieve/handle/10281/19795/25152/phd_unimib_716844.pdf
[32] https://www.telt.eu/en/alpine-climate-data-challenge-2025/
[33] https://www.wsl.ch/en/publications/stop-danger-climate-change-and-natural-hazards/
[34] https://esurf.copernicus.org/articles/13/705/2025/
[35] https://earthobservations.org/our-work/solutions/ecosystems-biodiversity-and-carbon-management
[36] https://www.alpine-region.eu/fileadmin/user_upload/ACTION_GROUPS/AG5/EUSALP_Work_plans_23-25_AG5.pdf

increasingly emphasize cross-sectoral integration and community-centered approaches that align with the Smart Villages[37] and Smart Communities[38] initiatives emerging across the region[39].
The three themes explored in this report thus represent not merely the application of existing AI technologies to Alpine contexts, but the development of specialized approaches that respond to the unique characteristics, challenges, and opportunities of mountain environments. They demonstrate how artificial intelligence can be adapted and refined to serve the specific needs of Alpine communities while contributing to the broader goals of sustainable mountain development and climate resilience[40].

[37] https://www.alpine-space.eu/project/smartvillages/
[38] https://www.alpine-space.eu/project/smartcommunity/
[39] https://capacitycooperation.danube-region.eu/cross-macro-regional-cooperation-at-digital-alps-conference-2025/
[40] https://smartera-project.eu/wp-content/uploads/2025/01/SMART-ERA-Comparative-study-of-MRS20250129.pdf

6 AI Applications in Alpine Tourism and Sport

6.1 BeyondSnow[41]

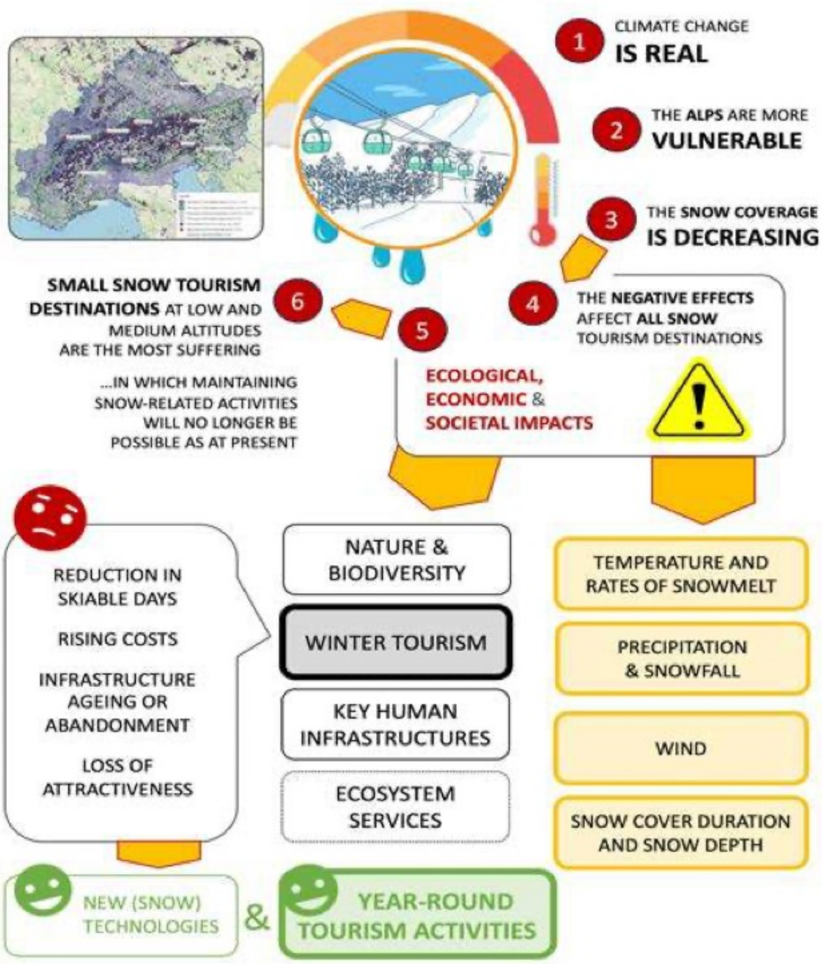

Figure 8 - BeyondSnow Executive Summary[42]

6.2 The BeyondSnow project aims to enhance the resilience of Alpine snow tourism destinations to climate change by developing sustainable development paths and implementable solutions (this project is therefore relevant to section 7.15:

AI for water management in the Alpine region is moving from a patchwork of research prototypes and demonstrators toward more integrated, multi-stakeholder deployments, but many initiatives remain at pilot or demonstrator scale rather than full operational rollout. Demonstrators such as the Digital Twin Alps provide operational EO-driven products (snow/SWE, soil moisture, river discharge, drought

[41] https://www.alpine-space.eu/project/beyondsnow/
[42] https://www.alpine-space.eu/wp-content/uploads/2024/03/Beyondsnow-Report-on-the-effects-of-CC-on-the-AS-Snow-Tourism-Destinations-deliverable-1.1.1-april-2023-DEF.pdf

indicators) that already inform stakeholders; sector projects (FARMWISE, DARROW, EO4Alps–Snow and others) explicitly embed AI or machine-learning components for tasks from precision irrigation to wastewater optimization; and EU frameworks (ICT4Water cluster, Water4All, and EUSALP Action Group 6) create coordination, Living Lab methodologies and standards roadmaps that aim to accelerate uptake. At the same time, several cross-cutting bottlenecks are visible in public analyses: data availability and interoperability, skills and governance gaps, limited long-term financing for operational scaling, and uneven transposition of standards—all factors that keep many AI initiatives in pilot mode.

Governance

The governance of AI in water hinges on multi-level coordination (EU → macro-region → national → local utilities) and clear institutional responsibilities for data, liability, and decision-making. EU-level initiatives (ICT4Water cluster, Water4All) create strategic roadmaps, funding pipelines and Living Lab networks to bridge R&I and operational practice; EUSALP Action Group 6 offers the Alpine territorial layer that can translate EU outputs into cross-border pilot replication and policy alignment. However, governance analyses point to persistent institutional barriers: many government AI deployments remain pilots due to risk aversion, unclear procurement and accountability, lack of shared data governance, and limited measurement of ROI for public actors. The OECD's review of "governing with AI" highlights such system-wide barriers—skills gaps, difficulty accessing and sharing high-quality data, limited actionable guidance, and risk aversion—that are highly relevant to water agencies and Alpine municipalities. Likewise, academic governance studies of AI in the European water sector document that collaborative governance strategies (who does what, and through which legal and network forms) are still evolving, and regional leaders must negotiate trade-offs between centralized data services and local sovereignty over water decisions.

Practical governance implications for the Alps: mechanisms are needed to designate custodians for shared digital assets (e.g., DTA products), to define liability when AI-based recommendations feed operational actions (reservoir releases, irrigation curtailment), and to create procurement paths for public utilities to buy/subscribe to AI services. The ICT4Water cluster and the EU rolling plan on water digitalization offer standards and interoperability roadmaps that can reduce governance friction, but adoption requires institutional capacity-building (legal, procurement, IT) at the municipal and basin levels. EUSALP AG6 can act as the regional convenor to harmonize cross-border data sharing agreements and to embed Digital Twin / Living Lab outcomes into transnational water strategies.

Sustainability (environmental + economic + technical)

Sustainability of AI initiatives in Alpine water management must be assessed across three linked axes:

1) environmental impact (do AI systems lead to better water-ecosystem outcomes?)
2) economic viability (can solutions be sustained financially beyond project grants?)
3) and technical longevity (are systems maintainable and interoperable?).

Evidence from current EU projects shows clear environmental promise: Digital Twin Alps and EO4Alps-Snow deliver snow/SWE and drought anomaly indicators that materially improve the spatio-temporal understanding of water storage and risk, enabling more targeted reservoir and catchment management that can reduce ecological stress. FARMWISE's precision-agriculture focus and DARROW's wastewater AI demonstrate pathways to reduce water use, nutrient runoff, and energy emissions—outcomes aligned with Alpine sustainability goals.

Economic sustainability, however, is more fragile. Many projects are funded as time-limited R&I grants (Horizon Europe, ESA, Interreg). The transition to operational services requires business models (subscription, service contracts with utilities, public procurement) and recurrent funding for data hosting, model retraining, and helpdesk/support. The Water4All Atlas and Water-Oriented Living Labs (WOLLs) promote market uptake pathways and co-funding models by linking pilots to utilities and industry partners, but scaling still requires proof of sustained cost-benefit and often regulatory incentives (e.g., water agencies adopting KPIs linked to AI outputs).

Technical sustainability depends on standards and data ecosystems. The ICT4Water roadmap and recent assessments on water data ecosystems stress the need for interoperability, open APIs, and common metadata to ensure longevity; without these, AI models risk becoming siloed and brittle as data sources change. Research into requirements for water data ecosystems underlines the importance of reproducible pipelines, documentation, and community governance so that models can be maintained and updated as climates and infrastructures change. In sum, environmental benefits are demonstrable in pilots; economic and technical sustainability remain conditional on governance reforms, standardization, and viable business models.

Adoption challenges (operational, social, technical)

Adoption in Alpine contexts faces multiple, interdependent challenges:

- Operational: Alpine water systems are managed by many small utilities and municipalities with limited IT budgets and staff. Implementing AI services requires integration into existing SCADA, decision workflows, and legal compliance processes. Demonstrators (Digital Twin Alps, EO4Alps-Snow) show value, but integration into operational SOPs (standard operating procedures) is slow when staff resources for deployment and maintenance are lacking. Utilities need packaged, low-friction services and training, not raw models.
- Social & institutional trust: AI outputs may be probabilistic and require interpretation; operators and citizens may distrust “black-box” recommendations. This heightens the need for explainable AI, transparent validation, and participatory Living Labs where users co-design thresholds and alerting rules. Water4All’s WOLL guidance and DARROW’s emphasis on explainability respond directly to this challenge by embedding user validation and explainable models in pilot design.
- Data & technical: High-quality labelled data (long time series, local sensor networks) are essential to train and validate AI—yet many Alpine catchments lack dense in-situ networks and face cloud cover / radar shadow issues in EO. Fusion approaches (EO + reanalysis + local sensor networks) reduce these gaps, but they increase complexity and processing needs. Standards from ICT4Water and EU rolling plans can ease interoperability, but the operational burden of data pipelines, model retraining, latency reduction for near-real-time alerts, and cybersecurity remain critical technical hurdles.
- Regulatory & ethical: The EU is accelerating an AI policy and risk-management agenda (see EU reports on AI ambition and OECD analyses). Water AI deployments must comply with data protection, algorithmic accountability, and sectoral regulation; these evolving rules create uncertainty for vendors and utilities and can slow procurement. Clear regulatory guidance (classification of critical water AI as high-risk systems, validation requirements) will be essential to scale adoption responsibly.

6.3 Concluding synthesis (what this means for the Alps)

AI initiatives show concrete value for Alpine water management—better snow/SWE mapping, drought monitoring, precision irrigation, and wastewater optimization are already demonstrable. Yet to move from pilots to systemic uptake across the Alps requires aligning governance (data custodianship, liability, procurement), securing sustainable funding models and standards for technical interoperability, and tackling social and operational adoption barriers through Living Labs and capacity building. The existing EU ecosystem—ICT4Water, Water4All, EUSALP AG6, Water-Oriented Living Labs and demonstrators like Digital Twin Alps—provides the institutional scaffolding; the near-term priority is to convert demonstrator success into repeatable service models and cross-border governance agreements that sustain AI-enabled water resilience for Alpine communities.

AI in Natural Hazard Risk Management and Climate Change Monitoring in the Alps). A key outcome of this project is the Resilience Adaptation Model (RAM), designed to assess and strengthen the resilience of Alpine snow tourism destinations in the face of climate change. The RAM model provides a framework for evaluating a destination's vulnerabilities, management capabilities, and tourism reliance through various indicators, including climatic and environmental factors. This assessment supports Destination Management Organizations (DMOs) in identifying critical vulnerabilities and prioritizing investments in technologies and practices that lower these risks. The project is also developing a Resilience Decision-Making Digital Tool (RDMDT) to automate the process of data collection and analysis, helping destinations make informed decisions. While the available information does not explicitly mention the use of AI within the BeyondSnow project, the innovative and data-driven nature of the RAM model and the RDMDT suggest a potential role for AI in analyzing the complex interplay of factors affecting snow tourism resilience. The automation of data collection and analysis for strategic decision-making aligns with the capabilities of AI, particularly machine learning, to identify patterns and support informed choices in the face of climate change.

6.4 TranStat[43]

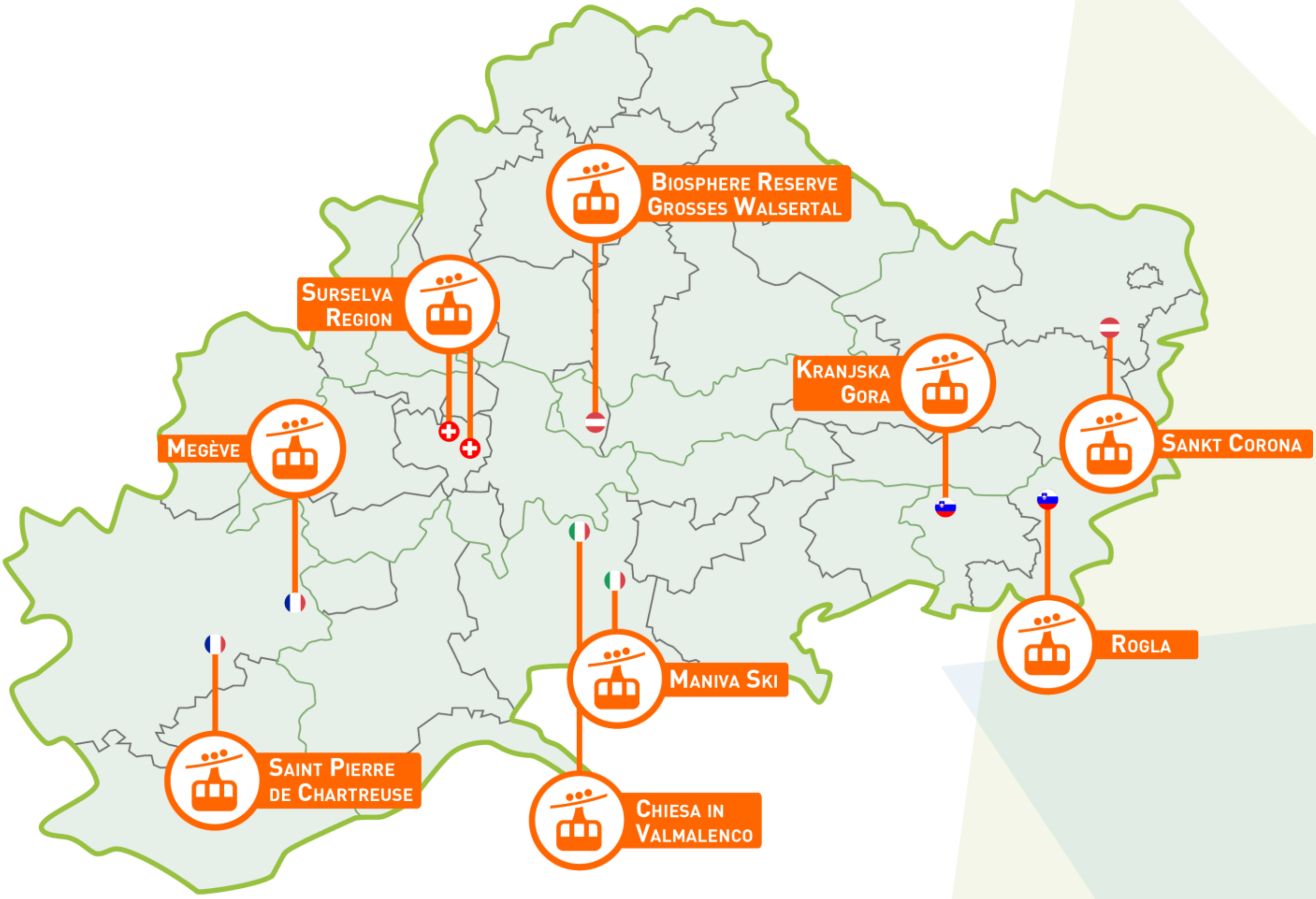

Figure 9 - TranStat living labs in the Alpine Area[44]

[43] https://www.alpine-space.eu/project/transtat/
[44] https://www.alpine-space.eu/project-news/the-living-labs-in-transtat-experimental-roles-and-objectives/

6.5 The TranStat project focuses on transitions to sustainable ski tourism in the Alps of tomorrow, aiming to promote climate change adaptation and disaster risk prevention **Errore. L'origine riferimento non è stata trovata.**. As the BeyondSnow project, this is also relevant to section 7.15:

AI for water management in the Alpine region is moving from a patchwork of research prototypes and demonstrators toward more integrated, multi-stakeholder deployments, but many initiatives remain at pilot or demonstrator scale rather than full operational rollout. Demonstrators such as the Digital Twin Alps provide operational EO-driven products (snow/SWE, soil moisture, river discharge, drought indicators) that already inform stakeholders; sector projects (FARMWISE, DARROW, EO4Alps–Snow and others) explicitly embed AI or machine-learning components for tasks from precision irrigation to wastewater optimization; and EU frameworks (ICT4Water cluster, Water4All, and EUSALP Action Group 6) create coordination, Living Lab methodologies and standards roadmaps that aim to accelerate uptake. At the same time, several cross-cutting bottlenecks are visible in public analyses: data availability and interoperability, skills and governance gaps, limited long-term financing for operational scaling, and uneven transposition of standards—all factors that keep many AI initiatives in pilot mode.

Governance

The governance of AI in water hinges on multi-level coordination (EU → macro-region → national → local utilities) and clear institutional responsibilities for data, liability, and decision-making. EU-level initiatives (ICT4Water cluster, Water4All) create strategic roadmaps, funding pipelines and Living Lab networks to bridge R&I and operational practice; EUSALP Action Group 6 offers the Alpine territorial layer that can translate EU outputs into cross-border pilot replication and policy alignment. However, governance analyses point to persistent institutional barriers: many government AI deployments remain pilots due to risk aversion, unclear procurement and accountability, lack of shared data governance, and limited measurement of ROI for public actors. The OECD's review of "governing with AI" highlights such system-wide barriers—skills gaps, difficulty accessing and sharing high-quality data, limited actionable guidance, and risk aversion—that are highly relevant to water agencies and Alpine municipalities. Likewise, academic governance studies of AI in the European water sector document that collaborative governance strategies (who does what, and through which legal and network forms) are still evolving, and regional leaders must negotiate trade-offs between centralized data services and local sovereignty over water decisions.

Practical governance implications for the Alps: mechanisms are needed to designate custodians for shared digital assets (e.g., DTA products), to define liability when AI-based recommendations feed operational actions (reservoir releases, irrigation curtailment), and to create procurement paths for public utilities to buy/subscribe to AI services. The ICT4Water cluster and the EU rolling plan on water digitalization offer standards and interoperability roadmaps that can reduce governance friction, but adoption requires institutional capacity-building (legal, procurement, IT) at the municipal and basin levels. EUSALP AG6 can act as the regional convenor to harmonize cross-border data sharing agreements and to embed Digital Twin / Living Lab outcomes into transnational water strategies.

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4) environmental impact (do AI systems lead to better water-ecosystem outcomes?)

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Evidence from current EU projects shows clear environmental promise: Digital Twin Alps and EO4Alps-Snow deliver snow/SWE and drought anomaly indicators that materially improve the spatio-temporal understanding of water storage and risk, enabling more targeted reservoir and catchment management that can reduce ecological stress. FARMWISE's precision-agriculture focus and DARROW's wastewater AI demonstrate pathways to reduce water use, nutrient runoff, and energy emissions—outcomes aligned with Alpine sustainability goals.

Economic sustainability, however, is more fragile. Many projects are funded as time-limited R&I grants (Horizon Europe, ESA, Interreg). The transition to operational services requires business models (subscription, service contracts with utilities, public procurement) and recurrent funding for data hosting, model retraining, and helpdesk/support. The Water4All Atlas and Water-Oriented Living Labs (WOLLs) promote market uptake pathways and co-funding models by linking pilots to utilities and industry partners, but scaling still requires proof of sustained cost-benefit and often regulatory incentives (e.g., water agencies adopting KPIs linked to AI outputs).

Technical sustainability depends on standards and data ecosystems. The ICT4Water roadmap and recent assessments on water data ecosystems stress the need for interoperability, open APIs, and common metadata to ensure longevity; without these, AI models risk becoming siloed and brittle as data sources change. Research into requirements for water data ecosystems underlines the importance of reproducible pipelines, documentation, and community governance so that models can be maintained and updated as climates and infrastructures change. In sum, environmental benefits are demonstrable in pilots; economic and technical sustainability remain conditional on governance reforms, standardization, and viable business models.

Adoption challenges (operational, social, technical)

Adoption in Alpine contexts faces multiple, interdependent challenges:

- Operational: Alpine water systems are managed by many small utilities and municipalities with limited IT budgets and staff. Implementing AI services requires integration into existing SCADA, decision workflows, and legal compliance processes. Demonstrators (Digital Twin Alps, EO4Alps-Snow) show value, but integration into operational SOPs (standard operating procedures) is slow when staff resources for deployment and maintenance are lacking. Utilities need packaged, low-friction services and training, not raw models.
- Social & institutional trust: AI outputs may be probabilistic and require interpretation; operators and citizens may distrust "black-box" recommendations. This heightens the need for explainable AI, transparent validation, and participatory Living Labs where users co-design thresholds and alerting rules. Water4All's WOLL guidance and DARROW's emphasis on explainability respond directly to this challenge by embedding user validation and explainable models in pilot design.
- Data & technical: High-quality labelled data (long time series, local sensor networks) are essential to train and validate AI—yet many Alpine catchments lack dense in-situ networks and face cloud cover / radar shadow issues in EO. Fusion approaches (EO + reanalysis + local sensor networks) reduce these gaps, but they increase complexity and processing needs. Standards from ICT4Water and EU rolling plans can ease interoperability, but the operational burden of data pipelines, model

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- Regulatory & ethical: The EU is accelerating an AI policy and risk-management agenda (see EU reports on AI ambition and OECD analyses). Water AI deployments must comply with data protection, algorithmic accountability, and sectoral regulation; these evolving rules create uncertainty for vendors and utilities and can slow procurement. Clear regulatory guidance (classification of critical water AI as high-risk systems, validation requirements) will be essential to scale adoption responsibly.

6.6 Concluding synthesis (what this means for the Alps)

AI initiatives show concrete value for Alpine water management—better snow/SWE mapping, drought monitoring, precision irrigation, and wastewater optimization are already demonstrable. Yet to move from pilots to systemic uptake across the Alps requires aligning governance (data custodianship, liability, procurement), securing sustainable funding models and standards for technical interoperability, and tackling social and operational adoption barriers through Living Labs and capacity building. The existing EU ecosystem—ICT4Water, Water4All, EUSALP AG6, Water-Oriented Living Labs and demonstrators like Digital Twin Alps—provides the institutional scaffolding; the near-term priority is to convert demonstrator success into repeatable service models and cross-border governance agreements that sustain AI-enabled water resilience for Alpine communities.

AI in Natural Hazard Risk Management and Climate Change Monitoring in the Alps. The project intends to provide mountain resorts and decision-makers with tools and a scalable methodology to support the implementation of transition paths and test solutions for winter tourism territories to adapt to climate change. The available information for the project does not explicitly mention of the use of Artificial Intelligence within it. However, the broader context of sustainable tourism and transportation suggests potential applications for AI. For instance, AI could be used to optimize transportation networks serving ski resorts, predict tourist demand to minimize environmental impact, or personalize travel experiences to encourage longer stays and reduce the reliance on snow-dependent activities.

6.7 HEALPS-2[45]

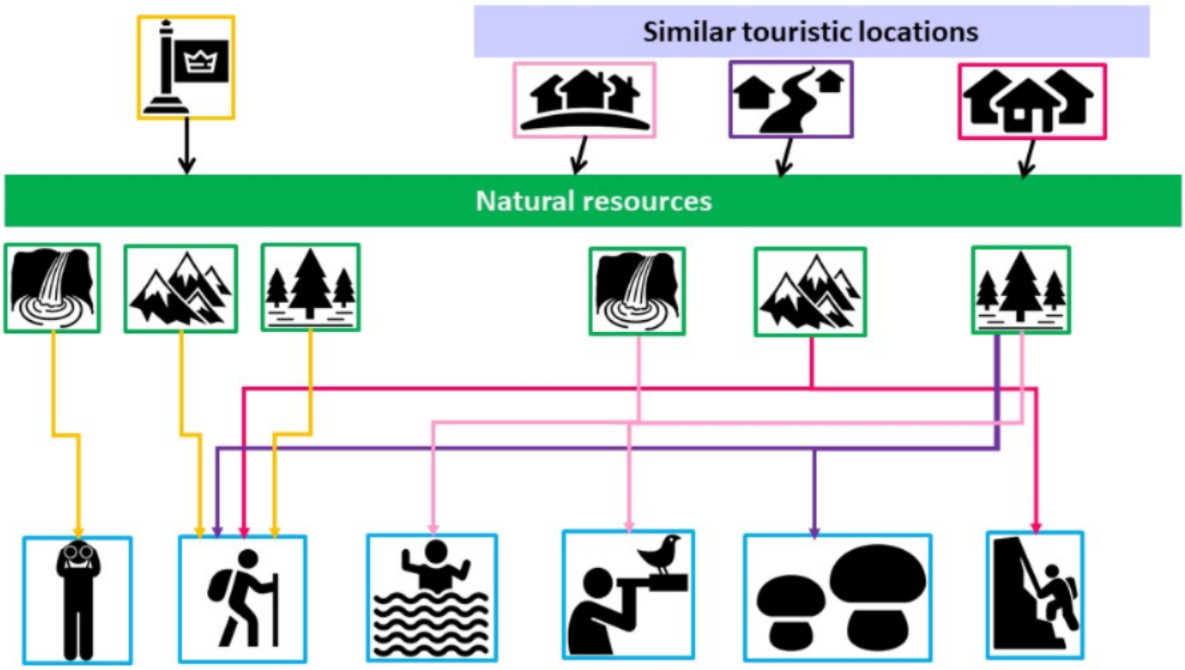

Figure 10 - HEALPS-2 Semantic Assesment Tool[46]

The HEALPS-2 "Healing Alps: Tourism based on natural health resources as strategic innovation for the development of Alpine regions" is an Interreg Alpine Space project (programme period 2014–2020; project runtime Oct 2019–Jun 2022) that aims to enable evidence-based, nature- and health-oriented tourism across Alpine destinations by delivering digital decision support, an innovation model and training materials to regional stakeholders. The project consortium is multisectoral (led by Paracelsus Medical University Salzburg) and produced a Tactical Health Management Toolset (a "Scenario Tool"), an Alpine Health Tourism Innovation Model, a training toolkit and an action plan targeted at policy and destination managers.

HEALPS2 built a data pipeline and knowledge representation layer that underpins automated analysis and tailored recommendations. Key technical building blocks described in the Tactical Health Management Toolset are: (1) an Alpine Health Tourism database to collect destination KPIs; (2) an

[45] https://www.alpine-space.eu/project/healps-2/
[46] https://www.stiima.cnr.it/progetti-ricerca/healps2/

ontology — “a computable and logic-based graph representation of Alpine Space natural assets”; (3) “user cases on semantic reasoning mechanisms”; and (4) automated generation of recommendation texts and PDF reports based on a questionnaire completed by destination stakeholders. The Scenario Tool matches destination KPI inputs against defined optima stored in the ontology and produces individualized development paths (target groups, matching natural resources, services and suggested actions). These outputs are explicitly described as driven by logical/mathematical model implementation and semantic analyses.[47]

HEALPS2 implements symbolic knowledge engineering at scale — an ontology + rule/semantic-reasoning layer that operationalizes domain evidence (medical literature, natural resources, KPIs) into actionable recommendations. This is a mature, explainable approach: the use of ontologies and semantic reasoning supports transparency and traceability of recommendations (important for evidence-based health tourism). The project leverages AI-adjacent techniques (knowledge graphs, semantic rules and automated report generation), rather than black-box statistical models.

Natural extensions where contemporary AI (statistical/ML) could augment HEALPS2: 1) enrich the ontology with embeddings and semantic similarity models to improve matching between user descriptions and evidence (e.g., transformer embeddings for unstructured descriptions of local offerings); 2) integrate predictive models (time-series of demand, climate impacts on natural assets) to forecast suitability windows for health offers; 3) use recommendation-system techniques (hybrid content- and collaborative-filtering) to personalize product bundles to segments; 4) apply NLP to ingest and continuously update the evidence base (medical studies, clinical guidelines) into the ontology; 5) create conversational front-ends (chatbots) to guide less-expert destination managers through the KPI questionnaire and interpret results. These augmentations would preserve the project’s explainability ethos while adding scalability and improved adaptation to new data.

[47] https://www.alpine-space.eu/wp-content/uploads/2022/09/20220420_healps2_o.t2.2_tactical_health_management_toolset.pdf

6.8 EYOF2023[48]

Figure 11 - Showcase of EYOF2023 results from the MLP lab@UNIUD.

The collaboration between the Machine Learning and Perception Laboratory of the University of Udine and the 16th European Youth Olympic Winter Festival (EYOF 2023) represents one of the most significant recent attempts to apply advanced artificial intelligence to winter sports and, more broadly, to alpine tourism environments. The project was conceived in connection with the EYOF event held in Friuli Venezia Giulia in January 2023, a large international youth competition that served as an ideal testbed for developing and validating AI systems directly on snow. The initiative aimed to bridge the gap between the widespread use of AI in mainstream sports—such as football, basketball, and athletics—and its limited adoption in alpine disciplines, where environmental conditions, camera mobility, and the nature of the terrain make data acquisition and analysis far more challenging.
The project's core research centered on computer vision, focusing on developing algorithms for automatic athlete detection, tracking, and trajectory reconstruction from ordinary video footage. Instead of relying on wearable sensors or GPS devices, the system processes monocular or multi-camera video streams to recover an athlete's path on the slope or during a jump. This involves compensating for camera motion, which is particularly important in dynamic settings where cameras are mounted on drones or moving platforms. The method operates online, processing each frame in real time and reconstructing the skier's trajectory as the video unfolds. Once the trajectories are extracted, they can be visualized, compared between athletes, or superimposed on reference tracks. The analysis enables coaches and broadcasters to measure distances to gates, identify sections of the run where time was lost, and visualize the speed and precision of turns through color-coded temporal cues.

[48] https://machinelearning.uniud.it/projects/eyof2023/

A key technical achievement was the creation of the “Alpine Skiing Track 2.0” at the Tarvisio ski resort, where a dedicated slope was equipped with network cabling, multiple synchronized cameras, and edge-computing devices. This smart-slope infrastructure forms a “living laboratory” for data-driven sport science, supporting simultaneous video capture from several viewpoints and enabling advanced AI algorithms to operate in situ. The data gathered from these real conditions were used not only for analysis and visualization but also for developing benchmark datasets to evaluate AI performance in outdoor alpine scenarios—an aspect still largely unexplored in computer vision research.
From the perspective of alpine tourism and sport innovation, the EYOF 2023 project demonstrates how digital transformation can extend beyond competitive sport and become a tool for the modernization of mountain environments. The same AI infrastructure that enables athlete performance analytics can be adapted to enhance the tourist experience, offering real-time visualization of ski runs, interactive comparisons with professional athletes, or even augmented-reality overlays for recreational skiers. It also opens possibilities for operational analytics, such as monitoring slope usage, optimizing safety, and predicting snow conditions.
Although the project documentation does not explicitly mention the specific EU funding programme supporting it, it clearly aligns with EU priorities on digital innovation, smart regions, and sport technology. Its emphasis on sustainable, non-intrusive data acquisition and real-time AI processing illustrates a transferable model that could be replicated across European alpine resorts. Beyond its immediate scientific achievements, the EYOF 2023 initiative stands as a compelling demonstration of how AI—especially computer vision and trajectory analysis—can serve both athletic excellence and tourism competitiveness, transforming alpine resorts into intelligent, data-aware ecosystems that enhance performance, safety, and visitor engagement.

6.9 Inter Bike III[49]

The Inter-Bike III project aims to create a sustainable cross-border cycling tourism destination between Italy and Slovenia by improving infrastructure and promotion. While the project does not explicitly mention Artificial Intelligence, its framework is ideal for integrating AI to create a "smart tourism" ecosystem. The upgraded `www.bike-alpe-adria.eu` platform could be transformed with an AI-powered recommendation engine, offering cyclists personalized routes based on their fitness level, interests, and real-time data like weather and trail congestion. The new e-bike charging and rental stations could become part of an IoT network, where AI predicts demand, optimizes asset placement, and manages maintenance, ensuring service reliability. Furthermore, AI can directly support the project's sustainability goal by analyzing cyclist flow data to prevent overcrowding on sensitive trails, suggesting alternative routes to distribute the environmental impact. By leveraging AI, Inter-Bike III can evolve from an infrastructure initiative into a dynamic, data-driven destination that provides a highly personalized, efficient, and sustainable experience for tourists, while offering valuable business intelligence to local tourism operators.

6.10 SmartVillages[50]

[49] https://www.ita-slo.eu/it/inter-bike-iii
[50] https://www.alpine-space.eu/project/smartvillages/

Figure 12 - SmartVillage and SmartCommUnity relations to the EUSALP strategy

SmartVillages was an Interreg Alpine Space project running from 2018 to 2021 with a budget of about 2.7 million euros and partners from Austria, France, Germany, Italy, Slovenia and Switzerland. The initiative addressed the structural disadvantages of Alpine and rural villages such as depopulation, lack of local employment, limited mobility and digital exclusion. Its goal was to enable these communities to benefit from digital transformation by improving access to services, fostering local innovation and strengthening participation of citizens in shaping their future. The project introduced the concept of "smartness" for mountain areas, structured around six dimensions—Smart Governance, Smart Mobility, Smart Economy, Smart Environment, Smart Living and Smart People—and worked through regional stakeholder groups that designed and tested new digital services in eleven pilot areas. The main digital product was the Digital Exchange Platform, an online environment where municipalities could assess their degree of smartness, learn from other regions and access the SmartVillages Toolbox, a collection of methods, policy models and digital solutions ready for adaptation. The pilots developed through the project included coworking spaces for remote workers, car-sharing schemes, digital village platforms for local commerce, public WiFi networks and mobile applications for local engagement. Through these actions, SmartVillages helped communities to build digital literacy, increase cooperation and raise the attractiveness of rural areas for residents, entrepreneurs and visitors. Although the project's deliverables do not describe explicit use of artificial intelligence or machine learning, many of its components are AI-relevant. The Digital Exchange Platform collects structured data on local contexts and outcomes, providing a base for data-driven analytics. The smartness assessment framework defines measurable indicators that could train algorithms to identify which types of interventions are most effective for specific demographic, geographic or economic profiles. Texts and surveys gathered from stakeholders could feed natural language processing models that extract needs, sentiment or policy trends across regions. Predictive analytics could forecast which digital services would yield the strongest social or economic impact, and recommender systems could guide communities towards the most suitable smart actions or funding opportunities. AI-enhanced dashboards could monitor the performance of pilots in real time, while conversational assistants could support local administrators in navigating the Toolbox or interpreting assessment results. In essence, SmartVillages established the digital and governance foundations for a data-driven Alpine development model. Its achievements in connectivity, participation and digital capacity building created the preconditions for integrating artificial intelligence in later projects, where algorithmic decision support and intelligent recommendation systems could transform the way Alpine communities plan, manage and sustain tourism, mobility and local services in the future.

6.11 SmartCommUnity[51]

The SmartCommUnity project aims to support Alpine rural areas through digitalization, creating smart, sustainable and resilient communities across the Alpine Space region. Beyond the relevance to big data applications, the project demonstrates sophisticated AI integration through multiple technological dimensions. It shares connections with the Green Point Living Lab in Slovenia's Pomurje and Podravje regions that implements innovative models including blockchain and big data technologies, suggesting advanced AI algorithms for supply chain optimization and food system analysis. The project's tourism applications are particularly noteworthy, with pilot areas addressing demographic challenges through smart mobility solutions and digital nomad initiatives. Valle d'Aosta's pilot explores "Workcation" concepts for digital nomads, developing new hospitality models in natural protected areas and leveraging digital technologies for authentic local product. The project employs LoRaWAN technology for IoT-based smart monitoring in both urban and rural contexts, including smart waste management, water level detection, and building safety.

The Digital Exchange Platform (DEP) and the Digital Toolbox platform centralizes datasets, assessment instruments and matchmaking logic (DEP features) and adds semantic/value features such as user profiling, points/karma gamification and automated matchmaking between communities and solutions. The project’s technical consortium (including Software Competence Center Hagenberg) and the design of a reusable Innovation Platform position SmartCommUnity as a data-rich, integrative infrastructure that can host algorithmic services. Deliverables already describe structured data collection flows and gamification mechanics used to increase engagement.

AI could add value via:

- Personalization & recommendation: hybrid recommender systems to suggest best-fit smart actions or peer communities to local stakeholders based on platform activity and contextual attributes.
- NLP and knowledge extraction: ingest policy documents, local proposals and user comments to auto-classify needs and map them to Toolbox interventions.
- Predictive analytics: forecast demand for services (housing, mobility) or detect early signs of service gaps in pilot territories.
- Citizen engagement automation: chatbots to guide less-tech users through assessments, and conversational agents that summarize discussion threads and proposals.
- Sensor analytics & anomaly detection: for pilots using LoRaWAN or mobility sensors, lightweight ML models could surface operational issues or usage patterns to inform local policy.
- Digital twin/simulation: lightweight simulation models to test pilot outcomes (mobility centre impacts, housing matchmaking scenarios) before roll-out.

[51] https://www.alpine-space.eu/project/smartcommunity/

6.12 DEGREE4ALPS[52]

Degree4Alps ("DigitalisEd and GREEn mobility for ALPine Space communities") is an ongoing (2021-2027) Interreg Alpine Space project funded under the priority "Innovation and digitalisation supporting a green Alpine region" with the specific objective to "Reaping the benefits of digitisation for citizens, companies, research organisations and public authorities." It gathers partners including University of Passau (lead), German Alpine Club Oberland, Redmint Social Enterprise, DOLOMITIBUS (IT), municipalities in Slovenia, Swiss and Austrian organizations, and others. Degree4Alps addresses the problem of low public transport viability in scattered, rural areas, especially for aging populations or vulnerable groups, and the lack of flexible/shared mobility in peri-urban or alpine valleys. Its purpose is to improve accessibility by integrating fixed public transport with demand-responsive transport (DRT), shared mobility, carpooling, and informal mobility, using co-designed digital tools and social innovation. In the six pilot regions the project is developing and testing various pilots: for example in Belluno (Italy) a digital trip planner for vulnerable citizens, demand responsive transport in remote areas, and energy flow analysis for e-bus operations; in Bavarian Oberland, live/digital booking & information systems for sustainable mobility and last-mile connections; in Maribor, digitalization of DRT for vulnerable groups; in Canton of Ticino promoting carpooling, on-demand shuttles, cross-border intermodal services; in Šmartno pri Litiji focusing on automated order systems, inclusive mobility services; and in Ausseerland working on interregional connectivity, adaptative services, intermodal hubs. Alongside pilot implementation the project is building instruments: action plans for upscaling, guidelines on digitalization and social innovation trends in mobility, and two e-courses for public administrations, planners and mobility operators. Across the pilots Degree4Alps is combining digital functionalities such as trip-planning, booking, routing, payment; monitoring and assessment of energy consumption (especially for e-vehicles and charging infrastructure), tools for assessing digital readiness and user needs; and investigating integration of renewable/distributed energy sources in mobility systems. While explicit machine learning or statistical AI methods are not prominently featured in public deliverables to date, the project clearly operates in a data-rich, digitally enabled mobility domain. The digital trip planner, routing, booking, payment systems and monitoring energy flows generate structured datasets; assessments of digital readiness and user needs yield qualitative and quantitative data; energy flow monitoring, usage logs and vehicle sharing operations offer temporal, spatial, and user behaviour data. Potential AI add-ons include predictive models for demand responsive routes or DRT scheduling; optimization of routes, charging operations and shared vehicle allocation; recommender systems to guide users toward mobility options based on preferences, constraints, vulnerability; anomaly detection in energy systems; simulation models to forecast the impacts of scaling shared mobility / carpooling or e-mobility in remote valleys; and conversational interfaces to assist vulnerable users in booking/trip planning. Degree4Alps is thus a strong example of combining digital tools, mobility innovation, inclusive design and social innovation to address accessibility in alpine.

[52] https://www.alpine-space.eu/project/degree4alps/

6.13 DEPLOYTOUR [53]

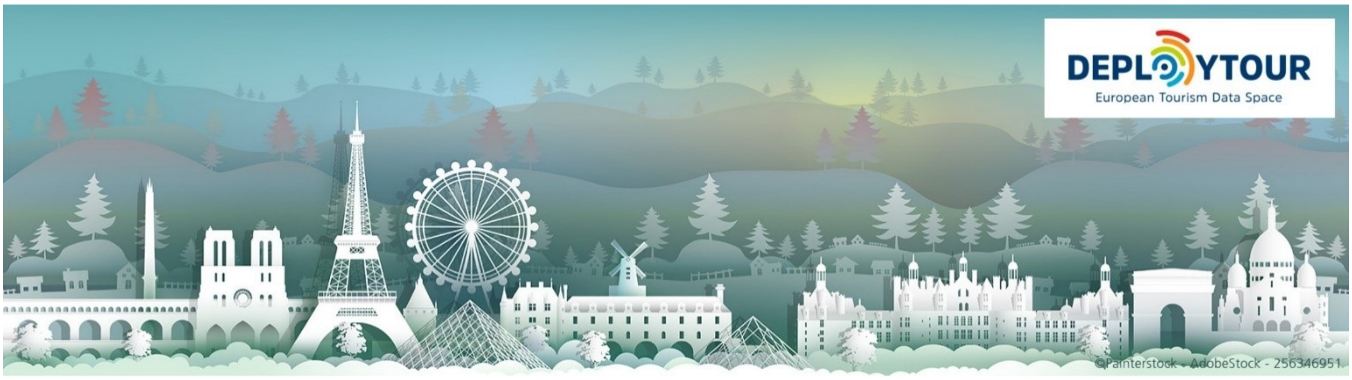

Figure 13 – Deploytour strategic European Digital Programme[54]

DEPLOYTOUR ("Deployment of the European Tourism Data Space") is a three-year Digital Europe Programme project (October 2024-September 2027), coordinated by AnySolution and comprising 43 partners across 13 countries. Its mission is to build a trusted, secure, interoperable European Tourism Data Space (ETDS) that addresses fragmentation and inaccessibility of tourism-related data, supports the green and digital transition for SMEs and DMOs, empowers innovation, and strengthens competitiveness and resilience in the tourism sector.[55] [56]

DEPLOYTOUR builds on earlier preparatory actions (DATES, DSFT) and aligns with the SIMPL data infrastructure framework. Its core components are construction of the technical infrastructure, definition of governance and roles ("minimum viable rulebook"), implementation of five real-life pilot use cases across diverse tourism contexts, ensuring interoperability with other data-space initiatives, and policy or regulation outputs to support data sharing.[57]

One of the five pilots is "Sustainable Tourism Management in Alpine Regions," covering Alpine regions of Austria and Slovenia[58]. This pilot explicitly leverages AI and data analytics to monitor and guide tourist activity, reduce environmental impact, promote responsible behavior, and improve visitor awareness. It includes dashboards for destination capacity, end-user applications for enriched data sharing across borders, and tools to balance environmental protection with development. [59]

Other pilots cover mature destinations (e.g. Canary Islands, Andalusia, Balearic Islands), the MICE sector in Paris, cultural heritage diversification (Syros Island, Greece), and empowering SMEs in more peripheral/northern areas (Lapland) via TravelTech and data marketplace tools. These are intended to demonstrate ETDS value across contexts (coastal, urban, heritage, peripheral) and to showcase data-driven, AI-enhanced services (for predictive insights, sustainability, personalized offerings) in practice.

From an AI-perspective, DEPLOYTOUR already integrates AI-relevant components in its design: the pilot on sustainable tourism in Alpine regions explicitly refers to advanced AI tools[60]; the dashboards and monitoring tools rely on data analytics; the project seeks to enable predictive insights and enriched data

[53] https://deploytour.eu
[54] https://www.isst.fraunhofer.de/en/departments/mobility-und-smart-cities/projects/DEPLOYTOUR.html
[55] https://deploytour.eu/the-project/
[56] https://data.europa.eu/it/news-events/news/deploytour-new-project-future-european-tourism-data
[57] https://www.fiware.org/project/deploytour.html
[58] https://eona-x.eu/deploytour/
[59] https://www.arctur.si/en/rd-projects/deploytour/harnessing-ai-and-data-analytics-to-transform-european-tourism/
[60] https://deploytour.eu/use-case-pilot/sustainable-tourism-management-in-alpine-regions

sharing; governance of data, rules for access, privacy, interoperability are key technical and socio-legal enablers; SMEs' access to data and analytics tools is intended be facilitated.

While detailed deliverables are still forthcoming (given the project's recent start), the public documentation does not yet show wide-scale deployment of advanced machine learning models (beyond "AI tools and analytics" references). The project seems to be more upstream: building infrastructure, governance, data pipelines, enabling environment, pilot proof-of-concepts rather than deploying fully mature, large-scale predictive or generative AI systems.

DEPLOYTOUR is well positioned within the Alpine tourism & sport domain thanks to its Alpine pilot use case. In that context, the project's AI relevance is substantial: it could enable seasonal or event demand forecasting, visitor flow management to prevent overcrowding, ecological impact modelling under climate variation, recommendations for visitor behavior or routes, real-time monitoring of environmental indicators (air quality, trail usage etc.), and decision support for destination managers.

In summary, DEPLOYTOUR represents a strategic, infrastructure-level EU project where AI is built into its ambitions, especially in forestry of pilots like sustainable tourism in Alpine regions.

6.14 Crowd-in-Motion[61]

Figure 14 - Crowd-in-motion European Digital Innovation Hubs Network

Crowd in Motion (EDIH "Crowd in Motion") is a European Digital Innovation Hub (EDIH) based in Austria (provinces including Salzburg, Carinthia, Tyrol), active since 1 January 2023 through to December 2025, with a consortium of seven core partners (Salzburg Research, ISN – Innovation Service Network, Werksstätte Wattens, Pioniergarage Salzburg, Makerspace Carinthia, ADV – Austrian Digital Value, Gemini Startup Base) and an extended network of national and international cooperation partners[62]. Its mission is to support small and medium-sized enterprises (SMEs) and public organisations in the sectors of tourism, sport, leisure and public services to accelerate digital and green transformation by offering free or low-threshold services under the Digital Europe programme. [63]

From the AI perspective, CiMo explicitly includes motion data analytics, Internet of Things (IoT), digital fabrication, crowd technology, artificial intelligence & decision support among its competence areas. Its description in the EDIH catalogue states that "Crowd in Motion is an EDIH aiming to accelerate the use of crowd technology and AI for motion data analytics through Internet of Things, FabLabs and access to finance for the green and digital transformation of the alpine tourism and sports industry." [64]

[61] https://www.crowd-in-motion.eu
[62] https://innovation.at/crowd-in-motion-edih/
[63] https://www.salzburgresearch.at/en/projekt/edih-crowd-in-motion/
[64] https://european-digital-innovation-hubs.ec.europa.eu/edih-catalogue/crowd-motion

One concrete application/demonstrator is the “Digital MountAIn Lab”[65] - a prototype test environment offering mobile digital test infrastructure and test tracks for “AI-based innovations in alpine outdoor sports with analysis of human movements in mountain scenarios in real environments.” This lab will allow sports equipment manufacturers, service providers etc. to test, in real mountain contexts, innovations relying on human motion analysis for performance or health or experience enhancement.
Another example is the “Digital Climbing Hold” project[66]: with support from CiMo, ArtRock (a climbing wall company) developed climbing holds that can detect climbers, provide feedback or instructions, and adapt routes / difficulty/instruction according to user ability; the holds are networked (IoT), interactive, used for experience enhancement and personalization.
CiMo also emphasizes combining AI with “human swarm intelligence” (crowd intelligence) in its support model. That is, it does not treat AI as purely algorithmic, but rather as interacting with ideas, participatory/crowdsourced feedback, ideation, and the inclusion of user needs via collective processes.
Despite these concrete demonstrators and lab/test-infrastructure offerings, CiMo is more of an enabler/hub than a project delivering large-scale deployed AI systems. Public sources do not present extensive evidence yet of mass AI deployment (e.g. large predictive models, widespread algorithmic decision systems in tourism operations) but rather prototyping, experimentation, small scale devices, motion tracking in specific test contexts, and facilitating SMEs to adopt/integrate such technologies. The “Test before Invest” strand is especially geared to reduce risk and allow SMEs or public organisations to trial new AI-or IoT-enabled systems[67].
Given this, CiMo has significant potential for impact in alpine tourism & sport if its enabling work is leveraged. The kinds of data motion analytics (human movement, sensor / IoT data, user behaviour in outdoor settings) that are central to its labs/test tracks lend themselves to AI methods: computer vision or inertial sensor-based motion tracking, pattern recognition, predictive modelling of user fatigue or risk, feedback for performance (for sport), adaptive experience enhancement (for tourists). The Digital MountAIn Lab is a strong base for gathering rich motion data in challenging terrains, which could support research in e.g. biomechanical or physiological modelling, anomaly detection (unsafe motion trajectories), trail usage forecasting, or personalised training tools. Interactive devices like the climbing holds suggest possibilities for reinforcement learning or adaptive difficulty, perhaps even combining sensor feedback, user profiling, and real-time adaptivity.
Since CiMo also supports training, skill building, innovation brokerage and prototyping infrastructure, it plays a crucial role in capacity building: helping SMEs, public entities, and research organisations to experiment, fail fast, learn, and adopt AI/IoT-based innovations in alpine sport and tourism. CiMo iss one of the most relevant enablers of emergent AI usage: not yet full-scale production systems in many cases, but pushing forward testbeds, demonstrators, and innovation services, especially around motion analytics, interactive IoT devices, and crowd/collective intelligence.

[65] https://www.salzburgresearch.at/en/projekt/mountain/
[66] https://www.crowd-in-motion.eu/en/praxisbeispiele/digital-climbing-hold
[67] https://www.crowd-in-motion.eu/our-services/

6.15 MountAIn[68]

Figure 15 - MountAIn project

MountAIn (Salzburg Research — “The digital mountain”) is an AI-centred project: the project describes a test environment and “digital mountain” for testing AI-based innovations for alpine outdoor activities, with the stated objective to develop and demonstrate a sustainable concept for a test environment for AI-based human motion analytics systems in real mountain scenarios. The project aims at concrete otuputs: creating mobile digital test infrastructure, test tracks, and physical infrastructures to validate effectiveness, validity and reliability of AI human-motion analytics under real-world alpine conditions (weather, slopes, different grounds). It explicitly targets stakeholders such as sports equipment manufacturers, tech providers, mountain lift operators, tourism regions and research institutes; the platform is aimed at testing AI systems that analyse human movement (for performance or health use cases). AI here is central and concrete — the project is a living testbed for AI human-motion analytics in mountain tourism and sport contexts.

[68] https://www.salzburgresearch.at/en/projekt/mountain/

6.16 The VisionAlps Initiative[69]

Figure 16 - Vision Alps Initiative topics/focus.

VisionAlps is a business-to-business initiative launched in 2022 in Italy with the aim of accelerating the digital and sustainable transformation of the Alpine ecosystem, oriented toward both public and private operators. It describes itself as the first B2B initiative in Italy dedicated to the “Digital Transformation of Alps”, oriented toward enabling operators in tourism, hospitality, local public administrations, startup ecosystems, mobility, energy, health sectors, etc., to engage with emerging technologies (5G, IoT, AI, Blockchain, AR/VR) to shape innovative business models and services.

VisionAlps organizes forums, meetings, and digital community platforms, which include “VisionAlps FORUMS” and “VisionAlps MEETINGS”, plus thematic events in various Alpine towns (Aosta, Merano, Sondrio, Belluno, etc.). These events bring together decision makers (public administrators, companies, managers), startup founders, service providers, and ICT actors to exchange best practices, showcase solutions, deepen knowledge of technologies, and build networking and matching opportunities.

In its initiative, AI is among the core emerging technologies alongside 5G, IoT, Blockchain, AR/VR that are explored as tools for developing and improving services and business models in B2B and B2C settings, especially for tourism, hospitality, mobility & transport, energy, and public administration.

Within the events, thematic tables have dealt with “AI & Smart Land, how AI transforms mobility” (in Alpine mountainous (“Smart Land”) territories) and how AI can optimize transport flows, flow of people, infrastructures, more efficient mobility, emergency services, etc. For example, in a VisionAlps 2024

[69] https://www.visionalps.com/en/

event in Trento there was a round table on AI and mobility and discussions about AI-in mobility, especially for transportation, dispatch, resource management, etc. [70]

VisionAlps also addresses issues beyond tourism: depopulation, ageing, remoteness, lack of digital infrastructure, and the possibility of attracting digital nomads and smart workers to Alpine valleys. It aims to support small administrations, startup enterprises, local companies (including producers, artisans, and those in energy, health, etc.) in adopting digital tools.

Despite the strong emphasis on emerging technologies and AI in discussions, show-case examples, and forward-looking agendas, there is no public evidence that VisionAlps currently develops or manages large-scale AI systems, pilots or deployed AI models. The initiative appears to function more as a platform and community for matchmaking, awareness raising, exhibition of technology, sharing of best practices and case studies, and facilitating cooperation.

From an AI perspective, VisionAlps plays a valuable role in building the ecosystem: it identifies potential use cases, surfaces needs of local operators who may lack experience, incubates ideas via startups and ICT providers, and amplifies visibility of tech solutions. It helps generate demand and awareness, connect supply and demand, and build capacity in local public administrations and private firms. These are crucial preconditions for the adoption of AI in Alpine tourism and sport.

As for potential directions for VisionAlps to deepen its AI relevance: it could move from expo/discussion toward sponsoring actual pilot projects (e.g. AI-driven mobility optimization, visitor flow estimation, predictive climate risk or avalanche risk, personalized experience for visitors, smart trail monitoring) in Alpine territories; it could incorporate infrastructure for data sharing, open data among municipalities; it could develop hackathons / challenge grants to generate AI prototypes; it could host or facilitate access to testbeds in situ; it could link to EU funded programmes to secure funding for AI deployment; it could help establish explicit standards, data governance, transparency frameworks for AI usage in the Alpine context.

In summary, VisionAlps is an ecosystem accelerator/connector rather than a project that itself builds AI-based interventions, but it is important in shaping demand, influencing public administrators, stimulating innovation, and setting the scene for AI usage in tourism, mobility, energy etc.

6.17 Use Cases and Potential Benefits

Across the Alpine region, AI is proving not just promising in theory but deeply useful in practice. What emerges clearly is that the most transformative gains come when AI is oriented toward pressing local challenges—snow instability, seasonality, infrastructure limits, environmental fragility—and when its deployment is embedded in regional strategy rather than being an isolated technical solution.

One major benefit is in enhancing resilience. Destinations that rely on snow increasingly face uncertainty; AI-based modelling and decision support tools help steer policy and operations toward diversification—of attractions, of seasons—and away from over-reliance on winter sports. At the same time, AI assists with risk management: hazard prediction, emergency services, and planning under climate stress.

Sustainability is another core win. AI helps smooth visitor flows (avoiding overtourism during peaks), optimize transport and last-mile mobility, and shift behaviour toward lower impact forms of tourism. The environmental cost of tourism—energy use, emissions, land use—can be better managed when

[70] https://innovazionesociale.org/index.php/2132-visionalps-2024-a-trento-lia-al-servizio-della-mobilita-sostenibile-in-montagna

data-driven insights guide investment and operations. The capacity for real-world monitoring (of energy, traffic, visitor movement, ecosystem strain) provides feedback loops, enabling adaptive management rather than reactive fixes.

Economic benefits are equally significant. Many SMEs and DMOs (destination management organisations) in alpine areas lack large IT or analytical capacity; AI-infused services, when designed to be accessible, open up possibilities for demand forecasting, tailored offerings (e.g. health tourism, cultural heritage experiences), and new kinds of cross-region partnerships. This contributes both to competitiveness and to the diversification of income bases, reducing vulnerability in downturns (e.g. low snow years).

Finally, there is a quality and safety dimension. Enhancing visitor experience through personalization, motion analytics, or real-time feedback, raising safety via monitoring and predictive alerts (weather, terrain, health) not only improves satisfaction but also reduces risk. In a terrain as unforgiving as the Alps, these aren't secondary concerns—they are mission-critical.

In sum, AI applications in Alpine tourism are delivering (or poised to deliver) benefits in resilience, sustainability (both environmental and economic), local empowerment, safety, and visitor experience. The critical factor is alignment: alignment with local ecosystem capacities, with policy frameworks, with regional differences in geography and exposure.

6.18 Collaborations and best practices at EU and EUSALP levels

AI projects in the Alpine Space are succeeding when three levels of collaboration are present and aligned:

1) EU programme level (Digital Europe, Interreg Alpine Space, Horizon funding, Digital Innovation Hubs, ETDS pilots) which provides finance, interoperability blueprints and regulatory guard-rails;
2) transnational networks & action groups (EUSALP action groups, Alpine Space programme consortia) which align regional strategies and share pilots across borders; and
3) local/sectoral ecosystems (DMOs, lift operators, SMEs, research institutes) which provide contextual knowledge and operational capacity.

Successful projects use all three. Evidence: Alpine Space projects (BeyondSnow, SmartCommUnity, DEGREE4ALPS, HEALPS-2) and Digital Europe pilots (DEPLOYTOUR) explicitly structure consortia across these levels.

The Alpine region's diversity—geographical, climatic, infrastructural—makes isolated interventions risky. What projects have repeatedly shown is that collaboration, institutional alignment, and shared practices matter just as much as technical innovation.

At the EU level, programmes and funding instruments are increasingly designed to encourage cross-border, multi-stakeholder consortia that combine research institutions, territorial authorities, SMEs, and local operators. One of the best practices is designing pilots whose learning can be transferred: setting up use cases in different Alpine countries, under varied conditions, to stress-test tools' adaptability. Similarly, building infrastructures and rulebooks (for data sharing, governance, interoperability) that are reusable by other regions or future projects amplifies impact.

Within EUSALP, the role of Action Groups has been vital. These groups provide structure for aligning regional strategies across multiple thematic domains: economic development, connectivity and accessibility, natural resources, risk governance, etc. They act as platforms for joint policy guidance, for aligning KPIs, for setting shared priorities. For example, in recent workshops under Action Groups AG2 and AG5, stakeholders have been debating dataspace approaches and AI's role in public services,

infrastructure, and economic opportunity, especially as a counterbalance to rural depopulation and infrastructural lag.
Another recurring best practice is embedding capacity building early. Collaborations that include training toolkits, "train-the-trainer" modules, shared labs, living testbeds, and stakeholder engagement (communities, local businesses, local government) tend to achieve better uptake. Institutionalizing mechanisms for knowledge sharing—via platforms, regular meetings, shared outputs—is also important; Alpine Space projects like SmartCommUnity are good examples, bringing together communities across countries to share good practices in digital resilience, rural service provision, and sustainable tourism.
Finally, good governance and trust frameworks are among the linchpins of success. Data spaces and similar constructs require clear rules: who owns which data, who can access what, under what conditions, how liability is handled, how privacy is respected. Projects such as DEPLOYTOUR are explicitly building "rulebooks" and governance structures to manage these issues. When trust is built (between partners, across levels of government, between public and private actors), adoption accelerates and innovations scale

6.19 Status of AI initiative implementation

Across the Alpine Space EU projects, AI adoption is heterogeneous but maturing:

- Some projects are explicitly AI-centric and operational (MountAIn; DEPLOYTOUR pilots integrating AI/analytics).
- Several projects are data-driven with latent AI potential (BeyondSnow RDMDT in development, HEALPS-2 THMT uses semantic/analytics foundations).
- Others are digital infrastructure or capacity projects (DEGREE4ALPS, Inter-Bike III, SmartCommUnity, Crowd-in-Motion) that are creating the preconditions for practical AI adoption (data, connectivity, EDIH support) rather than shipping mature ML products yet.

Overall: proof-of-concepts & pilots are abundant; scalable, governed deployments are emerging but still limited. The next 12–24 months will be relevant because ETDS/DEPLOYTOUR and national/regional EDIHs will either enable SMEs to run scalable AI pilots or leave benefits concentrated among well-funded partners.

Governance

Current state & gaps

- Fragmented governance models: Projects use different data governance approaches (from open data to partner-only data pools), meaning interoperability and trust remain barriers to cross-regional AI services. DEPLOYTOUR is explicitly addressing interoperability and trust via ETDS blueprints — a necessary but not sufficient step.
- Regulatory readiness is uneven: Operators and SMEs lack operational guidance on compliance with the EU AI Act (where applicable), data protection (GDPR) and liability frameworks for automated decision support in tourism (e.g., safety warnings). Many EDIH trainings help but standardised templates for ML risk assessment in the tourism context are scarce.

Recommendations

- Adopt a common, minimal governance stack for pilots: shared metadata schema, provenance tagging, consent frameworks and risk classification aligned to EU AI Act categories. Use DEPLOYTOUR as the interoperability anchor for tourism datasets.

- Mandate model-cards & field validation for operational AI: especially for safety-critical motion analytics (MountAIn) and hazard models (BeyondSnow RDMDT). Field validation reports should be a deliverable in all pilots.
- Strengthen EDIH role in compliance: EDIHs should provide templated compliance checks and insurance-friendly documentation to reduce liability frictions for SMEs. Crowd-in-Motion is a good model to scale this.

Sustainability

Current state

- Projects are explicitly targeting sustainability (TranStat, BeyondSnow, DEGREE4ALPS) and DEPLOYTOUR pilots include eco-friendly cases. However, measurement frameworks that tie AI interventions to absolute environmental outcomes (e.g., CO_2 saved, biodiversity impacts avoided) are still nascent.

Sustainability risks

- Rebound effects: AI-driven personalization can increase travel volumes or bring more visitors to fragile sites unless constrained by sustainability objectives.
- Energy & compute footprint: edge/cloud trade-offs for motion analytics and large-scale forecasting models must be considered (especially where connectivity is poor). MountAIn and DEGREE4ALPS pilots provide an opportunity to benchmark the compute cost vs. benefit.

Recommendations

- Include environmental KPIs in AI model objectives — e.g., models should optimise for "visitor satisfaction per unit of ecological impact" rather than pure revenue or visits. DEPLOYTOUR pilots should require such KPIs where possible.
- Prefer edge/low-compute approaches in the field — for safety and sustainability (e.g., lightweight fall-detection models on-device vs streaming high-resolution video). MountAIn testbeds are the right place to test such tradeoffs.
- Evaluate socio-economic impacts — ensure AI pilots embed measures of local employment, SME competitiveness, and equitable benefit sharing (e.g., how platform revenues and data value are distributed). SmartCommUnity's community approach is a useful template.

Adoption challenges

Key challenges

- Data quality & heterogeneity: tourism data is fragmented: sensors, ticketing, accommodation bookings, weather stations, local surveys. Semantics differ across regions — HEALPS-2's ontology approach is a best practice to reduce this friction.
- Connectivity & edge constraints in mountain environments: intermittent networks complicate streaming analytics and cloud-only models — projects that provision LoRaWAN or edge testbeds (SmartCommUnity, MountAIn) mitigate but not eliminate the problem.
- SME capacity & trust: many local operators lack skills, budgets and trust for AI; EDIHs and "test before invest" schemes (Crowd-in-Motion) reduce friction but scaling capacity building is still required.
- Interoperability & business incentives: without standard APIs and clear commercial models for data sharing (revenue split, anonymization guarantees), cross-regional AI services stall. DEPLOYTOUR and ETDS aim to create incentives but commercial models must be field-tested.

Practical mitigation actions

- Rapid prototyping pathway: use EDIHs to run 3–6 month “sandbox” pilots where a minimal dataset and an MVP AI model produce one measurable KPI (e.g., 10% reduction in queuing time). This builds trust fast. Crowd-in-Motion and EDIH resources are ideal hosts.
- Federated learning & privacy-preserving analytics: when local businesses won’t share raw data, federated or privacy-preserving aggregation allows cross-domain models without centralizing sensitive records — a likely win for destination consortia. DEPLOYTOUR should consider this for ETDS pilots.
- Operational handover plan: every pilot must include a handover to a local operator (DMO/SME/municipality) with clear O&M budgets and training. This prevents the “pilot graveyard” phenomenon

6.20 Concluding Synthesis (What This Means for the Alps)

Taken together, the use-cases and collaborative patterns demonstrate that AI in Alpine tourism and sport is no longer an abstract promise but a set of tangible practices with growing strategic significance. For the Alps, this implies a transition from reactive management—responding to climate shocks, overtourism, or infrastructural strain after they occur—to proactive, data-driven planning that anticipates risks and distributes benefits more evenly.

The synthesis also highlights a broader cultural shift. Alpine tourism has long been shaped by natural endowments and seasonal patterns; the introduction of AI reframes these dynamics by making destinations more adaptive, diversifying their offerings, and embedding sustainability into daily operations. This is particularly important for communities whose economic identity has been tied to winter sports, as AI provides pathways to broaden their appeal without undermining ecological integrity.

On a governance level, the Alpine macro-region is positioning itself as a laboratory for how data-driven innovation can be deployed in complex, fragile environments that cross national borders. The lessons learned here—about interoperability, trust, stakeholder inclusion, and sustainability metrics—will not only benefit the Alps but may also inform mountain and rural regions across Europe.

Ultimately, what this means for the Alps is an opportunity to redefine competitiveness on their own terms. Rather than chasing volume-based growth that risks degrading the very landscapes on which tourism depends, Alpine regions can leverage AI to pursue a model of intelligent, sustainable, and inclusive tourism. This vision aligns local well-being, environmental stewardship, and economic vitality, ensuring that the Alps remain both livable for residents and attractive for visitors in the decades to come.

7 AI for Sustainable Water Management in the Alps

7.1 A-DROP[71]

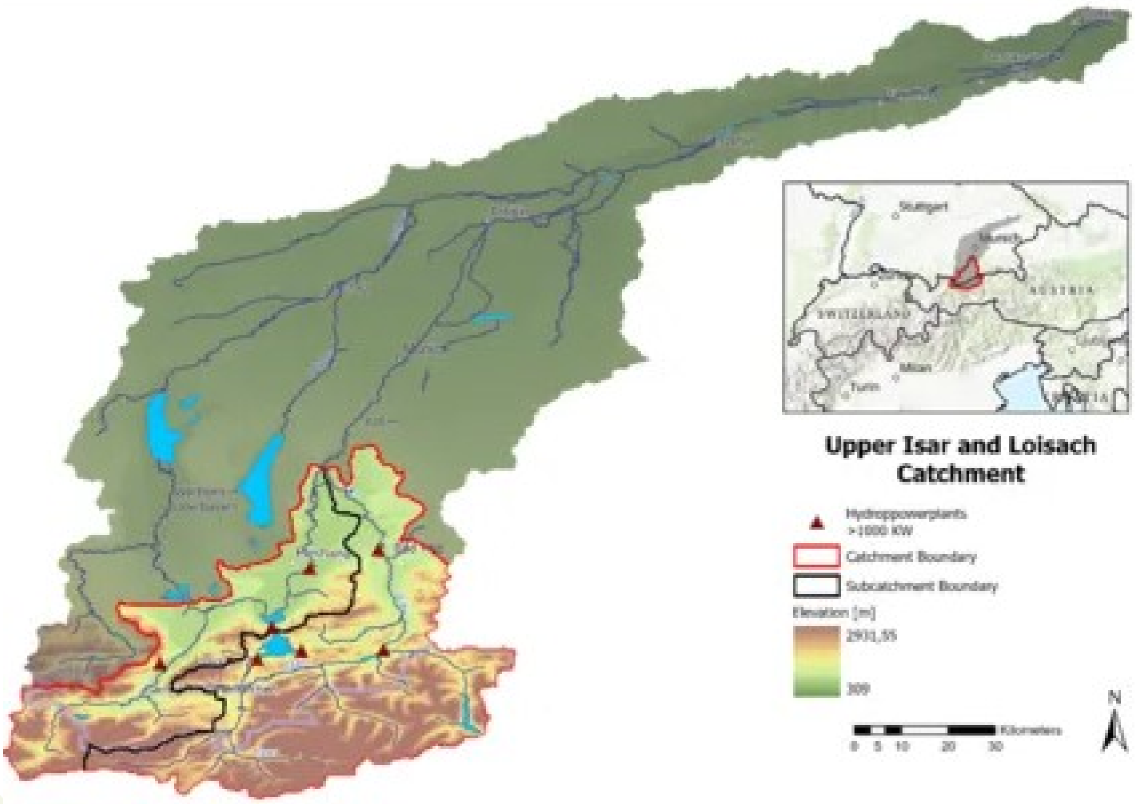

Figure 17 - A-DROP Area of interest for AI/ML tools deployment

A-DROP ("Alpine Drought Prediction") is an Interreg Alpine Space project designed to improve drought risk management and forecasting tools tailored for the Alpine region. The A-DROP's consortium includes 11 partners from five Alpine Space countries, ranging from research institutions to public authorities. The project addresses a problem of critical importance: the increasing frequency and severity of droughts in the Alps, driven by climate change, which affect agriculture, hydropower, tourism (both winter and summer), freshwater supply, and ecosystem services —all of which depend heavily on Alpine water resources. The main goal is to enhance readiness of Alpine territories to cope with droughts through better monitoring, prediction, and sustainable water resource management[72] [73].
To this end, A-DROP is generating high-resolution climatic and hydrological data; developing and calibrating drought indices and impact tools; integrating these into an interoperable open database (open source), underpinned by the ADO (Alpine Drought Observatory) platform, following FAIR data

[71] https://www.alpine-space.eu/project/a-drop/
[72] https://www.eurac.edu/en/institutes-centers/institute-for-earth-observation/projects/a-drop
[73] https://www.cimafoundation.org/en/project/a-drop

principles; testing tools in real-world pilots; and performing climate model simulations to estimate future drought trends under climate change, to support decision making and adaptation[74].
There are five pilot areas representing varied sectors: agriculture (e.g. in Slovenia's Podravje region, with enhancements of irrigation decision support tools, soil moisture sensing, etc.), hydropower (Upper Isar catchment in Germany/Austria), tourism/ski resorts (e.g. ski-resorts like Avoriaz & La Thuile), regional administration (Valle d'Aosta), and river basin (Adige basin) where seasonal forecasts are produced and tested. These pilots are intended to validate tools and datasets in operational settings, engaging stakeholders, measuring costs/benefits, and assessing constraints in uptake.
From an AI standpoint, A-DROP explicitly includes modeling, forecasting, and prediction tools that combine new and existing datasets. At least one pilot (Upper Isar) is developing a tool that integrates physics-based and machine learning models for simulating hydropower operations under drought conditions. This suggests substantive usage of statistical / AI modelling for predictions and trade-off analyses[75].
Moreover, A-DROP's architecture entails open, high-resolution data streams, climate model simulations, drought indices, impact assessments, and forecasting tools with lead times (seasonal forecasts, etc.), which are all core inputs for AI methods. The interoperable database and the enriched ADO platform likely serve as platforms where algorithmic services can be hosted. Stakeholder co-design, integration with local water governance, and operational validation are built in.
Gaps/potential for further AI enhancement include: improving real-time predictive performance (e.g., nowcasting of drought onset); integrating remote sensing/satellite imagery and unstructured data (e.g., news / social media) for early detection of impacts; deploying deep learning models for complex, non-linear interactions among climatic, hydrological and anthropogenic variables; user-facing recommendation systems for water managers/tourism operators to adjust operations under forecasted drought; combining AI with optimization methods for resource allocation (e.g. irrigation scheduling, ski-resort snowmaking vs. water availabilities) under multiple constraints; and developing anomaly detection in sensor / hydrological networks to detect unexpected drought stress. The project seems well placed to deliver many of these, though as of the latest public documents, some are under development rather than completed.
In sum, A-DROP stands as a high-relevance EU-funded project in the Alpine region that does explicitly deploy AI-relevant techniques (especially prediction, forecasting, climate model simulations, pilot-tested tools) in sectors that directly overlap with tourism, hydropower, agriculture, ecosystem health and water availability. It offers both a dataset backbone and modelling innovation that can support downstream AI applications (in tourism scheduling, ski-resort planning, summer visitor flow, etc.).

[74] https://www.geosphere.at/en/about-us/research-and-cooperations/project-database/a-drop
[75] https://www.cee.ed.tum.de/en/hydrologie/research/current-projects/a-drop/

7.2 WATERWISE[76]

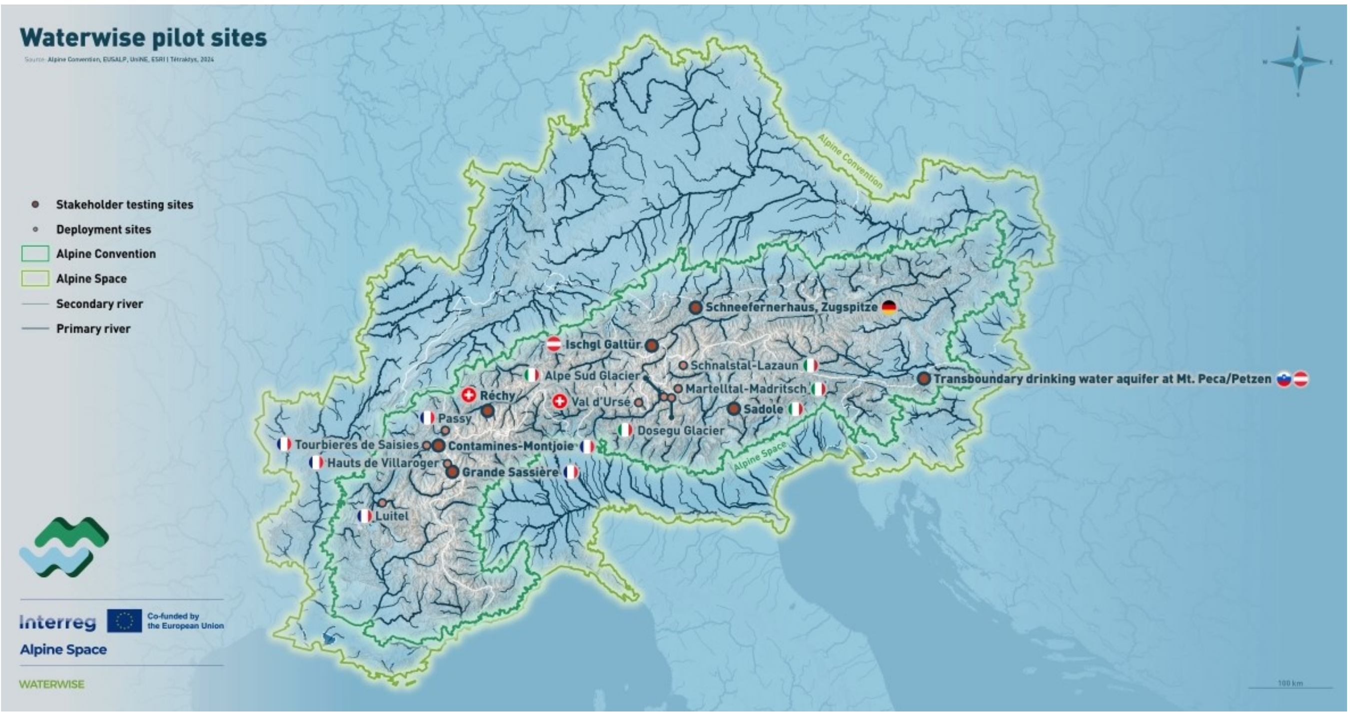

Figure 18 - WaterWISE pilot sites

WaterWISE is an Interreg Alpine Space project coordinated by the University of Neuchâtel (Switzerland) and Fondazione Edmund Mach (Italy), with twelve partners from six Alpine countries (France, Italy, Switzerland, Germany, Austria, Slovenia). WATERWISE addresses the rising threats that climate change and human pressures pose to Alpine headwaters—especially shifts in precipitation, melting glaciers, changes in snowpack, extreme weather events—that affect water quantity and quality, with knock-on effects on biodiversity, agriculture, hydropower, tourism and ecosystem services[77].

The core aim is to co-design with local stakeholders a digital toolbox (web-platform) to assess vulnerability of headwater catchments ("mountain source" areas) under climate and land-use change, and to test sustainable strategies for water and land management suited to these vulnerabilities. The toolbox will allow collection, processing, and visualization of in-situ climate and ecohydrological data, enable vulnerability assessments, support scenario modelling, and be accessible via a user-friendly platform. Seventeen pilot or test sites (or at least seven main pilot headwater catchments) are involved, representing a wide variety of environmental, hydrological and socio-economic conditions. Among these are Sadole in Trentino (Italy), Val d'Ursé / Valposchiavo (Switzerland), Grande Sassière (France), Jamtal Valley (Austria), Réchy (Switzerland), Schneefernerhaus at Zugspitze (Germany), the transboundary aquifer of Mount Peca / Petzen (Austria/Slovenia), Contamines-Montjoie (France), among others. Each pilot is monitoring numerous variables: streamflow and discharge, piezometric data, climate / meteorological data, snow and cryosphere dynamics, connectivity of stream networks, water chemistry,

[76] https://www.alpine-space.eu/project/waterwise/

[77] https://cri.fmach.it/en/Research-activity/Projects/WATERWISE-A-Governance-Toolbox-for-Designing-and-Testing-Water-Management-Strategies-of-Headwater-Catchments

temperature, conductivity, morphology, geological maps, vegetation, and related ecological / biodiversity indicators[78].

WATERWISE is explicit about using modelling techniques and predictive tools[79]. In Trentino, researchers are implementing predictive models to simulate the evolution of Alpine hydrological systems; in general the project intends to generate models of climate change impact on water flows and quality to support sustainable management strategies. Co-design with stakeholders ensures not only scientific model development but validation, local adaptation, and uptake. The governance toolbox will integrate scientific, ecological, and socio-economic parameters, and local actors will use workshops and participatory processes to co-develop adaptation strategies. Data collection will involve both existing monitoring networks and field data, low-cost sensors, crowdsourcing approaches, remote sensors for snow and glacier metrics, etc. One partner (Karlsruhe University of Applied Sciences) plays a role in developing harmonized data compilation methods and low-cost sensors/crowdsourcing for remote catchments[80].

Thus far, as of the most recent public sources, there is no indication that WATERWISE has deployed large-scale machine learning or statistical AI models in production (e.g., neural nets, complex time series forecasting, or computer vision). The project is mostly in the data acquisition, modelling, tool building, and stakeholder engagement phase. It is laying the groundwork—harmonized monitoring, open data, tool development—for later, more advanced algorithmic work.

WATERWISE stands out as a foundational project that is preparing the technical and scientific terrain for advanced AI integration into alpine hydrology and resource governance. The project's architecture—spanning multi-source data acquisition from in-situ sensors, low-cost monitoring devices, remote sensing, and crowdsourced observations—creates precisely the heterogeneous, high-frequency data environment that modern AI systems require to generate actionable insights. By harmonizing data across pilot sites and combining hydrological, climatic, ecological, and socio-economic variables, WATERWISE enables the development of machine learning models capable of learning complex, nonlinear interactions among environmental factors. These could later support applications such as early drought or flood warning systems, predictive modelling of snowmelt and groundwater recharge, anomaly detection in sensor networks, and optimization of water allocation between competing users (agriculture, hydropower, tourism, ecosystems). While the current phase emphasizes modelling and co-design rather than operational AI deployment, the digital toolbox under development will offer an ideal platform for integrating such algorithms. Moreover, its participatory approach—where researchers and local stakeholders co-create and validate the tools—ensures that any future AI components are socially robust, interpretable, and aligned with real-world decision-making needs. In this sense, WATERWISE exemplifies how data-driven modelling can evolve toward AI-augmented, adaptive management of mountain headwaters, balancing environmental protection, human use, and climate resilience across the Alpine region.

[78] https://www.crealp.ch/en/waterwise/
[79] https://www.uni-passau.de/bioecon/forschung/waterwise
[80] https://www.h-ka.de/en/die-hochschule-karlsruhe/aktuelles/news/2024/climate-change-in-the-alpine-region

7.3 PlanToConnect[81]

PlanToConnect ("Mainstreaming Ecological Connectivity in Spatial Planning Systems of the Alpine Space") is an Interreg Alpine-funded project with the primary mission to support the creation of a coherent Alpine-wide network of green and blue infrastructures (GBI) for ecological connectivity, including rivers, wetlands etc., by harmonizing regional networks and incorporating ecological connectivity into spatial planning and territorial policies. It involves multiple pilot case studies, training & capacity building, mapping of priority connectivity areas, analyses of barriers, and development of strategic planning tools[82].

Although PlanToConnect is not explicitly a water-management project per se, its focus on green and blue infrastructures (GBIs) means that water features (rivers, wetlands, streams, floodplains) are central to its connectivity networks. The "blue" parts of "green & blue infrastructure" physically involve aquatic ecosystems, riparian corridors, wetlands, natural waterways, and hydrological connectivity. Moreover, one of the project's key working groups includes stakeholders from water management among others (nature conservation, forestry, wildlife, spatial planning) in cross-border Regional Connectivity Working Groups[83]. The mapping and GIS-based components include mapping of priority connectivity areas, barrier analyses (including linear infrastructures like roads, dams), ecosystem services, land use conflicts, and typologies of blue and green infrastructure connectivity[84].

From the perspective of AI for sustainable water management, PlanToConnect offers several latent capabilities and enabling datasets/tools that could be leveraged, though it does not (as of the latest published materials) implement advanced AI or machine learning models specifically for water prediction or hydrological forecasting. The project has produced GIS data layers (ecological conservation areas, ecological intervention areas, connectivity restoration areas), maps showing barriers, potential corridors, identified bottlenecks for connectivity, and data relating to land use conflict, protection status, etc[85].

Because of this, PlanToConnect provides a strong spatial, landscape and hydrological-ecological framework that could support AI applications for water management in the Alps. For example, AI models could use these GIS layers plus hydrological and climatic data to predict how changes in connectivity (or loss of blue infrastructure corridors) affect watershed health, water flow regimes, flood resilience or pollutant transport. Also, machine learning could help identify which barriers (infrastructure, land use) are most critical to remove or mitigate to restore hydrological connectivity, or detect where restoration of wetlands or riparian buffers would yield the biggest gains for water quality, retention, flood mitigation, or maintaining base flow in dry periods.

Furthermore, blue infrastructure restoration and connecting waterways are directly relevant for sustainable water management: natural corridors help with floodplain storage, stream connectivity helps species movement and ecosystem function which often regulate water purification and sediment retention. PlanToConnect's data on barriers (dams, roads, urbanization) could feed into AI-driven optimization: choosing priorities for barrier removal, designing restoration interventions that maximize hydrological and ecological benefits under constraints. The project's planning strategy, training, and

[81] https://www.alpine-space.eu/project/plantoconnect/
[82] https://www.eurac.edu/en/institutes-centers/institute-for-regional-development/projects/plantoconnect
[83] https://www.alpine-space.eu/wp-content/uploads/2024/07/PlanToConnect_D2.1.2_ECO.pdf
[84] https://www.alpine-space.eu/wp-content/uploads/2024/06/D1.1.1_Mapping-report-of-priority-connectivity-areas-for-spatial-planning.pdf
[85] https://e-c-o.at/project-details-en/pid_382.html

toolkit development indicate there is institutional readiness: spatial planners, nature conservation bodies, regional authorities are already involved and producing harmonized maps and guidelines. That means uptake of AI tools would be facilitated by existing stakeholder structures.

Challenges remain: PlanToConnect does not (seem to/yet) collect high-frequency hydro-climatic sensor data (e.g., streamflow time series across many sites) as part of its published work. Also, many water-management processes require temporal forecasting, rapid data assimilation, perhaps remote sensing, or real-time monitoring, which are not core in PlanToConnect's deliverables as documented. Moreover, AI-based tools would need integration of domain expertise in hydrology, ecology, and climate; there may be gaps in data resolution, consistency across borders, and computational modelling capacity.

In sum, PlanToConnect is a project that builds essential spatial and ecological connectivity infrastructure and datasets (GBI maps, barrier analyses, priority corridors) that are highly relevant to water sustainability (flood risk, hydrological connectivity, water quality, ecosystem service regulation). While it doesn't yet implement AI/ML models for water predictions or decision support, its outputs offer valuable foundations upon which AI systems could be built to support sustainable, nature-based water management interventions in Alpine regions.

7.4 DIVERSE[86]

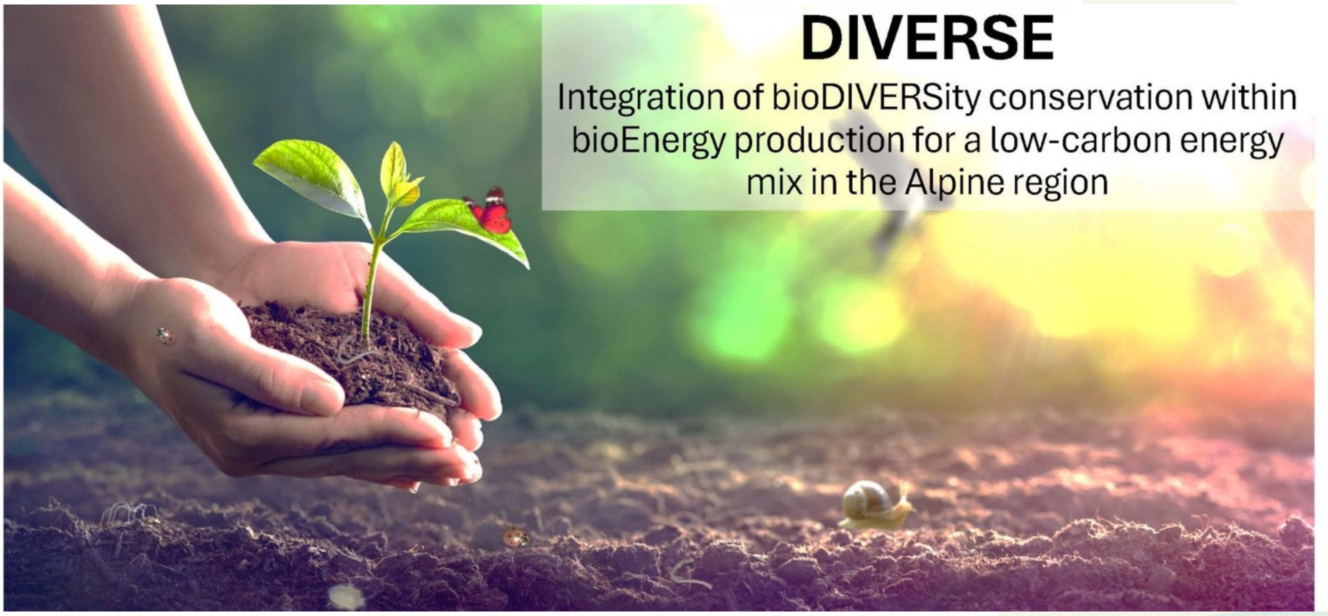

Figure 19 - Diverse project teaser

DIVERSE ("Integration of bioDIVERSity conservation within bioEnergy production for a low-carbon energy mix in the Alpine region") is an Interreg Alpine Space that involves 12 partners from five Alpine countries (Italy, Slovenia, France, Austria, Germany), coordinated by RSE (Italy)[87].

The core aim of DIVERSE is to tackle conflicts between bioenergy production (using biomass and residues) and biodiversity conservation in Alpine ecosystems. It seeks to define under what local/regional conditions biomass can be used sustainably (taking into account biodiversity criteria), and to integrate these criteria into bioenergy policies, management practices, business models and value

[86] https://www.alpine-space.eu/project/diverse/
[87] https://rralur.si/en/projects/diverse

chains. The project plans to produce an Open Dialogue Toolkit (including sustainability & biodiversity indicators, summaries of trade-offs, protocols for stakeholder dialogue), to activate Focus Labs in partner regions engaged with two main biomass/residue value chains (agricultural / agro-food residues; forestry residues/wood chips) and to derive “Alpine Trajectories” – guidance, policy suggestions and circular business model pathways that balance bioenergy goals with ecosystem protection[88] [89].

From the perspective of sustainable water management, DIVERSE is not principally targeted on water systems, hydrology, or water quality, but it is relevant in multiple indirect ways. Biomass operations, forestry practices, residue management, and land-use change strongly influence hydrological cycles, soil moisture, runoff, infiltration, evapotranspiration, and potentially water quality (through nutrient runoff, erosion, sedimentation). Biodiversity-friendly biomass production often requires maintaining riparian buffers, soil cover, avoiding over-harvesting, preserving forest ecosystems, which all have hydrological implications (flood mitigation, groundwater recharge, streamflow regulation). Thus, there is an overlap where decisions in bioenergy chains affect water sustainability.

As for explicit AI/ML usage, project documentation does not indicate that DIVERSE currently employs advanced machine learning, statistical AI or predictive models for water management, hydrology, or related forecasting. The deliverables and project description focus on value chain analysis, indicator development, policy/business model design, stakeholder dialogue and mapping of sustainability and biodiversity trade-offs rather than algorithmic modelling.

However, DIVERSE generates and will generate data and frameworks that could support AI applications for sustainable water management. For example, the sustainability & biodiversity indicators produced for bioenergy value chains could be augmented with hydrological indicators; biomass supply chain data (source, amount, harvesting timing, residue handling) paired with land-cover / land-use GIS layers could feed machine learning models to predict effects on watershed stability or runoff. The Focus Lab regions will gather local data on forest residue harvesting, agro-residue flows, soil and ecological conditions; these could be used in data-rich settings to train predictive models of soil moisture loss, streamflow alteration, erosion risk under different bioenergy production regimes. Also, trade-off summaries and protocols could be translated into decision support systems using rule-based or even hybrid ML/rule systems to help policy-makers visualize water-related impacts when selecting bioenergy plans.

In sum, DIVERSE, while not directly focused on water management, lays down many structural components that are relevant to sustainable water in Alpine environments: indicators, value chains, residual biomass flows, land use practices, policy/business model design, and stakeholder engagement.

[88] https://keep.eu/projects/29568/Integration-of-bioDIVERSity-EN
[89] https://www.rse-web.it/en/projects/integration-of-biodiversity-conservation-within-bioenergy-production-for-a-low-carbon-energy-mix-in-the-alpine-region/

7.5 EO4ALPS-Snow[90]

Figure 20 - eo4Alps-Snow interface

eo4Alps-Snow is an ESA-funded initiative under the Alpine Regional Initiative (EO4alps) implemented from January 2021 to January 2023, led by the private company Waterjade S.r.l. (Italy) with partners Eurac Research (Italy) and Sinergise (Slovenia). Its objective is to develop a service delivering high spatial and temporal resolution snow monitoring over the entire Alpine arc to support improved water resource management. Key outputs include maps of snow water equivalent (SWE), snow depth, and snow-covered area (SCA), generated via a hybrid methodology combining Earth Observation data (from Sentinel-1, Sentinel-2, and Sentinel-3) with physically-based snow models. The service is built on cloud-computing infrastructure integrating EO datasets, meteorological inputs including reanalysis (ERA5), and physically based modelling. Resolution is about 250 meters, aiming for quasi-real time outputs across the Alps. A web platform / prototype was made available for free (initially ≈ six months) to stakeholders including hydropower operators, environmental agencies, research centers, and companies concerned with snow and hydrology[91].

From the perspective of sustainable water management in Alps, eo4Alps-Snow provides essential capabilities: SWE is a direct indicator of the water that will become available once snow melts; accurate,

[90] https://waterjade.com/eo4alps-snow/

[91] https://www.eurac.edu/it/institutes-centers/istituto-per-osservazione-della-terra/projects/eo4alps-snow

spatially distributed SWE estimates allow planners to anticipate water availability for downstream users (hydropower, agriculture, municipalities), make seasonal water balancing decisions, prepare for drought or low flow periods, and manage reservoir operations more effectively. The combination of EO and physical modelling improves robustness: EO data (optical, SAR) helps locate and measure snow cover and depth, while physical model adds understanding of snow accumulation & melt processes under varying meteorological conditions. Use of cloud-computing infrastructure allows the service to be scalable and responsive[92].

As for AI: eo4Alps-Snow does not appear to use complex machine learning models or statistical learning in published outputs (e.g., no mentions of neural networks, learning-based SWE estimation from past training data beyond physical + EO hybrid models). What is documented is the hybrid physical + EO modelling, cloud infrastructure, data assimilation, but less about learned models or predictive analytics beyond the physical model forecasts or forecast inputs.

However, the project's outputs and data flows strongly enable AI integration for sustainable water management. For example, the high-resolution SWE maps, SCA, and snow depth time series provide labelled spatial-temporal datasets that could train machine learning or deep learning models to better predict snowmelt timing, downstream flow volumes, or risk of water scarcity. AI could be used to improve forecast accuracy under changing climate patterns, integrating upstream meteorological forecasts (or Earth system model outputs) with observed EO data to produce probabilistic forecasts of meltwater yield. Also anomaly detection could be applied to sensor or EO streams to notice unusual snowpack behavior (e.g. rapid melt, unexpected snow loss) that might threaten water supply or increase flood risk. Recommender-type tools could inform water managers when to adjust reservoir release schedules based on expected inputs from snowpack.

Moreover, the web platform prototype, APIs, and cloud infrastructure are important foundational assets: they enable deployment of AI services, user-driven tools, dashboards, and automated workflows. Because the service aims for quasi-real time snow monitoring, there is potential to enhance timeliness and predictive power via AI; for example, integrating physics-based models with data-driven models to capture local irregularities, biases, or microclimatic effects not easily captured by physical models alone. Also, the use of EO data (optical and radar) suggests potential for using computer vision/image processing / deep learning to detect snow cover, melt onset, or snow wetness more precisely, especially under difficult conditions (cloud cover, mixed pixels, etc.).

In conclusion, eo4Alps-Snow is a strong exemplar of a project delivering core physical + remote sensing services for snow metrics that are critical for sustainable water management in Alpine regions. While it does not principally deploy AI/ML models (beyond hybrid modelling), it generates exactly the kind of data, infrastructure, resolution, and stakeholder engagement necessary for integrating AI: predictive, anomaly-detection, optimization, and decision-support applications.

[92] https://eo4society.esa.int/projects/eo4alps-snow

7.6 UNIVERSWATER[93]

Figure 21 - Universewater teaser.

UNIVERSWATER (Grant Agreement ID 101135422) is a Horizon Europe Research & Innovation Action running from 1 June 2024 to 30 November 2027, with total EU funding of about €5,996,600, involving 15 partners across six European countries[94]. Its core focus is improving water quantity and quality in agricultural contexts, especially addressing runoff of nutrients and pesticides, soil salinization, overuse of natural water sources, and increased pressure from climate change[95].

UNIVERSWATER operates under a “system of systems” framework. It aims to integrate several technological components: development of portable, in-situ sensors for pollutants and soil/water quality parameters (salinity, nutrients, microbiological indicators, cation exchange capacity); the use of Earth Observation (satellite imagery) to monitor land/water conditions; and coupling those with advanced, explainable AI techniques to process data, derive decision-support outputs, and feed back into water-use / pollutant control actions[96].

The project will test these tools in three agricultural demo/case study sites located in Ireland (Teagasc Moorepark), Italy (Torre Guaceto, southern Adriatic), and Greece (Prespa region)[97]. These case studies address specific water-management challenges: treatment of dairy soiled water (wastewater from dairy

[93] https://universwater.eu
[94] https://cordis.europa.eu/project/id/101135422
[95] https://akisplataforma.es/en/projects/horizon-europe-universwater-project-universal-interoperable-platform-sustainable
[96] https://universwater.eu/about
[97] https://universwater.eu/use-cases/

operations), mitigation of soil salinization through reuse of water, and optimization of fertilizer and pesticide application to reduce freshwater pollution[98].

One of UNIVERSWATER's objectives is to build a modular, adaptable Decision Support System (DSS) platform where the sensor + remote sensing + AI technologies can be adapted to a variety of local/regional agricultural water settings. This includes using explainable AI, ensuring robustness, and validating with in-situ data from the use cases. The project also includes the development of nature-based and technology-based remediation methods, and mechanisms (incentives, pricing) to promote uptake among users.

From the perspective of Sustainable Water Management in the Alps, UNIVERSWATER has high relevance, even though its demo sites are not explicitly all in Alpine headwater regions. The techniques it develops (sensors, EO, AI, DSS) are directly applicable to Alpine challenges: in Alpine regions, snowmelt, precipitation variability, steep terrain, and sensitive ecosystems intensify issues such as runoff, nutrient transport, soil salinity in valley floors, and water scarcity during dry spells. Having portable, rapid sensors can help monitor pollutant concentrations, interacting with the heterogeneous terrains. AI methods trained with remote sensing + in-situ data could help forecast runoff events, detect contamination early, or predict soil moisture/salinity condition in alpine soils. The modular DSS could be tailored for small farms or pastures in alpine valleys to optimize fertilizer/pesticide use or reuse of water, reducing eutrophication risk in lakes and rivers downstream.

Potential AI augmentations/contributions include predictive modelling of pollutant runoff under different precipitation/snowmelt scenarios; anomaly detection in sensor networks across alpine farms; integrating altitude, slope, precipitation, snow cover, seasonal variation as features in ML models for runoff risk; optimizing irrigation scheduling under water-scarce alpine summers; adaptive decision systems that take into account remoteness, access difficulties, terrain variability; and explainable AI to ensure trust among mountain farmers or alpine communities.

In summary, UNIVERSWATER is a strong and very relevant current EU-funded project that explicitly deploys AI/ML techniques, remote sensing, sensors, and decision support, with direct pertinence to sustainable agricultural water use. In the Alps, its methods and tools could be adapted to improve water quality and quantity management in agricultural areas, especially in valley regions or lower alpine zones, and could form part of a portfolio of AI-enhanced solutions for sustainable water management in Alpine spaces.

[98] https://www.planetek.it/en/projects/universwater

7.7 DARROW[99]

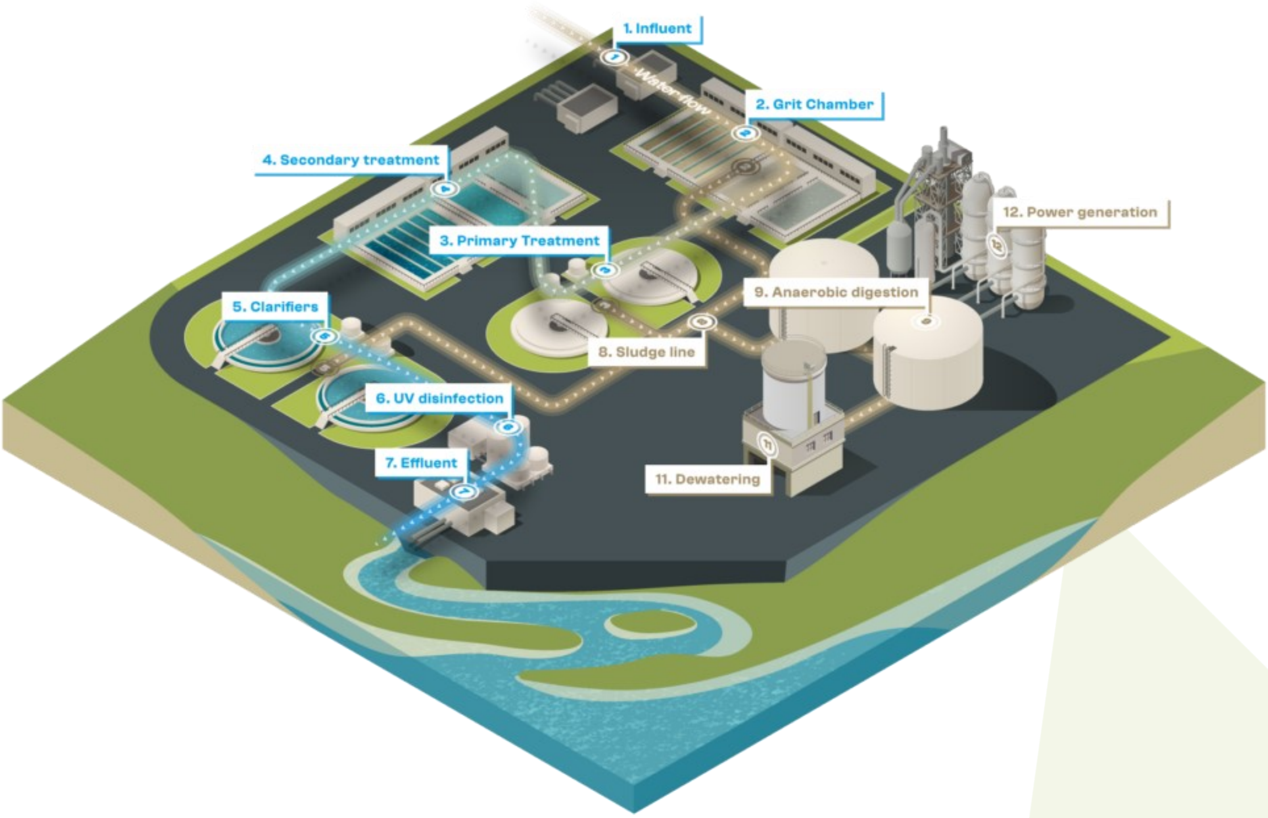

Figure 22 - DARROW wastewater analysis pipeline

DARROW (DarRROW / "Driving the future of water resource recovery facilities through data intelligence") is an EU-funded project (Horizon Europe, call HORIZON-CL4-2021-DIGITAL-EMERGING-01) active from 1 September 2022 to 28 February 2026. It involves eight partners from four EU countries (Spain, Belgium, Germany, the Netherlands). Its declared mission is to transform wastewater treatment plants (WWTPs) into more sustainable, autonomous, and energy-efficient water resource recovery facilities (WRRFs) by developing modular, flexible, and explainable AI systems. The project aims to address multiple goals: reduce energy consumption and greenhouse gas emissions, recover nutrients (particularly nitrogen and phosphorus), increase energy generation (e.g., via biogas from anaerobic digestion), reduce sludge generation and chemical use, and improve overall treatment efficiency[100].
A key demonstration site is the Tilburg wastewater treatment plant (RWZI Tilburg) in the Netherlands, which treats large volumes of wastewater daily and includes biological treatment, anaerobic digestion, secondary and tertiary treatment units. DARROW will deploy its AI-powered modules there to test resource recovery and operational optimization in real operational conditions[101].
DARROW's AI system is intended not only to give recommendations to plant operators but to provide transparent, explainable rationales for those recommendations. It aims to include software sensors,

[99] https://www.wastewater.ai/the-project/
[100] https://www.esci.eu/project/darrow/
[101] https://cordis.europa.eu/project/id/101070080

anomaly detection, real-time prediction of process variables, and closed-loop or semi-automated control support (with human oversight) rather than fully replacing operator decisions[102].
In terms of what has been realized so far (from the public sources), DARROW is in development and demonstration phases. Models are being built using sensor data, operational metrics, chemical, biological, sludge and energy flows to support predictive analytics. The full scale deployment at Tilburg is part of validation. It is not yet clear from public sources whether climate or alpine-region specific deployments have been done. DARROW's focus is general WRRFs, not necessarily Alpine headwater regions or mountainous water catchments.
Under the theme AI for Sustainable Water Management in the Alps, DARROW is highly relevant, though with caveats. Its core technologies—AI-based optimisation of resource recovery, explainable decision support, energy performance, nutrient recovery—address several challenges Alpine water systems face: energy constraints, variable water availability, water quality, and the need for resilient infrastructure under climate change. For example, Alpine WWTPs are often in remote or mountainous valleys where energy cost, carbon footprint, and nutrient loading matter for downstream ecosystems; DARROW's tools could be adapted to those contexts.
DARROW's data-driven models, sensor integration, anomaly detection and predictive components could be employed in Alpine settings to optimize operations of WWTPs under variable inflows from snowmelt or rainfall, manage pollutants under seasonal flows, and help minimize greenhouse gas footprints in fragile mountain ecosystems. The explainability requirement is especially important in Alpine communities where operator trust, regulatory oversight, and environmental sensitivity are high.
However, DARROW does not explicitly target Alpine headwater catchments, hydrological modelling under altitude, snow/ice melt timing, or watershed-scale flow variability in steep terrain. Those are specific factors in Alpine water management that require adaptation. For full relevance, the models and AI modules would need to integrate alpine-specific features (snowpack/snowmelt timing, steep slope hydrology, cold-region microbial dynamics, seasonal connectivity, freezing/thaw cycles). Also, distributed smaller WWTPs in Alpine valleys may have different data availability or sensor coverage and less continuous monitoring, which may challenge model training and deployment.
In sum, DARROW is among the EU-funded projects that explicitly deploy AI for water treatment and resource recovery, and its methods and infrastructure show strong potential for transfer and adaptation to Alpine sustainable water management.

[102] https://www.wastewater.ai/new-video-unlocking-the-potential-of-wastewater-using-ai/

7.8 Courmayeur Climate Hub[103]

Figure 23 - The Residency Living Lab initiative for the Courmayer Climate Hub call.

Courmayeur Climate Hub is a project of the Comune di Courmayeur, financed under NextGenerationEU via the Italian national recovery plan (PNRR, "Bando borghi" Line B), with a total EU/NGEU grant of ~€1,585,268 plus about €350,000 of municipal co-funding (CUP I74H22000050005). It is structured around the rehabilitation of the ex Hotel Ange in Courmayeur's historic center, and around ten lines ("linee di intervento") of action that combine restoration, heritage, cultural events, digitalization, youth engagement, participatory planning, and a strategic plan for sustainable tourism (Alta Montagna) with community involvement[104]. Among the ten, relevant lines include the digital library of mountain heritage ("Biblioteca Digitale delle Montagne"), the "Residency Living Lab" involving experts in climate risk, and the "Piano Strategico Integrato per il Turismo Sostenibile" (Integrated Strategic Plan for Sustainable Tourism), which includes themes like preserving water ("preservazione dell'acqua") as expressed in stakeholder workshops[105]. There have also been "Climathon" hackathon events (24-hour challenge formats) to generate proposals or ideas on climate adaptation, including one where water scarcity ("situazioni di carenza idrica") in Alpine areas was explicitly named among challenge themes[106].
From a sustainable water management standpoint, Courmayeur Climate Hub's current concrete activities do not appear to include deployment of monitoring infrastructures (e.g., sensors, hydrological modelling) or algorithmic/AI-driven predictive systems in water resource management in the publicly

[103] https://climatehub.courmayeurmontblanc.it
[104] https://www.comune.courmayeur.ao.it/amministrazione/attuazione-misure-pnrr/courmayeur-climate-hub
[105] https://www.comune.courmayeur.ao.it/novita/courmayeur-climate-hub-al-via-gli-incontri-con-gli-operatori-del-territorio
[106] https://www.comune.courmayeur.ao.it/novita/un-climathon-ben-riuscito-premiate-nuove-idee-di-sostenibilita

visible documentation. The focus is largely on cultural, social, educational, heritage, participatory planning and strategic/communication/event organization. There is no explicit mention of water flow forecasting, snow-melt modelling, remote sensing for hydrological data, or real-time digital water management tools. The project's line "Piano Strategico Integrato per il Turismo Sostenibile" and stakeholder tables include the theme of water preservation, but mainly in a qualitative and planning context.

However, there are multiple enabling conditions in the Courmayeur Climate Hub that could support future AI applications in sustainable water management. First, the project is building participatory governance, stakeholder engagement, and generative idea production (Climathon, Living Lab). These create strong social legitimacy and may help in gathering local data, eliciting local knowledge, and defining relevant local indicators (of water scarcity, usage, risk). Second, the infrastructure for digitalization (e.g., the digital library) and the plan for digital/multimedia spaces suggest familiarity or capacity with digital platforms; this could ease deployment of digital dashboards or information systems. Third, the strategic plan for sustainable tourism, with explicit inclusion of water preservation themes and participatory visioning, provides a framework in which water-management goals can be integrated in planning, regulation, and design (e.g., controlling water usage in tourism, preserving mountain streams, ensuring sustainable water supply) if data and tools are inserted.

If Courmayeur Climate Hub were to adopt AI / ML tools for sustainable water management, plausible avenues include: implementing a monitoring network of hydrological sensors (streamflow, snowpack, precipitation) to feed time series data; using remote sensing to monitor snow cover, glacier retreat, vegetation cover affecting runoff; constructing predictive models of water availability, particularly considering snowmelt and seasonal variability; anomaly detection to warn of low water, or risk to water supply (e.g. due to drought); decision-support tools for local authorities for water allocation, reservoir management, or designing interventions in water catchments; integrating citizen science (local observations) into datasets; using hackathon outputs to prototype algorithms or tools.

Challenges for such integration include: data availability (especially hydrological/meteorological/snowpack data at required spatial and temporal resolution), resource for deploying sensors or accessing EO data; ensuring technical know-how for AI modelling; establishing clarity around governance of data, privacy, reliability; ensuring that predictions / algorithmic outputs are interpretable and trusted by local actors; adaptation of models to the high variability and steep gradients of Alpine terrain (altitude, slope, microclimates) which require specialized modelling; ensuring sustainable funding and maintenance of any technical tools.

In conclusion, Courmayeur Climate Hub is not yet a strong example of AI deployment for sustainable water management, but it is an important enabler and incubator: it builds social, institutional, digital, and strategic infrastructure and raises awareness, which are all necessary preconditions.

7.9 FARMWISE[107]

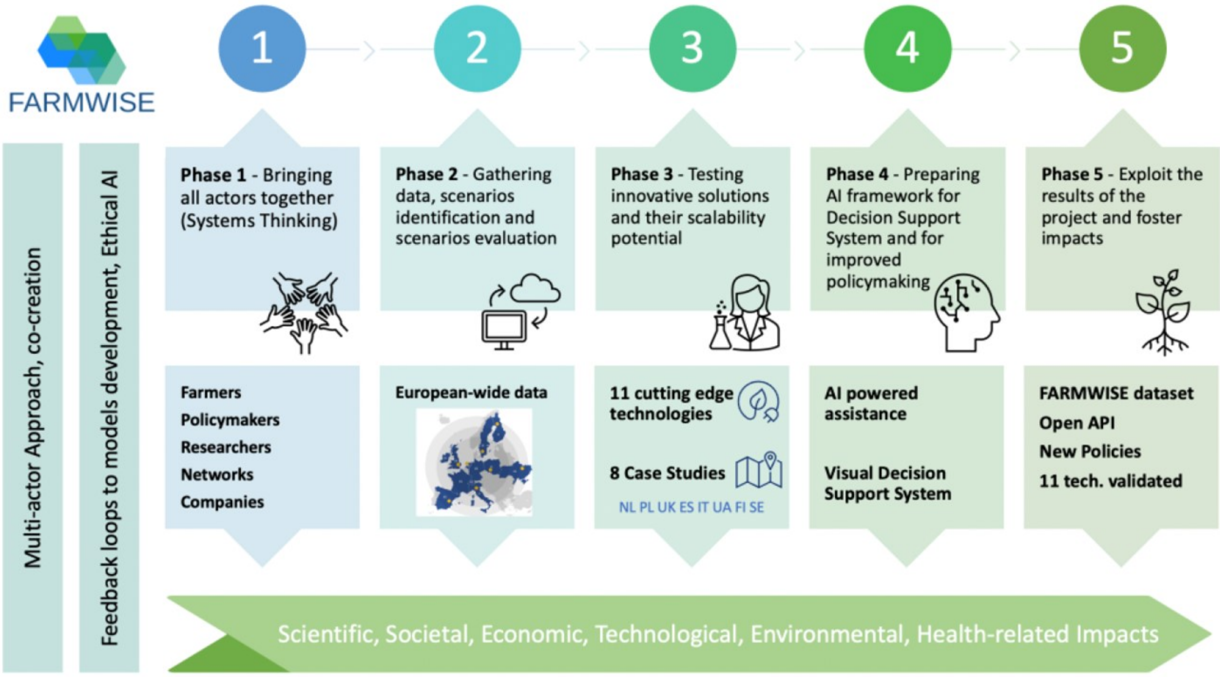

Figure 24 - FARMWISE project phases.

FARMWISE is a Horizon Europe Research & Innovation Action with a consortium of 18 beneficiaries + associated partners across 13+ European countries including Sweden, Italy, France, Spain, Poland, etc. Its core mission is to transform European agriculture by equipping farmers, researchers, and policy-makers with an advanced Decision Support System (DSS) that combines AI, remote sensing, precision agriculture, and systems thinking, with major attention to water quality, water quantity, soil health and nutrient management[108].
Key work package objectives include: co-creating water management strategies via multi-stakeholder engagement; developing predictive / scenario modelling for water availability & water quality under climate change and land-use change (for horizons 2030, 2050, 2100), with interactive maps; verifying innovative agricultural water/nutrient management/drainage/precision irrigation and runoff mitigation techniques; and building an AI-based visual decision support and policy modelling tool that integrates physics-based models and machine learning to offer scenario-based options[109].
From the perspective of sustainable water management in the Alps, FARMWISE is highly relevant. Although its case studies are not all explicitly in high Alpine headwater zones (unless some of its partners/trials do overlap Alpine regions), its methods and tools are directly applicable to the Alpine water challenges: in alpine areas, water scarcity in summer, runoff/erosion during snowmelt or heavy rainfall, nutrient pollution downstream, and variability in water availability are pressing issues. The idea of precision irrigation, drainage control, innovative biosensors, integrating remote sensing, soil health,

[107] https://farmwise-project.eu
[108] https://www.brgm.fr/en/current-project/farmwise-future-agricultural-resource-management-water-innovations-sustainable
[109] https://farmwise-project.eu/index.php/the-project/

and using AI for scenario modelling and decision support all map well onto what alpine agricultural and peri-alpine systems need.
In particular, the project's scenario modelling for water quantity and water quality under various climate and land-use futures could be used in Alpine catchments to forecast seasonal water yield (from snowmelt or rainfall), risk of runoff/floods, and to inform adaptation measures (e.g., which crops, which timings, how to adjust land use to protect water quality). Precision irrigation and drainage systems are especially relevant in valleys where steep slopes cause rapid runoff; sensors and drainage control could mitigate nutrient loss into streams. The AI-based DSS with visuals (interactive maps) is potentially a very powerful instrument for local alpine farmers and local authorities to see trade-offs under different management and climate scenarios and to plan water management accordingly.
FARMWISE's inclusion of physics-based models plus machine learning is important because purely physically parameterized models may struggle in Alpine terrain, where elevation, snow, microclimate, soil types, aspect, solar radiation, vegetation cover, etc., cause strong heterogeneity. ML could help correct for local biases, adapt to data scarcity, or infer patterns in sensor or remote sensing data that physical models don't capture. Also, the plan to build precision irrigation/drainage management for extreme weather events (droughts, runoff after heavy rains) is especially relevant: in Alpine contexts, snowmelt and heavy precipitation events can rapidly produce runoff, and droughts in summer can stress ecosystems and agriculture. The runoff of nutrients/pesticides after heavy rains is also a concern for alpine downstream water bodies (lakes, rivers used for drinking or recreation).
On the limitations/adaptation challenges: Alpine regions often have more complex topography, steeper slopes, greater spatial heterogeneity, and more rapid climatic variation (e.g., snow/ice, freeze-thaw). FARMWISE will need high spatial resolution, frequent data (sensors, remote sensing), good ground truth, and possibly specialized models for snowmelt, cryosphere processes if it's to be applied in high Alpine zones. Also, sensor deployment in remote, high altitude terrain is harder; data transmission may be challenging; maintenance in harsh weather; plus smaller farms / fragmented landscapes may reduce economies of scale. The DSS and AI tools will need to be interpretable and trusted by local stakeholders, adaptable to small-scale, and robust to data gaps.
In summary, FARMWISE is a strong example of a current EU-funded project with explicit use of AI, remote sensing, precision agriculture, and scenario modelling to improve agricultural water management. FARMWISE could serve as a prime case of a project that can be adapted or is already relevant to Alpine settings: its tools could help address alpine water scarcity, runoff, nutrient pollution, and seasonal variability.

7.10 SnowPower[110]

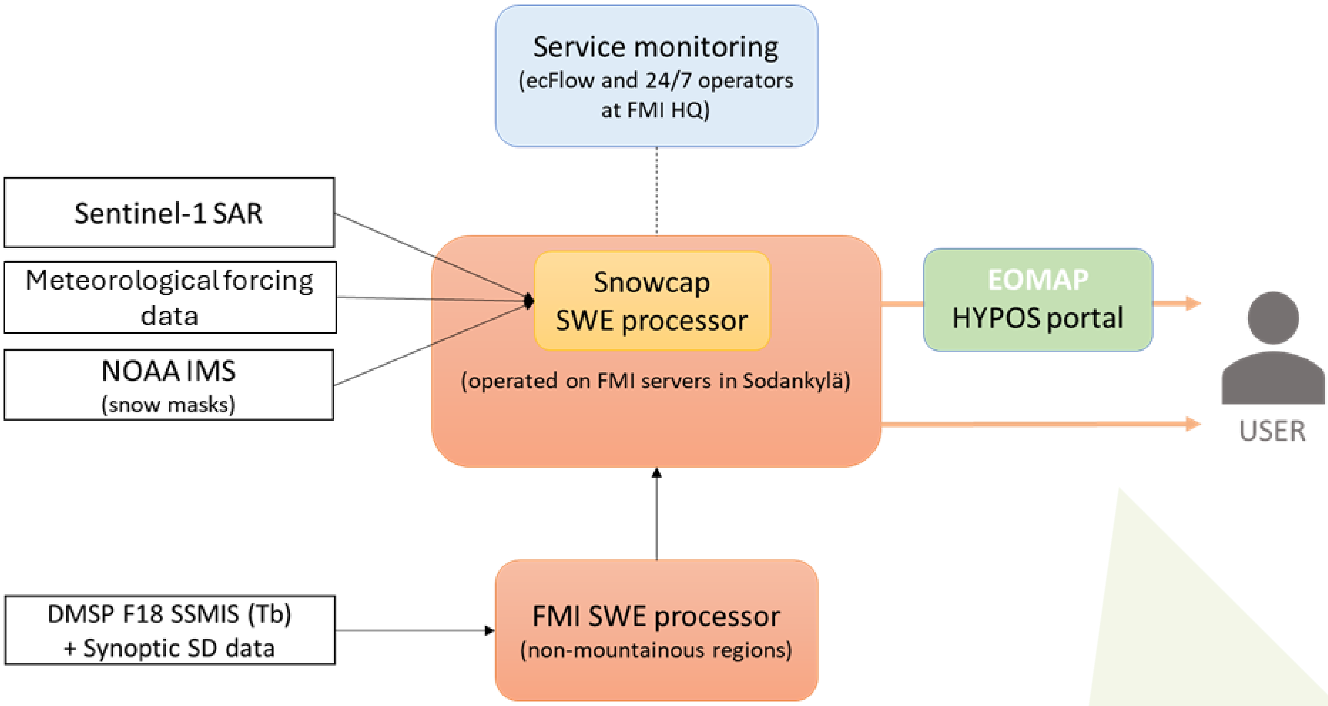

Figure 25 - SnowPower system architecture. Image credits: EOMAP (https://farmwise-project.eu)

SnowPower is an ESA Space Solutions / Business Applications project (feasibility → demonstration phase) led by EOMAP GmbH, with partners including Snowcap (Belgium) and the Finnish Meteorological Institute. Its aim is to provide operational, near-real-time snow information—specifically snow water equivalent (SWE) and snow depth (SD)—over mountainous regions, using satellite data (SAR from Sentinel-1, passive microwave radiometers, meteorological forcing data) plus data assimilation and physics-based snow modelling. It targets hydropower operators (especially those managing clusters in Alpine and Apennine areas), energy traders, water management authorities, meteorological services, insurance, etc. The system delivers daily or near-daily SWE/SD at fairly high spatial resolution (≈ 500 m) via tools like the eoapp Hypos. Historical snow data for the Alps (and more broadly) is also made available. The service was operational for the Alps in winter 2024[111].

In terms of AI/machine learning, several parts are explicit or strongly implied: the project uses data assimilation techniques and a physics-based snow model, combined with remote sensing, to infer spatial and temporal patterns of snow depth and SWE. It does not (from the public sources to date) rely purely on large black-box ML models as primary elements (e.g., deep learning); rather, the approach is hybrid: combining physically-based modelling + satellite observations + assimilation + perhaps statistical post-processing. There is mention in ESA documentation of performance improvements (≈ 20%) and improvements in algorithms/processing pipeline, likely through algorithmic upgrades—but less detail is public about specific ML models in production[112].

[110] https://business.esa.int/projects/snowpower-0
[111] https://business.esa.int/projects/snowpower
[112] https://business.esa.int/news/satellite-data-powers-eomaps-pioneering-snow-modelling-solution

From the perspective of sustainable water management in the Alps, SnowPower is highly relevant. Snowpack in the Alps is a crucial component of the water cycle: it stores water during winter and releases it during melt periods (spring/summer), feeding rivers, reservoirs, hydropower generation, agriculture, drinking water supply, and sustaining ecosystems in dry periods. Accurate knowledge of SWE and snow depth—distributed across catchments—helps downstream water managers, hydropower operators, and municipal supply systems plan reservoir levels, anticipate meltwater inflows, adjust operations to avoid water deficits, manage floods, ensure supply, and adapt under climate change which is altering patterns of snowfall, snowmelt timing, and snow retention. In particular, SnowPower's ability to produce daily (or near real-time) SWE / SD at relatively high spatial resolution over large mountainous areas addresses a long-standing problem: traditional measurements (snow poles, LiDAR flights, in-situ stations) are sparse, expensive, discontinuous, or not feasible in remote Alpine terrain. SnowPower thus fills a gap in spatial coverage and timeliness, offering actionable data.

Potential or ongoing impacts include enabling more efficient hydropower operations (by better anticipating water availability and melt timing), improving risk management (e.g. flood risk when snow-melt is rapid, or low flow during dry spells), supporting water resource allocation (for agriculture, ecosystems, domestic supply) with better predicted inputs, improving drought preparedness, supporting decisions about snow-melt adaptation infrastructure (snow storage, artificial snow in tourism, etc.), and improving trade-offs between downstream water uses. Also, the data could feed into broader hydrological models, climate change adaptation planning, or early warning systems. Because SnowPower is designed to operate at scales that include whole mountain ranges and catchments, it can support cross-basin / transboundary planning, which is very relevant in the Alps.

Limitations/challenges: because the project is (or was) at the demonstration phase, some aspects are still being validated (accuracy, resolution, timeliness). Remote sensing in mountain regions is challenging: effects of terrain (slope, aspect), forest cover, deep snow, snow wetness, cloud cover (for optical / some sensors), need for ground truth validation. Also, physical models + assimilation often require good meteorological forcing data; availability and quality of such data across all Alpine microclimates can be variable. Another limit is that while SnowPower focuses on snow metrics, actual management of water (reservoir operations, downstream water usage, ecological needs) requires integrating those snow metrics with full hydrological modelling (soil moisture, groundwater, evapotranspiration, channel flows) + institutional processes. Also, since much of the project is in the domain of snow → hydropower, translation to tourism (e.g., artificial snow, snow reliability, visitor safety) or other water uses may require adaptation. Finally, there's a potential risk of model biases under climate change (if trained or validated under past snow regimes), which need careful calibration/updating. The AWS / in-situ measurement network for calibration remains important.

Overall, SnowPower represents one of the strongest concrete examples currently of how satellite remote sensing, modelling, data assimilation, and algorithmic processing (though not all deep ML) are being pushed into operational service in the Alpine region for sustainable water management.

SnowPower is an interesting featured case: a near-operational system delivering snow information that is directly actionable for managing water resources, especially hydropower and catchment hydrology. It illustrates how combining physical and remote sensing models, with algorithmic processing, can yield data streams that allow better adaptation under changing snow regimes, improved resource allocation, and increased resilience of Alpine water systems.

7.11 INTERTWIN[113]

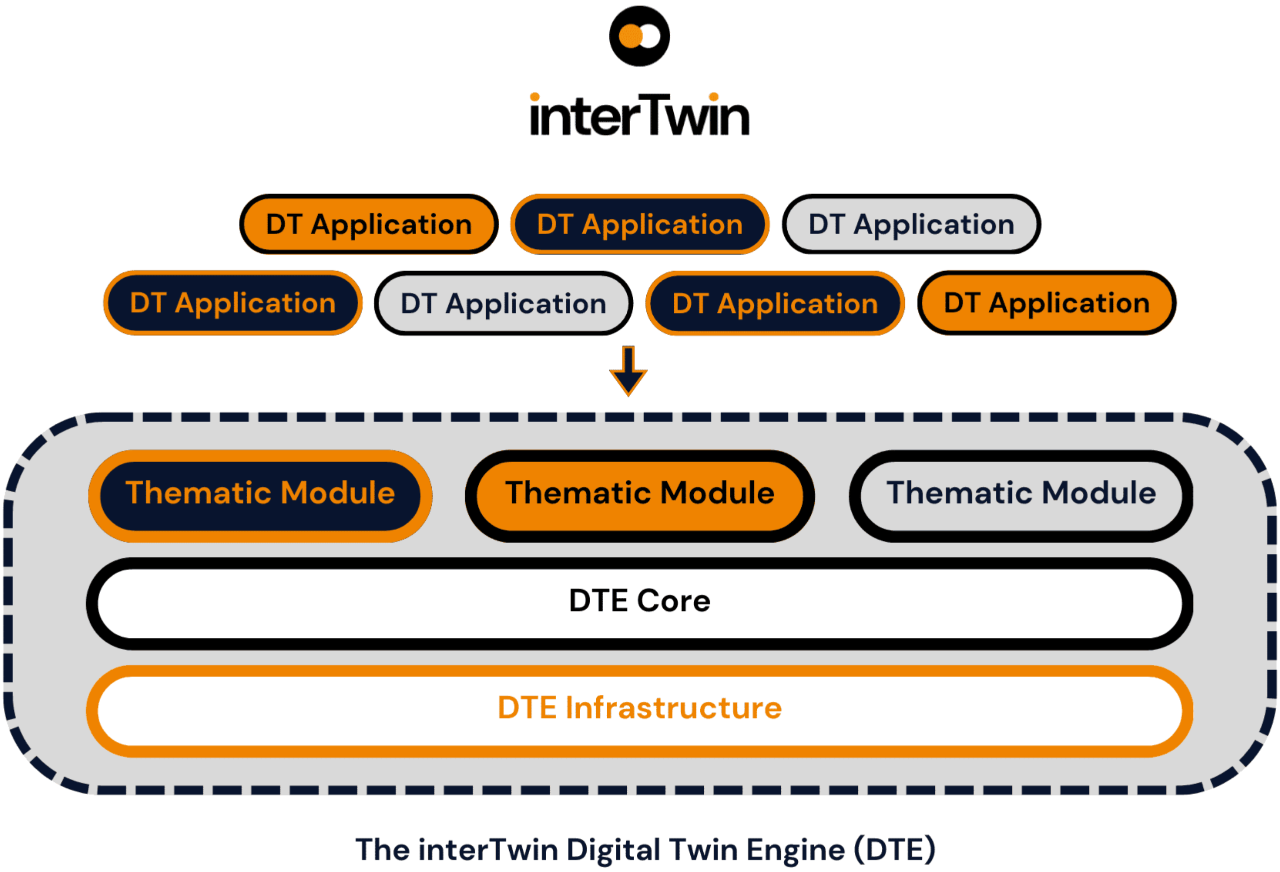

Figure 26 - InterTwin digital twin engine concept.

InterTwin ("An Interdisciplinary Digital Twin Engine for Science") is an EU Horizon Europe-funded project coordinated by the EGI Foundation[114]. The project aims to design and build a prototype of an open-source platform ("Digital Twin Engine" or DTE) that provides generic and application-specific Digital Twin (DT) components across multiple scientific disciplines[115], covering environmental monitoring, climate research, hydrology, astronomy, physics, etc. interTwin's architecture is based on a co-designed blueprint architecture, open standards, interoperability among DTs, workflow composition, real-time data management and processing, data quality and uncertainty tracing, data fusion and analytics[116]. It intends to validate its infrastructure with several diverse use cases, including environmental monitoring and, importantly, a use case specifically for drought early warning in the Alps[117] [118].

113 https://www.intertwin.eu
114 https://cordis.europa.eu/project/id/101058386
115 https://www.intertwin.eu/about-intertwin
116 https://www.egi.eu/project/intertwin
117 https://www.intertwin.eu/intertwin-use-case-a-digital-twin-for-drought-early-warning-in-the-alps
118 https://www.eurac.edu/en/institutes-centers/institute-for-earth-observation/projects/intertwin

One of the interTwin use cases is “Digital Twin for Drought Early Warning in the Alps”. In this use case the project combines process-based hydrological models (specifically the “Wflow_sbm” model) with machine learning surrogate models. EO (Earth Observation) data is used to improve representation of surface processes and snow accumulation/melt, soil moisture, and streamflow, and ML is used to emulate or speed up parts of the process-based model (i.e., surrogate modeling) to enable more efficient calibration and parameter estimation, as well as forecasting driven by reanalysis and seasonal forecast data. This is being tested especially in catchments such as the Adige basin in Italy, and plans exist to extend to other Alpine catchments. The interface is via openEO[119], allowing researchers (and potentially public authorities) to test the performance of the drought early warning system, forecast hydrological conditions, and identify areas likely to be impacted by drought.
From the point of view of Sustainable Water Management in the Alps, interTwin offers several strong contributions. First, the Drought Early Warning use case directly addresses the problem of water availability under climate change, which is a core concern in the Alps (reduced snowpacks, earlier melt, longer dry periods). The hybrid modeling (physical + ML surrogate) improves model responsiveness and possibly enables more frequent or real-time assessments, which are critical in mountainous terrain. Second, the framework of the Digital Twin Engine and the open, interoperable components (data ingestion, simulation, uncertainty tracing) provide a platform into which Alpine-specific water management functions (streamflow forecasting, runoff predictions, water supply risk alerts, reservoir operations, adaptation planning) can be incorporated. Third, by using EO data and ML, interTwin helps address issues of spatial heterogeneity (varying elevation, snow cover, vegetation, aspect) and temporal variability (seasonality, interannual climate variation) that are characteristic of Alpine hydrology. Being part of interTwin also helps build capacity (data, computational, modeling) for stakeholders who may later use these tools operationally.
There are also gaps and limitations. The drought early warning DT is still in prototype phase—not fully operational. Some components (e.g. flow forecasting or water allocation decision support) are not yet documented as deployed. The surrogate model emulation, while promising, depends on the availability of sufficient observations and ground-truth data across Alpine catchments; uncertainties must be quantified, especially given the complexity of mountain hydrology (snowmelt, glacier melt, subsurface flows). The infrastructure must cope with high spatial and temporal resolution data, which may be limited in some remote alpine zones. Also, translating forecasts into decisions (for farmers, tourism, water utilities) requires coupling of technical outputs with governance/institutional frameworks, which may lag.
In summary, interTwin is one of the most directly relevant recent EU projects for AI-enabled, predictive water management in the Alps. Its digital twin approach, use case for drought early warning, mixture of physics-based and ML/surrogate modeling, and EO integration make it a strong candidate for incorporation into sustainable water management portfolios in Alpine regions. interTwin is a great example of how AI (specifically hybrid hydrological models + DT infrastructure) is being developed to address water availability risk, offering both technological proof-of-concept and institutional architecture upon which operational water management (reservoirs, allocation, tourism, agriculture) in the Alps can be built.

[119] https://openeo.org

7.12 Digital Twin of Alps[120]

Figure 27 - Digital twin of alps concept

Digital Twin of Alps (DTA) is an ESA Regional Initiative project, active about September 2022 to August 2023, led by a consortium including Sinergise Solution GmbH (Austria), CNR-IRPI (Italy), Waterjade S.r.l., Terranum Sàrl (Switzerland), EOST/Université de Strasbourg (France), and others. The goal is to build a demonstrator platform for Decision Support that integrates Earth Observation (EO) data, numerical modelling (both physically-based and AI-driven) under a "Digital Twin" paradigm, focused on the Alpine region, in particular addressing Water Resource Management and Disaster Risk Management[121].
In the domain of water resources, DTA's demonstrator provides a suite of hydrology-related services: it produces datasets for snow cover, snow depth, Snow Water Equivalent (SWE), river discharge/ water heights, soil moisture/drought monitoring, and evapotranspiration. These are made available on a demonstrator platform, with spatial resolution typically about 250×250 m, with temporal resolutions ranging from daily to multi-day (e.g., three-day snow melt forecasts)[122].
On processing chains: the snow processing chain combines meteorological input data (ERA5, WRF where needed) + satellite Earth Observation data (optical indices, perhaps SAR or multi-source) + a physical model (e.g., the proposed GEOtop) and assimilation of satellite-derived snow-covered area (SCA) or snow depth when possible. Machine learning / algorithmic processing is used in satellite products (for example, the optical-satellite-based indices like NDSI, NDWI, etc.) and in gap-filling of satellite data; some of the SCA estimation involves machine learning to combine optical vegetation/water indices and geometry.

[120] https://digitaltwinalps.com
[121] https://eo4society.esa.int/projects/dta/
[122] https://eo4society.esa.int/2024/11/20/snow-cover-products-from-digital-twin-alps-for-alpine-water-management

For river discharge/flow /water height, DTA uses models that take in snowmelt, precipitation, evapotranspiration, catchment geometry, etc., via semi-distributed hydrological models (e.g., NewAge model in some basins), to derive discharge time series in selected catchments (e.g., Sarca, Entremont) and sections. DTA also provides water discharge/hydrographs, soil moisture maps, and standardized anomalies for drought (across several Alpine sub-regions).
In short, DTA is already implementing a hybrid physical/EO/algorithmic decision-support system with near operational capability, focused on supplying critical hydro-meteorological variables relevant to water resource management: snow (accumulation, melt, water stored), soil moisture/evapotranspiration, river flows, drought anomaly monitoring. These are essential inputs for managing water availability (for hydropower, agricultural use, drinking water, ecosystems), especially under climate change in Alpine environments.
From the perspective of AI for Sustainable Water Management in the Alps, DTA offers several strong contributions and immediate potentials:

- Data availability & resolution: The production of snow water equivalent, depth, snow cover, soil moisture at ~250 m spatial res, daily or quasi-daily frequency, gives good input for modelling and predicting water availability, especially from snowmelt, which is key in Alpine water cycles.
- Hybrid modelling and ML: The use of physical models plus machine learning for gap filling, error correction, possibly surrogate modelling, suggests possibilities for more advanced AI work such as forecasting, anomaly detection, bias correction, or even predictive operational tools.
- Forecasting snowmelt/snow depletion: The 3-day forecast of snow melt map products already in place can be very useful for downstream water users (reservoir managers, hydropower, municipalities) to plan releases, anticipate runoff volumes, and avoid or mitigate drought risk.
- Drought anomaly maps (standardized anomalies) combining soil moisture, SWE, precipitation etc., support early warning or decision support for water managers to detect emerging water scarcity.

Gaps or areas where development or extension could increase water sustainability impact:

- The DTA demonstrator does not yet cover everything relevant: e.g., groundwater, reservoir levels, anthropogenic withdrawals, full supply-demand balancing, or detailed water quality aspects.
- It is (still) a demonstrator: not clear how operational the decision support is for local authorities, whether the models are embedded in governance or operational water management routines.
- ML/AI appears more in support/gap-filling/algorithmic combination rather than large-scale predictive learning based on long historical data or for risk forecasts long ahead. More advanced ML/AI could potentially be added: e.g., forecasting seasonal water yield (not just snow melt), optimization of water allocation under competing uses, anomaly detection in real-time across sensors, integrating demand side data, etc.

In sum, the Digital Twin of Alps is among the most mature/operational/hybrid examples: combining remote sensing, physical modelling, EO assimilation, and some ML, focused on the water cycle variables most critical in the Alps (snow, melt, flow, soil moisture). It represents a near-state-of-the-art decision-support system for water availability under climate variability and change, and a model for what Digital Twin approaches can look like. It helps bridge data, model, forecasting, and user access. It is highly relevant as a case where AI-adjacent methods are already in use, and where adding further AI layers could push towards operational, predictive, adaptive and optimized sustainable water management in Alpine contexts.

7.13 Use Cases and Potential Benefits

AI is revolutionizing sustainable water management in the Alps by offering innovative solutions to address the region's unique hydrological challenges. One notable application is the development of hydrological Digital Twins, which integrate Earth Observation data with machine learning models to simulate and predict water availability. For instance, the InterTwin project combines process-based hydrological models with AI to create a digital twin for the Alps, enabling early warning systems for droughts at the river basin scale. This approach allows for real-time monitoring and forecasting, providing stakeholders with actionable insights to manage water resources more effectively.
Another significant use case is the integration of AI in precision agriculture. The FARMWISE project exemplifies this by employing AI-driven decision support systems that utilize remote sensing and machine learning to optimize irrigation and nutrient management. By analyzing soil moisture levels, weather forecasts, and crop characteristics, AI can recommend precise irrigation schedules, thereby reducing water waste and enhancing crop yields. This is particularly beneficial in the Alpine region, where agriculture is often practiced in challenging terrains with variable water availability.
Furthermore, AI is instrumental in enhancing flood prediction and management. Machine learning algorithms can analyze historical hydrological data, weather patterns, and topographical information to predict flood events with greater accuracy. This predictive capability enables authorities to implement timely interventions, such as controlled releases from reservoirs or issuing early warnings to communities, thereby mitigating the impacts of floods on both human populations and infrastructure.
The integration of AI in water management also extends to the energy sector. The SnowPower project utilizes machine learning to assess snow water equivalent and predict hydropower energy generation up to six months in advance. By combining climate data with machine learning models, this initiative provides valuable forecasts that assist in optimizing energy production and ensuring a reliable power supply in the Alpine region.
These AI applications offer several benefits, including improved water use efficiency, enhanced predictive capabilities, and better-informed decision-making. By leveraging AI, stakeholders can manage water resources more sustainably, ensuring their availability for future generations while maintaining ecological balance.

7.14 Collaborations and Best Practices at EU and EUSALP Levels

Collaborations across the EU and within the Alpine macro-region have built a dense ecosystem of projects, clusters and operational concepts that accelerate the uptake of digital tools — including AI where explicitly stated — for sustainable water management in the Alps. At the EU level, the ICT4Water cluster functions as a central hub for research and innovation projects applying ICT to the water sector; it aggregates dozens of Horizon projects, promotes common approaches (e.g., smart water grids, IoT interoperability), and disseminates results and standards relevant to digital water management. This cluster is intended to catalyse cross-project learning on topics such as data platforms, sensors, and decision-support systems that are directly applicable to Alpine water challenges.
Complementing ICT4Water's technology focus, the Water4All Partnership provides a strategic, research-to-innovation funding framework that targets systemic transformations in freshwater research and innovation across Europe. Water4All's remit—to enable long-term water security by matching problem owners and solution providers—supports demonstration and scaling of tools (including Water-Oriented Living Labs) that bridge research outputs and local implementation. The partnership's public materials

and its Atlas of Water-Oriented Living Labs (WOLL) document the concept as an operational best practice for testing, validating and upscaling water innovations in real territorial contexts. These Living Labs emphasize multi-stakeholder co-creation, iterative testing, and market uptake—practices that are essential for transferring EO/AI-driven services (e.g., Digital Twin or precision-agriculture tools) into Alpine municipalities and catchments.

At the Alpine macro-region scale, EUSALP Action Group 6 (AG6) explicitly addresses preservation and valorization of natural resources, explicitly including water, and its 2023–2025 workplan prioritizes cross-border governance, integrated resource management, and the uptake of innovation to strengthen resilience. AG6 provides the regional policy and coordination layer needed to align EU-level R&I outputs (ICT4Water, Water4All pilots) with Alpine priorities—supporting standardization, transnational pilot replication and institutional uptake. AG6's work plan also highlights the need to connect research/innovation ecosystems across the Alps, which is where Living Labs, digital twins, and cluster outputs converge into deployable solutions.

Concrete project exemplars illustrate how this collaboration mechanisms translate to practice. The Digital Twin Alps demonstrator (an EO4ALPS/ESA regional initiative) packages satellite products, hydrological models and operational services (snow/SWE, soil moisture, river discharge, drought indicators) into an Alpine-scale platform for water resource and disaster risk management; it explicitly leverages EO and a mix of physically-based and machine-learning methods for some products and is built to serve hydropower operators, municipalities and water managers. This kind of demonstrator is precisely the type that ICT4Water and Water4All aim to shepherd toward broader uptake via Living Labs and EUSALP coordination.

Best practices emerging from these initiatives converge on four actionable patterns:

1. Multi-scale governance—link EU funding and standards (ICT4Water, Water4All) to regional adoption paths (EUSALP AG6);
2. Living lab methodologies—co-design, field demonstration, and user validation ensure tools meet local Alpine conditions and regulatory needs (Water-Oriented Living Labs Atlas).
3. Data interoperability & standards—promoted by ICT4Water outputs and EU digitalization roadmaps (Smart Water Grid, IoT/OGC standards) to make EO, sensor, and administrative data reusable across catchments; and
4. Iterative scaling—moving from demonstrators (Digital Twin Alps, FARMWISE, EO4Alps services) through WOLL pilots toward operational services adopted by utilities and authorities.

In short, the EU ecosystem (ICT4Water, Water4All) provides funding, standards, and cross-project learning; EUSALP AG6 offers the territorial policy and replication framework for the Alps; Water-Oriented Living Labs supply the co-creation and validation methodology; and demonstrators such as Digital Twin Alps show how EO, models, and (where used) AI can be packaged into operational services. Together, these elements form a pragmatic pathway for moving EO/AI-enabled water innovation from prototypes to sustained Alpine practice.

7.15 Status of AI Initiative Implementation

AI for water management in the Alpine region is moving from a patchwork of research prototypes and demonstrators toward more integrated, multi-stakeholder deployments, but many initiatives remain at pilot or demonstrator scale rather than full operational rollout. Demonstrators such as the Digital Twin Alps provide operational EO-driven products (snow/SWE, soil moisture, river discharge, drought indicators) that already inform stakeholders; sector projects (FARMWISE, DARROW, EO4Alps–Snow and others) explicitly embed AI or machine-learning components for tasks from precision irrigation to wastewater optimization; and EU frameworks (ICT4Water cluster, Water4All, and EUSALP Action Group 6) create coordination, Living Lab methodologies and standards roadmaps that aim to accelerate uptake. At the same time, several cross-cutting bottlenecks are visible in public analyses: data availability and interoperability, skills and governance gaps, limited long-term financing for operational scaling, and uneven transposition of standards—all factors that keep many AI initiatives in pilot mode.

Governance

The governance of AI in water hinges on multi-level coordination (EU → macro-region → national → local utilities) and clear institutional responsibilities for data, liability, and decision-making. EU-level initiatives (ICT4Water cluster, Water4All) create strategic roadmaps, funding pipelines and Living Lab networks to bridge R&I and operational practice; EUSALP Action Group 6 offers the Alpine territorial layer that can translate EU outputs into cross-border pilot replication and policy alignment. However, governance analyses point to persistent institutional barriers: many government AI deployments remain pilots due to risk aversion, unclear procurement and accountability, lack of shared data governance, and limited measurement of ROI for public actors. The OECD's review of "governing with AI" highlights such system-wide barriers—skills gaps, difficulty accessing and sharing high-quality data, limited actionable guidance, and risk aversion—that are highly relevant to water agencies and Alpine municipalities. Likewise, academic governance studies of AI in the European water sector document that collaborative governance strategies (who does what, and through which legal and network forms) are still evolving, and regional leaders must negotiate trade-offs between centralized data services and local sovereignty over water decisions.

Practical governance implications for the Alps: mechanisms are needed to designate custodians for shared digital assets (e.g., DTA products), to define liability when AI-based recommendations feed operational actions (reservoir releases, irrigation curtailment), and to create procurement paths for public utilities to buy/subscribe to AI services. The ICT4Water cluster and the EU rolling plan on water digitalization offer standards and interoperability roadmaps that can reduce governance friction, but adoption requires institutional capacity-building (legal, procurement, IT) at the municipal and basin levels. EUSALP AG6 can act as the regional convenor to harmonize cross-border data sharing agreements and to embed Digital Twin / Living Lab outcomes into transnational water strategies.

Sustainability (environmental + economic + technical)

Sustainability of AI initiatives in Alpine water management must be assessed across three linked axes:

7) environmental impact (do AI systems lead to better water-ecosystem outcomes?)
8) economic viability (can solutions be sustained financially beyond project grants?)
9) and technical longevity (are systems maintainable and interoperable?).

Evidence from current EU projects shows clear environmental promise: Digital Twin Alps and EO4Alps-Snow deliver snow/SWE and drought anomaly indicators that materially improve the spatio-temporal understanding of water storage and risk, enabling more targeted reservoir and catchment management that can reduce ecological stress. FARMWISE's precision-agriculture focus and DARROW's wastewater AI demonstrate pathways to reduce water use, nutrient runoff, and energy emissions—outcomes aligned with Alpine sustainability goals.

Economic sustainability, however, is more fragile. Many projects are funded as time-limited R&I grants (Horizon Europe, ESA, Interreg). The transition to operational services requires business models (subscription, service contracts with utilities, public procurement) and recurrent funding for data hosting, model retraining, and helpdesk/support. The Water4All Atlas and Water-Oriented Living Labs (WOLLs) promote market uptake pathways and co-funding models by linking pilots to utilities and industry partners, but scaling still requires proof of sustained cost-benefit and often regulatory incentives (e.g., water agencies adopting KPIs linked to AI outputs).

Technical sustainability depends on standards and data ecosystems. The ICT4Water roadmap and recent assessments on water data ecosystems stress the need for interoperability, open APIs, and common metadata to ensure longevity; without these, AI models risk becoming siloed and brittle as data sources change. Research into requirements for water data ecosystems underlines the importance of reproducible pipelines, documentation, and community governance so that models can be maintained and updated as climates and infrastructures change. In sum, environmental benefits are demonstrable in pilots; economic and technical sustainability remain conditional on governance reforms, standardization, and viable business models.

Adoption challenges (operational, social, technical)

Adoption in Alpine contexts faces multiple, interdependent challenges:

- Operational: Alpine water systems are managed by many small utilities and municipalities with limited IT budgets and staff. Implementing AI services requires integration into existing SCADA, decision workflows, and legal compliance processes. Demonstrators (Digital Twin Alps, EO4Alps-Snow) show value, but integration into operational SOPs (standard operating procedures) is slow when staff resources for deployment and maintenance are lacking. Utilities need packaged, low-friction services and training, not raw models.
- Social & institutional trust: AI outputs may be probabilistic and require interpretation; operators and citizens may distrust “black-box” recommendations. This heightens the need for explainable AI, transparent validation, and participatory Living Labs where users co-design thresholds and alerting rules. Water4All’s WOLL guidance and DARROW’s emphasis on explainability respond directly to this challenge by embedding user validation and explainable models in pilot design.
- Data & technical: High-quality labelled data (long time series, local sensor networks) are essential to train and validate AI—yet many Alpine catchments lack dense in-situ networks and face cloud cover / radar shadow issues in EO. Fusion approaches (EO + reanalysis + local sensor networks) reduce these gaps, but they increase complexity and processing needs. Standards from ICT4Water and EU rolling plans can ease interoperability, but the operational burden of data pipelines, model retraining, latency reduction for near-real-time alerts, and cybersecurity remain critical technical hurdles.
- Regulatory & ethical: The EU is accelerating an AI policy and risk-management agenda (see EU reports on AI ambition and OECD analyses). Water AI deployments must comply with data protection, algorithmic accountability, and sectoral regulation; these evolving rules create uncertainty for vendors and utilities and can slow procurement. Clear regulatory guidance (classification of critical water AI as high-risk systems, validation requirements) will be essential to scale adoption responsibly.

7.16 Concluding synthesis (what this means for the Alps)

AI initiatives show concrete value for Alpine water management—better snow/SWE mapping, drought monitoring, precision irrigation, and wastewater optimization are already demonstrable. Yet to move from pilots to systemic uptake across the Alps requires aligning governance (data custodianship, liability, procurement), securing sustainable funding models and standards for technical interoperability, and tackling social and operational adoption barriers through Living Labs and capacity building. The existing EU ecosystem—ICT4Water, Water4All, EUSALP AG6, Water-Oriented Living Labs and demonstrators like Digital Twin Alps—provides the institutional scaffolding; the near-term priority is to convert demonstrator success into repeatable service models and cross-border governance agreements that sustain AI-enabled water resilience for Alpine communities.

8 AI in Natural Hazard Risk Management and Climate Change Monitoring in the Alps

8.1 DiMark[123]

Figure 28 - DiMark project overview.

DiMark ("Transnational Network for Linking Digital Earth Observation to Freshwater Markers for Better Understanding of Water-connected Climate Change Adaptation and Risk Prevention in Alpine Region") is an Alpine Space-funded project. It is grouped under Priority "Climate resilient and green Alpine region," specifically addressing objective SO 1.1: climate change adaptation and disaster risk prevention, resilience, with ecosystem-based approaches.

The driving problem is that Alpine lakes are increasingly under stress from anthropogenic pressures (notably tourism, agricultural runoff, shoreline development), climate warming, which exacerbate eutrophication and lead to frequent cyanobacterial and algal blooms, oxygen depletion, biodiversity loss, and health risks through cyanotoxins. These effects represent both environmental risk and hazard (health hazard, ecological collapse) and are sensitive to warming, changes in precipitation/runoff, lake thermal stratification, etc[124].

DiMark's core objective is to improve freshwater management via novel, ecosystem-based approaches, specifically by providing monitoring and early warning system solutions that link traditional freshwater markers (turbidity, pigments, etc.), environmental DNA (eDNA), in-situ sensor / sampled data, and satellite/Earth Observation (EO) data. The project intends to develop two main ready-to-use tools: (1) an online visualization tool with maps of Alpine lakes to inspect/compare water state based on key freshwater markers; (2) a cyano-risk prevention model for lakes, that minimizes health risk and supports

[123] https://www.alpine-space.eu/project/dimark/

[124] https://cri.fmach.it/en/Research-activity/Projects/DiMark-Transnational-Network-for-Linking-Digital-Earth-Observation-to-Freshwater-Markers-for-Better-Understanding-of-Water-connected-Climate-Change-Adaptation-and-Risk-Prevention-in-Alpine-Region

sustainable lake management. These tools are being developed via multi-stakeholder co-development (academia, policy, SMEs, NGOs, citizens)[125].
DiMark also establishes a transnational network of lake managers, decision makers, practitioners, academia, with pilot actions on selected lakes: 6 key pilot lakes (including cross-border ones), and testing of parts of the tools in a larger set (50-100) of lakes to account for Alpine lakes' diversity. Key pilot lakes named include Lake Bled (Slovenia), Lake Mondsee (Austria), Lake Garda (Italy), Upper Lake Constance (Germany/Switzerland), Lake Geneva (Switzerland/France), Greifensee (Switzerland).
The project's outputs include an Alpine meta-dataset combining in-situ (traditional sampling), eDNA, and satellite remote sensing observations for freshwater markers, harmonized across partner lakes. Also, in development are the visualization (mapping) tool, the cyano-risk model, and a transnational strategy for using satellite-based tools for freshwater risk/water state monitoring. It contributes to EUSALP action groups AG1, AG5, AG6, AG8 (Innovation, Connectivity, Natural Resources, Risk Governance).
Although the project does not explicitly reference artificial intelligence, its structure and data framework are ideally suited for the integration of AI-based environmental analytics. The combination of high-frequency in-situ observations and EO-derived indicators enables the development of machine learning models capable of predicting cyanobacterial bloom dynamics, estimating water quality parameters, or detecting early anomalies in lake ecosystems. Deep learning could be applied to multispectral satellite imagery to identify bloom patterns and classify optical water types, while time-series models could learn spatio-temporal dependencies between meteorological drivers and ecological responses. AI could further enhance the cyano-risk model by integrating nonlinear interactions among nutrient inputs, temperature, and stratification dynamics, improving its predictive capacity under changing climate conditions. Moreover, AI-assisted data fusion could fill observation gaps caused by cloud cover or sensor failure, increasing the robustness of real-time monitoring systems.
Through this multi-source integration, DiMark creates the digital and methodological infrastructure upon which next-generation, AI-enhanced water governance systems can evolve. Its participatory framework ensures that such systems will remain interpretable and aligned with the operational needs of Alpine stakeholders. In the broader context of natural hazard and climate risk management, DiMark represents a pioneering step toward data-driven resilience, demonstrating how transnational cooperation, Earth observation, and intelligent modelling can potentially converge to safeguard freshwater ecosystems under accelerating climatic change.

8.2 GreenRisk4ALPs[126]

GreenRisk4ALPs was an Alpine Space project (2018-2021) that sought to embed ecosystem-based methods, particularly the role of protective forests, into the routine governance and risk management of natural hazards in the Alps. The project brought together 12 partners from five Alpine countries, led by the Federal Research and Training Centre for Forests, Natural Hazards and Landscape in Austria. Its mission was to move beyond purely technical measures (e.g., engineered protection structures) and create decision support tools, strategies, and governance frameworks that integrate mountain forests' capacity to mitigate risks like rockfalls, snow avalanches, shallow landslides, torrents, and debris flows. GreenRisk4ALPs addressed the challenges posed by climate change—Heightened precipitation

[125] https://www.limnologie.uni-konstanz.de/forschung-research/dimark/
[126] https://www.alpine-space.eu/project/greenrisk4alps/

extremes, more frequent thaw-freeze cycles, and altered snow cover—that exacerbate such gravitational hazards and stress protective forest systems[127].

The project carried out its work in six Pilot Action Regions (PARs) across the Alps (including Brenner/Brennero, Courmayeur, Kranjska Gora, Parc de la Barbonnies, Oberammergau, etc.), enabling territorially specific evaluations. It developed several new tools. Among these were Flow-Py, an open-source simulation tool that models runout and stopping zones for gravitational mass flows (avalanches, rockfalls, etc.) based on terrain, starting zones, and a set of parameters. The Forest Assessment Tool (FAT), an interactive web-platform, allowed users to upload local data and compare protective forest impacts vs. alternative mitigation options (technical, forest-based, avoidance), including cost/benefit assessments. Additional outputs included a protective forest definition matrix to standardize terminology across countries, risk management workbooks, guidelines, strategies for actor-engagement, and roadmaps for integrating ecosystem-based risk mitigation into governance and policy processes[128].

Regarding AI or algorithmic modelling, GreenRisk4ALPs does not appear to explicitly deploy machine learning or statistical learning models in its published deliverables; rather, it uses process-based modelling, open-source simulation tools (Flow-Py), and economic/risk assessment modules. Flow-Py, for instance, is a deterministic or parametrized routing/stopping model rather than a trained ML system. Nonetheless, the structures established by GreenRisk4ALPs present good opportunities for the incorporation of AI to enhance natural hazard risk management and climate change monitoring in alpine landscapes. The terrain, topographic, forest cover, historical hazard event data, cost/benefit analyses, plus geospatial datasets (DEM, land cover, starting zones) used in Flow-Py and FAT are all rich input sources for machine learning models. For example, supervised ML could be trained on historical event outcomes to refine or calibrate runout-angle or intensity parameters in Flow-Py, or to predict probability of occurrence given various forest cover metrics, precipitation inputs, snowpack or freeze events. AI could be used for anomaly or change detection (forest degradation, wildfire, bark beetle damage or insect outbreaks) that reduce protective function. It could also support optimizing forest management regimes under current and future projected climate scenarios, balancing multiple services (protection, biodiversity, timber, recreation). Moreover, combining AI with remote sensing could yield near-real-time forest state monitoring, detecting losses in protective forest cover, and feeding into risk models for changed hazard potential.

GreenRisk4ALPs made substantial contributions to risk governance: it raised awareness among local and regional actors, developed standardized tools and definition matrices, created best practice examples, and facilitated communication among diverse institutions. In climate change monitoring, by projecting scenarios of forest cover changes, mapping exposure hotspots for hazards, and integrating ecosystem-based measures into risk assessments, it enhances the adaptive capacity of Alpine communities.

In sum, GreenRisk4ALPs is a completed EU-funded project that while not heavily AI-driven, has laid down essential methodological, data and geospatial infrastructure, decision tools, and governance frameworks. As such, it serves as a key case study: one showing how integrating ecosystem-based solutions with hazard modelling and actor engagement can improve resilience.

[127] https://www.eurac.edu/it/institutes-centers/center-for-climate-change-and-transformation/projects/greenrisk4alps
[128] https://www.bfw.gv.at/en/ecosystem-based-approaches-for-the-support-of-risk-management-activities

8.3 ADAPTNOW[129]

ADAPTNOW is an ongoing EU-funded project under the Interreg Alpine Space programme that aims to strengthen the adaptation and risk management capacities of the Alpine territories most deeply exposed to climate change impacts — termed Highly Affected and Exposed Territories (HAET). Its core ambition is to make climate adaptation planning more integrated, dynamic, participatory, and responsive, in sectors vulnerable to natural hazards made worse (or more unpredictable) by climate change, such as heatwaves, heavy precipitation/flooding, gravitational hazards (landslides), and their consequences on urban infrastructure, forestry, tourism, and public health[130]. Local and regional public authorities, research centers, sectoral agencies, and stakeholders across five Alpine countries (France, Italy, Austria, Germany, Slovenia) collaborate in the project[131] [132] [133].
The project selects more than seven pilot HAETs to test and evaluate adaptation and risk mitigation tools and practices. Among these, one prominent example is the Comunità Comprensoriale Val Pusteria/Bezirk Pustertal in South Tyrol, which comprises 26 municipalities over ~2700 km² at elevations between about 750-1,180 meters, combining challenges of gravitational hazard, intense rainfall, and tourism pressures. Within this pilot area, the sectors of forestry and tourism are focal. Project activities include design, implementation and assessment of pilot actions; tailoring existing climate support services to local needs; stakeholder engagement via workshops; raising awareness; knowledge exchange and policy-recommendations; and replication of good practices in at least six additional HAETs outside the core consortium[134].
In terms of outputs, ADAPTNOW is producing a guidebook on how to introduce advanced climate adaptation and risk mitigation planning at a local level, a service package for agencies to scale local climate and risk-mitigation actions, a replication guide, and policy recommendations. It is also in the process of developing "Climate Services" adapted to the varying hazard profiles of HAETs, supporting local authorities in decision-making[135].
As for AI or algorithmic/digital modelling: the current project documentation does not explicitly describe the use of machine learning, artificial neural networks, predictive AI models, or automated early-warning systems. The instruments being evaluated include tools and practices of adaptation, risk mitigation, climate services, stakeholder planning, and awareness. They are more qualitative / planning/governance tools rather than high-throughput algorithmic or real-time hazard modelling[136].
Nonetheless, ADAPTNOW's structure, pilot sites, and accumulated data provide a solid foundation for AI-enhanced approaches in natural hazard risk management and climate monitoring in the Alps. The frequent hazards addressed (heatwaves, extreme precipitation, floods, landslides) are all phenomena that benefit from predictive modelling. For example, AI systems (such as statistical/machine learning or deep learning) could analyse historical weather, terrain, vegetation, soil moisture, and infrastructural

[129] https://www.alpine-space.eu/project/adaptnow/
[130] https://www.selnica.si/projekti/adaptnow/
[131] https://www.alpine-region.eu/action-groups-projects/adaptnow
[132] https://www.energap.si/projekti/adaptnow
[133] https://www.alpine-space.eu/wp-content/uploads/2024/04/ADAPTNOW_Newsletter-3.pdf
[134] https://www.alpine-space.eu/wp-content/uploads/2023/10/ADAPTNOW_Newsletter-2.pdf
[135] https://www.auvergnerhonealpes-ee.fr/en/news/detail/adaptnow-local-adaptation-to-climate-change-a-new-guide-for-municipalities
[136] https://www.eurac.edu/it/institutes-centers/center-for-climate-change-and-transformation/projects/adaptnow

data to forecast flash floods, or model landslide susceptibility, taking into account rainfall intensity and antecedent moisture. Real-time or near-real-time sensor networks combined with Earth Observation (EO) data could feed predictive early warning systems for floods or landslides. Anomaly detection algorithms could help identify when municipal infrastructure or forest cover is under stress beyond normal variation (e.g., forest degradation that increases susceptibility). Climate services being developed could incorporate AI-driven dashboards to support scenario modelling: e.g., how increased heavy rainfall will stress drainage in urban infrastructure, or forecasting heatwave peaks to support public health responses in tourist zones.

In conclusion, ADAPTNOW is a project that strengthens governance, planning practices, stakeholder readiness, and climate-services infrastructure in exposed Alpine territories. While it does not (at least in publicly available materials) embed AI modelling explicitly, it creates many of the preconditions necessary for AI-infused natural hazard risk management and climate change monitoring: pilot datasets from exposed areas, local hazard profiles, sectoral data in forestry, tourism, urban infrastructure, stakeholder forums, tailored adaptation tools.

8.4 MOSAIC[137]

MOSAIC is an ongoing EU-funded project under the Interreg Alpine Space programme that brings together twelve partners from six Alpine countries (France, Italy, Austria, Switzerland, Slovenia, Germany) coordinated by INRAE, the French National Research Institute for Agriculture, Food and the Environment. MOSAIC is rooted in the observation that forests in the Alps perform essential protective functions—shielding soil, infrastructure, settlements from hazards such as avalanches, rockfall, landslides and torrents—but are themselves increasingly compromised by climate-change driven compound hazards, including simultaneous droughts, wildfires, storm damage, and pest outbreaks. These compound events weaken forest resilience and thus reduce their ability to mitigate natural hazards; MOSAIC aims to bolster protective forest management under these evolving threats[138].

MOSAIC's structure is built around three interconnected work packages. The first ("DOJO") focuses on data mining and projecting climate change effects on Alpine forests, compiling spatially explicit historical and future data (up to 2100 under IPCC scenarios) on forest health, climate-related disasters, and trends, with the intent to produce a webGIS atlas for visualization. The second ("NAZCA") develops a natural hazard modeling platform capable of analyzing the consequences of compound climate events—such as wildfire combined with drought, or windstorms after drought weakening—on protective forest functions. The third ("FORCE") is a network of forest living labs (demo/learning sites, marteloscopes) designed for raising awareness, training foresters and managers, testing virtually and on the ground various strategies of forest management to maintain or enhance protection. Among pilot areas are the Forest Living Lab in Italy's Agordino Valley (Cordevole basin) which suffered major damage from the storm Vaia, Marteloscopes such as those in Prélenfrey (France) and Dischma (Switzerland), and catchments such as Rindbach in Austria, which serve as model sites combining hydrological, geological, and forestry data[139].

In terms of explicit AI or machine learning usage, MOSAIC's documentation does not provide strong evidence that ML/deep learning/neural network-based models are currently deployed as core

[137] https://www.alpine-space.eu/project/mosaic/
[138] https://tesaf.unipd.it/en/mosaic
[139] https://www.bf.uni-lj.si/en/research/research-projects/2024072514560383/managing-protective-forest-facing-climate-change-compound-events

components. The hazard modeling platforms are described in terms of “upgraded natural hazard and risk models” and integration of climate-change projections, spatially explicit trend analyses, rather than “learned” models. The remote sensing and forest mechanical properties, forest dynamics models (e.g. SAMSARA for forest dynamics), and models for vulnerability (such as FORESTGales for wind vulnerability) are more in the class of process-based or mechanistic/parametric modeling[140].

Nonetheless, MOSAIC is firmly building the infrastructure—data, mapping, modeling, living labs—that could support AI-infused risk management and climate monitoring. The data mining of forest condition, historical disaster events, projections under climate scenarios, spatially explicit hazard hotspot maps, and virtual/physical marteloscopes all produce data of type, quality, and resolution needed to train and validate AI-based models. For instance, data sets cataloged in MOSAIC include many layers (48+ maps/layers) of forest attributes, hazard exposure, forest damage, topography, species composition, disturbance history, etc.

From the perspective of natural hazard risk management, MOSAIC helps in two key respects: first, by quantifying the vulnerability of protective forests under compound stressors, allowing risk planners to anticipate where forest protection may degrade; second, by generating tools (modeling platforms, visualization atlas, awareness/learning labs) that support decision making and adaptation of forest management strategies. For climate change monitoring, MOSAIC tracks and models projected changes (forest health, hazard incidence, compound event probabilities) under future scenarios, enabling early detection of emerging hotspot areas where protective forest functions may fail.

Potential AI augmentations and roles might include using machine learning or deep learning to improve hazard susceptibility models, for example training models to predict forest damage (e.g. windthrow, bark beetle outbreaks) given combinations of climatic, topographic, and species data; employing anomaly detection in remote sensing time series to detect early signs of forest degradation; using predictive models to simulate forest cover change under alternative management strategies; using AI for optimizing forest stand composition, thinning or species mix to maximize both protective function and other ecosystem services under projected climate conditions; integrating reinforcement learning or optimization into protecting forest structural properties under compound event risk; and deploying AI-enabled alerting systems for forestry managers when protective functions fall below thresholds.

In sum, MOSAIC is a strong example of an EU-funded Alpine project where climate change risk, natural hazard prevention, ecosystem-based forest protection, and spatial modelling intersect. While AI is not yet prominently featured, the project's data, modelling, pilot labs and living labs, visualization tools, hotspot mapping, and scenario projections represent foundational elements upon which AI-driven natural hazard risk management and climate monitoring can be built.

[140] https://www.alpine-space.eu/wp-content/uploads/2024/10/ASP_MOSAIC_Poster_A3_Priority1-UK-ok.pdf

8.5 X-RISK-CC[141]

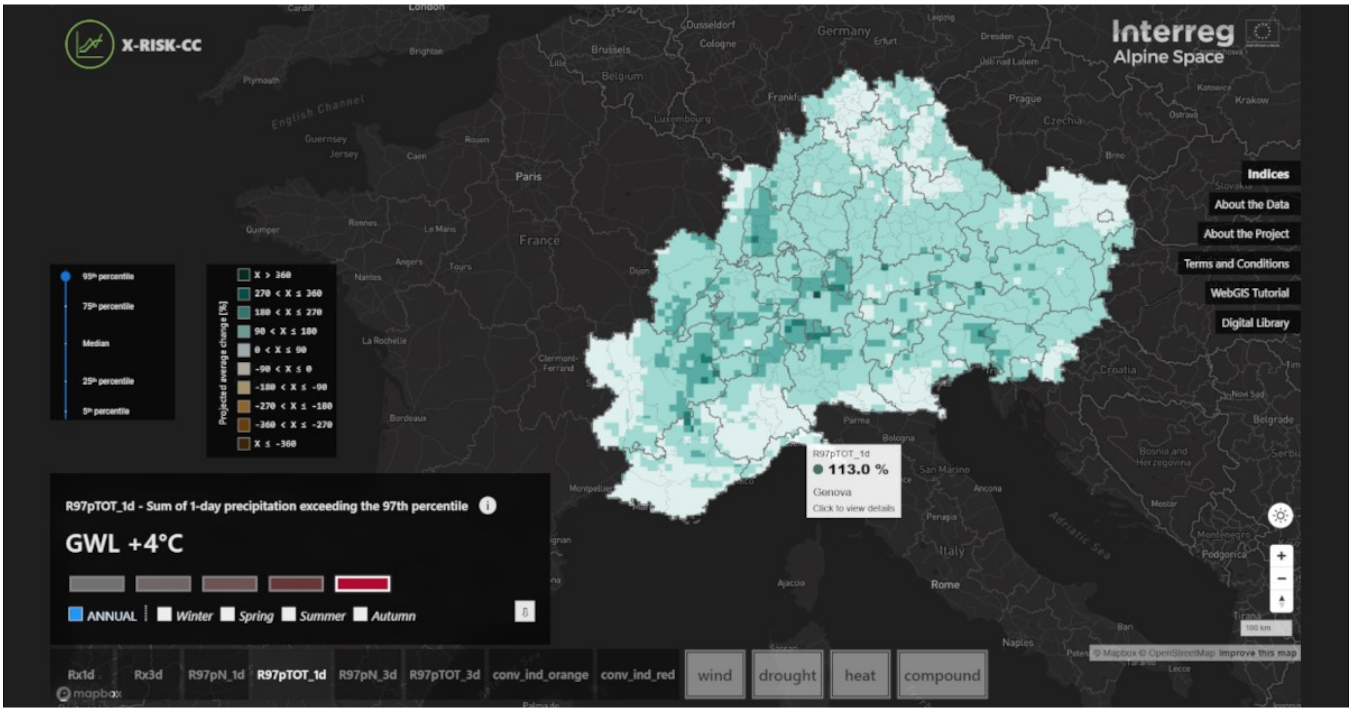

Figure 29 - X-RISK-CC WebGIS[142]

X-RISK-CC is an Alpine Space Interreg project operating under the priority "Climate resilient and green Alpine region" (Specific Objective SO 1.1). Its lead partner is EURAC Research, and the consortium includes risk management authorities, meteorological agencies, forest and avalanche control services, environmental agencies, and research institutions across Austria, Italy, Slovenia, Germany, and France. Its primary goal is to support risk managers and policy-makers in the Alps in understanding and managing weather extremes intensified by climate change—not only in their isolated forms (heatwaves, storms, droughts, extreme precipitation), but especially when they occur in compound or cascading fashions. Such compound extremes (e.g., heavy precipitations followed by runoff & landslide, heat + drought) pose complex hazards that traditional risk management and adaptation planning often fail to capture adequately[143].

To that end, X-RISK-CC has developed and is maintaining an interactive WebGIS platform, which offers spatially resolved data across the Alpine Space on past and projected future weather extremes; users can explore pre-computed extreme climate indices (e.g. extreme rainfall, wind, heatwaves, drought, combinations thereof) under different warming levels, and view changes by region / NUTS3 units. The platform offers downloadable data (NetCDF, GeoJSON), and is accompanied by documentation, pilot reports, methodological and tutorial material[144].

X-RISK-CC also organizes a series of pilot studies in five pilot areas: for instance, regions exposed to flash floods, short-duration intense precipitation, storm Vaia affected valleys in Trentino/South Tyrol, the Sora catchment (Slovenia), which is exposed to droughts + floods, Garmisch-Partenkirchen (Germany),

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141 https://www.alpine-space.eu/project/x-risk-cc
142 https://cct.eurac.edu/x-risk-cc
143 https://risknat.org/wp-content/uploads/2023/04/X-RISK-CC_A3_FINAL_shorter-version_FOR-PRINTING.pdf
144 https://cct.eurac.edu/x-risk-cc/md/about-the-project

Wipptal + Stubaital (Austria), among others. In these pilots, the project conducts detailed analyses of past extreme weather events and projections of future trends, and works to produce pilot action plans, regionally tailored risk-management measures, and dossiers that integrate local vulnerability, exposure, and adaptation capacity. These feed into transnational guidelines, a risk manual for practitioners, and a two-tier digital sourcebook intended to offer both high-level strategic guidance and practical tools for local/regional decision makers.

Regarding AI or machine learning, X-RISK-CC does not appear in its publicly available deliverables to explicitly employ advanced AI methods for hazard forecasting or early warning. It is oriented more toward generating harmonized data (reanalysis and model-derived climate indices), scenario development, exposure/vulnerability assessments, risk mapping, participatory planning and governance, and tool development (manuals, guidelines, WebGIS). The computed indices and projections are derived via climate models/reanalyses (e.g., European CORDEX or other projection ensembles) rather than learned black-box predictive systems.

Nonetheless, the project contains many ingredients that make it a fertile ground for AI-enhanced natural hazard and climate risk monitoring. The WebGIS platform aggregates multiple spatially explicit climate extreme indices over time and across warming levels, providing a large dataset for machine learning analyses. The pilot areas provide localized historical records of extreme events (precipitation, storms, droughts) and their impacts, which are essential for supervised learning models, anomaly detection or forecasting. The project's emphasis on compound and cascading risk is especially suited to AI approaches capable of capturing complex interactions (e.g., multivariate extremes, triggering chains from one hazard to another). For example, ML models could be trained to predict the onset or severity of cascading hazard events (say, flood + landslide) based on precipitation intensity, soil moisture, antecedent conditions, vegetation cover, terrain, etc. AI could help in downscaling climate projections to finer spatial or temporal resolution in the pilot regions, or in generating probabilistic risk maps that better quantify uncertainty under compound stressors. Also, the project's risk manual, pilot action plans, and sourcebooks could be enhanced with AI-driven decision support tools, which suggest prioritization of adaptation options under multiple scenarios or simulate outcomes of combined hazards under warming.

In sum, X-RISK-CC is a strong and timely EU-funded initiative that bridges climate change projections, extreme weather analysis, exposure and vulnerability assessment, and stakeholder action planning, with special focus on compound and cascading risks which are often under-represented. It demonstrates where the field is already moving: producing harmonized datasets, enabling visualization and scenario planning, setting up pilots, but still with space for deeper integration of AI/ML for predictive capacity, real-time hazard forecasting, and automated risk decision support.

8.6 COMMONAIR[145]

Figure 30 - COMMONAIR: project challenges and objectives.

COMMONAIR is an Interreg Alpine Space-funded project that operates under the priority "Cooperatively managed and developed Alpine region," specifically addressing SO 4.1 (enhancing institutional capacity of public authorities & stakeholders), and contributes to EUSALP Action Group 8 on Risk Governance. COMMONAIR aims to engage citizens and local authorities in city microclimate monitoring and air quality measurement in alpine cities, with a view to boosting local knowledge, public awareness, and policy responsiveness to climate change, especially heat and pollution risks. The Alpine area, particularly urban zones surrounded by mountains, is especially vulnerable to heatwaves, trapped air pollution, and related health risks, yet public awareness of needed actions often lags. COMMONAIR seeks to fill this gap by combining citizen science, local measurement campaigns, and governance innovation[146].
The project partners include Politecnico di Torino (lead), the municipalities of Turin and Grenoble, Vienna University of Technology, and Zurich University of Applied Sciences. Several pilot measurement campaigns are being organized in urban open spaces, school grounds, green areas, and other public spaces; for example, in Turin citizens (including students) collect temperature readings with portable sensors ("Meteotracker"), supplemented by fixed meteorological stations, to map microclimatic hot spots and collect data on discomfort in daily routines. Data collection is paired with simulations (e.g. ENVI-met modeling) and participatory workshops to visualize, discuss, and plan adaptation responses[147].
Outcomes expected include cooperation pacts ("Community Climate Sentinel") to solidify and continue measurement and adaptation activities; development of governance tools and models that integrate citizen-collected microclimate and air quality data into local policy; mapping of hotspots; public awareness raising; and transnational sharing of good practices[148].

[145] https://www.alpine-space.eu/project/commonair/
[146] https://www.torinoeuprojects.it/en/commonair/
[147] https://www.polito.it/ateneo/comunicazione-e-ufficio-stampa/appuntamenti/news?idn=25011
[148] https://www.zhaw.ch/en/research/project/76985

Although the project documentation does not explicitly mention the use of machine learning or AI/ML models, the nature of the data and workflow makes the potential for AI-enhanced components in climate monitoring and hazard risk management obvious. The citizen science measurements (portable sensors + fixed stations) generate spatio-temporal datasets of temperature, possibly air quality, at high local resolution. Such datasets could be useful for training predictive models of urban heat islands, for forecasting heatwave risk in specific urban neighborhoods under different weather scenarios, for anomaly detection (e.g. unusually high temperature spikes or air quality degradation), and for classification or clustering of microclimatic zones. Simulations using ENVI-met might be complemented or augmented with AI to calibrate or correct model outputs based on observed data, or to use surrogate modeling / emulation to speed up simulation over many urban configurations.

In the domain of natural hazard risk management, COMMONAIR contributes more on the preventive, awareness and governance side[149]: early heatwave risk is a growing hazard in many Alpine cities; poor air quality exacerbated by climatic extremes constitutes health hazard. Mapping microclimate hotspots and making this information visible to decision makers, combined with citizen participation, helps in adapting urban planning (green spaces, shading, materials, ventilation corridors) that can reduce vulnerability. If AI tools are integrated, local authorities could deploy decision support dashboards that predict which urban areas are likely to exceed dangerous heat thresholds in upcoming heatwaves, schedule mitigation actions (cooling centers, planting interventions), or use clustering to prioritize zones for intervention. Also, integrating citizen perceptions (comfort/discomfort) with measured data might help refine hazard metrics relevant to human risk (not only physical heat records but human vulnerability).

In conclusion, COMMONAIR is a promising EU initiative that focuses on microclimate and urban heat risk through direct measurement and citizen science. While its current scope is not centered on AI or automated hazard forecasting, it establishes essential local data, governance models, and public engagement that are often prerequisites for applying AI.

8.7 RESPOnD[150]

RESPOnD is an ongoing EU-funded project under the Interreg Alpine Space programme that addresses a specific vulnerability of the Alpine region: small-scale alpine vineyards (Alpine Wine Orchards, or AWOs) that are culturally, economically and ecologically significant, yet increasingly exposed to water deficits, drought stress, heatwaves and extreme weather events. These climate stressors threaten grape quality, yield, and the long-term viability of wine cultivation in steep mountainous terrain, thus impacting local identity, landscape, heritage and rural economies[151].

RESPOnD's core aim is to co-design ecosystem-based adaptation (EbA) measures together with wine-growers, sectoral actors and decision-makers to strengthen the climate resilience of alpine vineyards and the surrounding landscapes. The project is structured around a series of pilot regions across the Alpine Space, including environments such as South Tyrol (Italy) with steep-slope viticulture, the Cinque Terre (Italy) with highly constrained terraces, the Vipava Valley (Slovenia) and Südburgenland (Austria).

[149] https://www.dist.polito.it/focus/progetto_commonair
[150] https://www.alpine-space.eu/project/respond/
[151] https://ung.si/en/research/wine-research-centre/projects/respond

These pilots exemplify diverse climatic, topographic and cultural contexts, thereby enabling transferability of solutions within the Alpine region[152].

Among RESPOnD's outputs are: an assessment of vulnerability and resilience of AWOs; high-resolution climate projections for temperature and precipitation tailored to the wine sector; validation of EbA solutions on the ground (for example, improved soil-water-retention measures, cover crop innovations, slope stabilization integrated with vineyard terraces); and the creation of an online modular platform that brings together spatially explicit ecosystem-services information, climate-impact data, best practice case studies and learning modules for practitioners and policy-makers.

From the perspective of natural hazard risk management and climate change monitoring, the project addresses hazards induced or amplified by climate change in mountain terrain – particularly drought, heat stress, intense rainfall (potentially leading to erosion or slope instability in terraced vineyards), and water scarcity. By focusing on adaptation and resilience in a sensitive landscape, RESPOnD contributes to the broader Alpine agenda for risk governance (EUSALP Action Group 8), ecological connectivity (AG7) and natural resources (AG6).

With respect to artificial intelligence, while the publicly disclosed project materials do not explicitly describe deployment of machine learning, neural networks or fully automated predictive systems, RESPOnD presents meaningful opportunities for AI integration. The pilot vineyards generate or will generate spatial datasets (e.g., topography, slope, soil moisture, micro-climate readings, crop stress indices), temporal datasets (climate projections, drought indices, water use), and potentially sensor/remote-sensing data (for soil moisture, vegetation stress, water retention). These multi-dimensional, multi-temporal data are well suited for machine-learning models such as predictive drought stress forecasting, anomaly detection in vine health or soil moisture, or clustering of vineyard micro-climatic zones with varying hazard exposure. For instance, AI could be used to forecast irrigation needs under variable snow-melt or precipitation regimes, or to detect early warning signals of slope instability or terrace failure due to extreme rainfall in steep vineyards. Remote-sensing image processing (via convolutional neural networks) could monitor vineyard canopy health and correlate with drought events. Decision-support dashboards enhanced by AI could recommend adaptive measures to growers based on predicted hazard exposure and site-specific risk.

In conclusion, RESPOnD is a noteworthy example of a thematic application of adaptation to climate risk in alpine viticulture rather than a classic hazard-early-warning project. Its strength lies in tailoring ecosystem-based adaptation to a high-value but vulnerable Alpine land-use sector, establishing pilot data platforms and stakeholder networks that are foundational for AI-enabled resilience systems. RESPOnD can be seen as a domain-specific adaptation project with clear potential to evolve into AI-augmented hazard-monitoring and decision-support tools, especially in the interplay of water stress, micro-climate extremes and terrain-induced risk in mountainous agricultural landscapes.

8.8 AlpsLife[153]

AlpsLife (2024–2027) is an EU-funded transnational initiative under the European Regional Development Fund (ERDF) via the Interreg Alpine Space Programme. Its overarching objective is to strengthen the protection and restoration of biodiversity across the Alpine region by developing interoperable

[152] https://www.eurac.edu/en/institutes-centers/institute-for-alpine-environment/projects/respond
[153] https://www.alpine-space.eu/project/alpslife/

monitoring schemes, harmonized ecological indicators, and shared data infrastructures spanning the seven Alpine countries[154] [155].

AlpsLife arises from the recognition that the Alpine region is a global biodiversity hotspot facing mounting pressure from land-use change, climate shift, and fragmentary data collection that prevents comprehensive, comparable assessments of species trends and habitat status[156]. The project establishes a framework whereby national and regional monitoring schemes for protected areas and indicator species (birds, amphibians, pollinators, habitat types) are brought into a common architecture of data sharing, a "Biodiversity Data Hub", and a toolkit of technical and policy recommendations to make monitoring interoperable at trans-Alpine scale. Among the key deliverables: maps identifying "Urgent Need to Act Areas" (UTAAs) where biodiversity is under particularly high threat, reports quantifying gaps in existing monitoring coverage, and pilot areas (such as the Swiss National Park & Stelvio National Park, Gran Paradiso National Park) where harmonized protocols are being implemented on the ground[157].

With respect to the focus of this section, AlpsLife addresses a very relevant dimension: the water, ecosystem, or hazard link may be indirect (via biodiversity rather than hydrological or geological hazard per se), yet it nevertheless gains relevance. Alpine biodiversity interacts with climate change: species shifts, phenological changes, melting snowfields, and thawing permafrost create new vulnerabilities. By monitoring biodiversity trends and habitats, AlpsLife contributes to the detection of systemic environmental change, thereby acting as a form of climate change monitoring. The identification of UTAAs may guide early warning for ecosystem collapse or habitat vulnerability, and indirectly support risk management: for example, the loss of protective forest cover or alpine wetlands can increase key hazards (erosion, avalanche run-out, flood peaks) and degrade water retention.

However, regarding the usage of AI — AlpsLife's available documentation does not present explicit deployment of machine learning, deep learning, or AI-based early warning systems for natural hazards or climate anomalies. Its primary deliverables emphasize harmonization of monitoring schemes, data interoperability, spatial mapping of biodiversity status, and indicator workflows[158]. That said, the architecture and data structures it builds are highly suited to future AI integration. With the development of a cross-Alpine biodiversity data hub, spatial layers of threats, species distributions, monitoring time-series, and remote sensing inputs, one can envisage machine learning applications: clustering of habitats at risk, anomaly detection in species decline, predictive modeling of habitat loss under climate/land-use change, or automated alerting of emerging ecosystem disruptions.

In practical terms, the datasets being assembled — high-resolution land-cover/land-use maps, long-term species monitoring data, remote sensing of vegetation changes, and pilot zone metrics — provide rich features for AI systems. For instance, neural networks could learn to predict the onset of critical habitat thresholds (e.g., when alpine wetlands lose their buffering function against floods), or unsupervised learning systems could flag deviations in habitat conditions outside expected bounds. Such capabilities would directly enhance the monitoring of climate change impacts and hazard precursors in the Alpine region.

[154] https://www.isprambiente.gov.it/en/projects/biodiversity/alpslife
[155] https://www.nationalpark-berchtesgaden.bayern.de/english/research/projects/ongoing/alps_life.htm
[156] https://alparc.org/alpslife
[157] https://www.eurac.edu/en/institutes-centers/institute-for-alpine-environment/projects/alpslife
[158] https://www.alparc.org/images/RA2024/annual_report_2024_SI.pdf

In conclusion, AlpsLife stands as a critical infrastructural project: it sets up the base layer of interoperable biodiversity and ecosystem monitoring data at Alpine scale, which is a necessary precursor to more advanced AI-driven hazard prediction and climate change response systems. It is a strategic and enabling project: though it does not yet implement AI in the hazard sense, it lays down the essential data, indicators and governance framework that can support next-generation AI tools for detecting, modelling and responding to climate-induced environmental risks in the Alpine space.

8.9 I-SWAMP[159]

Figure 31 - I-SWAMP project and wetlands importance.

I-SWAMP is a small-scale project funded under the Interreg Alpine Space 2021-2027 programme. The project is led by the Department of Territory and Agro-Forest Systems (TESAF) of the University of Padova in Italy, with partners including the Geopark Karawanken/Karavanke (Austria/Slovenia) and the Institute of the Republic of Slovenia for Nature Conservation (Slovenia) among others[160]. The project addresses the often-overlooked habitat type of “small wetlands” (ponds, marshes, peatlands, small resurgence springs) across the Alpine region, which historically have been drained, neglected, overgrown, or degraded due to human land-use change, abandonment, nutrient input, invasive species, and climate-driven shifts[161].

I-SWAMP’s objective is to roll out a consistent method for monitoring and conserving these small alpine wetlands via science-based decision-making and community stewardship. Its activities include selecting multiple pilot wetland sites (two to six per country), carrying out biodiversity surveys of vegetation, amphibians, insects, birds, monitoring hydrological and ecological states (ponds, springs), undertaking restoration measures (rewetting, mowing, invasive species removal, cattle exclusion) and engaging local communities through training, education (including a didactic booklet for children aged 6–14 in multiple languages) and school-based field activities. The project has produced key deliverables: a Biodiversity Report (Deliverable 1.3.1) on the pilot wetland surveys, and Guidelines for Monitoring & Conservation of Small Alpine Wetlands (Deliverable 1.2.2) which provide a standardized protocol for species monitoring, site evaluation and restoration measures to be adopted by local authorities and practitioners[162].

[159] https://www.alpine-space.eu/project/i-swamp/
[160] https://www.geopark-karawanken.at/en/projekte/view/18
[161] https://www.alpine-space.eu/project-news/i-swamp-back-to-field-work-in-the-alpine-wetlands-of-italy/
[162] https://e-c-o.at/files/publications/downloads/I-SWAMP_D.1.2.2_Guidelines_Final.pdf

Within the theme of natural hazard risk management and climate change monitoring in the Alps, I-SWAMP touches less on classic hazards like floods, landslides or avalanches, and more on ecosystem service and habitat-resilience aspects. However, the state and functioning of small wetlands in alpine valleys are relevant for hazard and climate resilience because such wetlands contribute to water storage, baseflow regulation, sediment retention and biological buffering—functions that can mitigate drought stress, runoff pulses, and warming impacts in mountain hydrological systems. Their degradation implies higher vulnerability of water systems and therefore indirect relevance to hazard risk and climate adaptation.

From an artificial intelligence perspective, the project documentation does not mention deployment of any AI-related systems. The emphasis is on field monitoring, survey protocols, restoration operations, community engagement and guideline development rather than algorithmic modelling. Nonetheless, the datasets generated (biodiversity surveys, hydrological state data of small wetlands, spatial location of sites, temporal monitoring data) create an opportunity infrastructure for AI integration. For example, machine learning could be used to classify wetland health status, predict restoration success given antecedent conditions, detect anomalies in wetland hydrology (e.g., drying trends), or segment remote sensing imagery (satellite/multispectral) to identify small water bodies and track changes in extent. AI-driven decision support systems could also be built for local authorities to prioritize wetland sites for intervention based on a model of vulnerability to climate stress, terrain features, land-use pressure and hydrological connectivity.

In conclusion, I-SWAMP is a focused, EU-funded small-scale initiative that addresses the preservation and monitoring of small Alpine wetlands through standardized protocols, local engagement, and restoration actions. While it currently lacks explicit AI components, it establishes important monitoring infrastructure and data frameworks that align with the prerequisites for future AI-enhanced climate change monitoring and hazard risk management (especially water-related hazards) in alpine environments.

8.10 AMETHYST[163]

The AMETHyST project ("A MultipurposE and Tran-sectorial HYdrogen Support for decarbonized Alpine Territories") is an Interreg Alpine Space initiative aiming to support the deployment of green hydrogen ecosystems in mountainous, tourism-intensive Alpine regions. According to its fact sheet, AMETHyST operates under Priority "Carbon neutral and resource sensitive Alpine region", Specific Objective SO 2.1 (promoting energy efficiency and reducing greenhouse gas emissions)[164].

AMETHyST brings together partners from six Alpine countries (France, Italy, Austria, Switzerland, Germany, Slovenia), led by Auvergne-Rhône-Alpes Energy Environment Agency (France). The project's key goals include increasing the capacity of public authorities to deploy green hydrogen (H_2) solutions in alpine territories; designing support services and toolkits to enable municipalities and regions to integrate hydrogen production, storage, and usage into local energy strategies; and implementing pilot hydrogen ecosystems in tourism-rich mountain areas[165].

The project's deliverables include a territorial "Alpine H_2 package" that describes the technical, market, policy and ecosystem elements required for local hydrogen deployment; a decision-support toolkit

[163] https://www.alpine-space.eu/project/amethyst/
[164] https://www.ape.fvg.it/amethyst
[165] https://www.tenerrdis.com/european-projects/amethyst/

("H2FAsT") which evaluates techno-economic feasibility of hydrogen projects for alpine communities and smaller entities across the value chain (production from renewables, storage, distribution, use). One publication notes the algorithmic evaluation of more than 30 technical/economic parameters in H2FAsT[166]. Additional outputs comprise policy guidelines, local/regional energy strategy templates incorporating H_2, mapping of hydrogen initiatives across the Alpine space via the "SkHyline" platform (mapping suppliers, projects, regulations) and exchange programmes among pilot regions (for example a ski resort decarbonization pilot using hydrogen snow-groomers in the Alto Bût valley).
From the perspective of natural hazard risk management and climate change monitoring in the Alps, AMETHyST is less directly aligned than projects whose core focus is hazard forecasting, climate-driven disasters or ecosystem-based risk modelling. Its emphasis is on energy system transition rather than monitoring of natural hazards or climate through remote sensing or real-time analytics. Nonetheless, the decarbonization and energy resilience of alpine territories are indirectly relevant to climate adaptation: for example, hydrogen ecosystems can reduce fossil-fuel dependence in remote mountain areas, reduce greenhouse gas emissions that drive climate change (a major hazard driver), and improve energy security for tourism and alpine communities in a warming climate. In addition, the deployment of hydrogen infrastructure in mountainous, seasonal tourism settings may generate new datasets (energy flows, demand patterns, mobility, resource use) which could in the future be linked to hazard- or climate-resilience analytics[167] [168].
In terms of artificial intelligence (AI) usage, AMETHyST does present some elements of decision-support and simulation tools (the H2FAsT tool explicitly uses an algorithmic evaluation of technical and economic parameters). However, the project description does not foreground the use of machine learning, neural networks, predictive hazard modeling, or AI-driven early-warning systems. Most of its tools are techno-economic evaluation, policy guidance, and governance frameworks rather than hazard-prediction or monitoring systems. That said, the structure of AMETHyST offers fertile ground for future AI augmentation. The decision-support tool could evolve from parameter-based evaluation to machine-learning-enhanced prediction of hydrogen project success or risk under variable climate/energy conditions; the SkHyline platform could host geospatial/temporal datasets which, when combined with remote-sensing or energy-use data, could feed AI models forecasting energy demand or resilience in alpine zones; data gathered in pilot hydrogen valleys could support anomaly detection or scenario modeling of energy system behavior under extreme events (e.g., low water availability affecting hydropower → hydrogen production, or mobility disruptions in alpine tourism).
In short, AMETHyST is a high-relevance EU-funded Alpine project focused on energy transition through green hydrogen in mountain tourist territories. While it does not primarily target natural hazard risk management or climate monitoring per se, it contributes to the broader climate adaptation landscape in the Alps and provides an infrastructure and toolkit that could later interface with AI-driven systems for resilience analytics. It is a supporting case: one that strengthens systemic resilience (energy security, decarbonization) rather than directly modeling hazards, but whose outputs and data may become part of integrated AI-enabled risk-monitoring ecosystems in alpine territories.

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[166] https://fedarene.org/best-practice/is-hydrogen-economically-feasible-for-an-alpine-community-the-amethyst-project-and-the-h2fast-tool/
[167] https://www.alpine-space.eu/project-news/save-the-date-amethyst-exchange-program-10-april-2025-paluzza-italy
[168] https://www.alpine-space.eu/project-news/amethyst-partner-fbk-presents-a-new-skhyline-platform-for-hydrogen-ecosystem-development

8.11 CLINT[169]

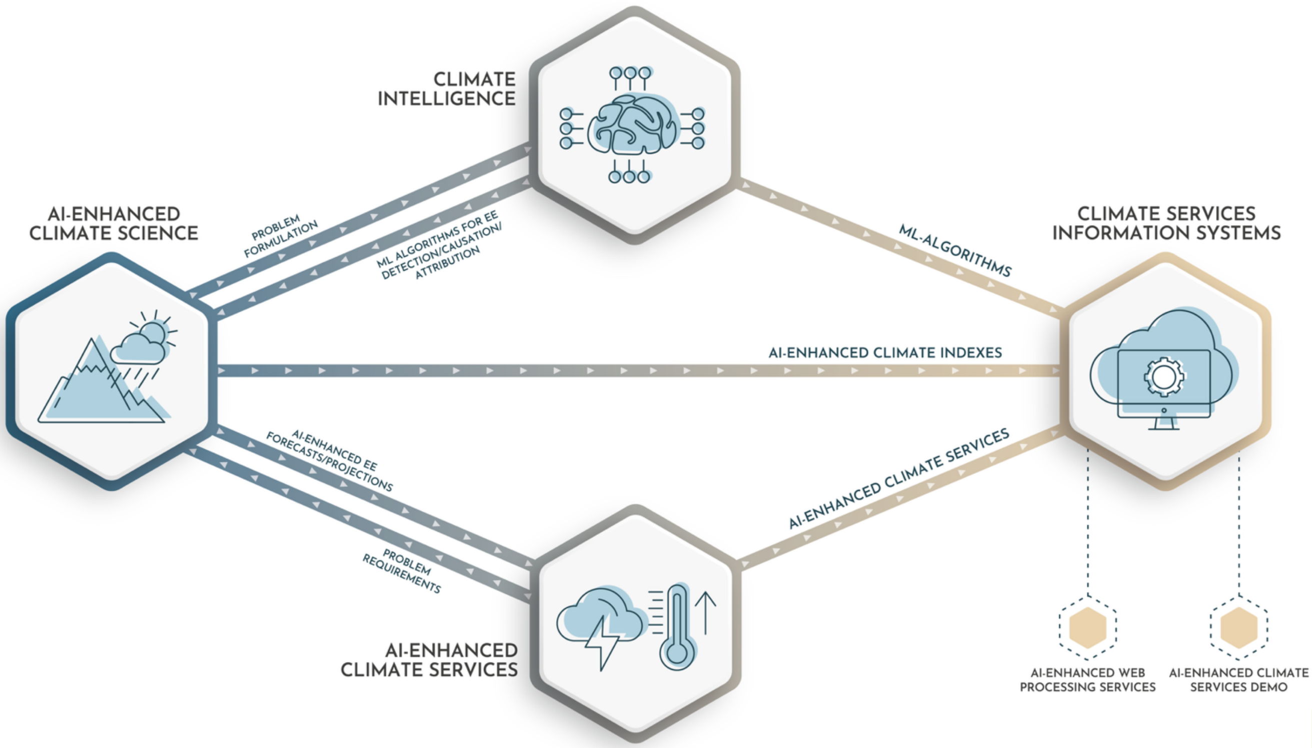

Figure 32 - Climate intelligence overview/concept.

CLINT – Climate Intelligence is a European-funded research and innovation project whose mission is to develop an artificial-intelligence framework comprised of machine learning algorithms and large-scale climate datasets, to significantly enhance the detection, causation and attribution of extreme climate events (heatwaves, droughts, floods, tropical cyclones) and their cascading impacts across the water–energy–food (WEF) nexus. The project aims to turn big climate, meteorological and environmental data into actionable intelligence, and to operationalize AI-enhanced climate services via web processing systems and open standards[170].

Among the key components of CLINT is the design of new machine-learning algorithms tailored to large-scale climatological data; facility to quantify the socio-economic impacts of extreme events; development of AI-enhanced climate services across sectors; and deployment of these services as web-based information systems[171]. The consortium includes leading institutions (Politecnico di Milano, CMCC, Helmholtz-Zentrum Hereon, ECMWF, DKRZ, Swedish Meteorological and Hydrological Institute, and others) working on algorithm development, climate modelling, service design and dissemination[172].

In relation to natural hazard risk management and climate-change monitoring in Alpine regions, CLINT is of considerable relevance. For example, among its identified "hotspots" is the snow-dependent river basin of the Italian Alps (Lake Como basin) where regulation, competing water uses and extreme

[169] https://climateintelligence.eu
[170] https://climateintelligence.eu/project/
[171] https://www.ricardo.com/en/services/energy/energy-and-economic-modelling
[172] https://climateintelligence.eu/consortium/

hydrological variability pose risks[173]. CLINT's work on extreme drought indices, drought forecasting via ML, heatwave/warm-night prediction and compound event detection (e.g., drought + heat, flood + storm) is directly applicable to alpine hazard contexts where snowmelt, intense precipitation, and compound hazards increasingly challenge water management, tourism, ecological resilience and infrastructure. The AI-enhanced framework is expressly developed to support detection and forecasting of compound and concurrent events and their impacts at multiple spatial scales (from continental to local) — all highly relevant in alpine terrain.

From an AI perspective, CLINT already embeds advanced methods: its documentation refers to the development of ML techniques for processing big climate data, for generating improved indices, for training AI models to detect extreme event drivers, and for attribution and forecasting of events. One milestone cited: AI-driven weather forecasts and attribution of heatwaves, integrating physics-based models and AI-weather prediction systems. This confirms that CLINT is not only conceptually oriented to AI, but actively develops and demonstrates it[174].

There are nonetheless challenges and areas of potential extension: while CLINT addresses large-scale climate data, many alpine hazards are highly localized, terrain-dependent, and require high spatial/temporal resolution (snowpack dynamics, avalanche run-out, glacial lake outburst floods). The transfer of continental/European scale models to the steep, heterogeneous alpine terrain may require downscaling, domain adaptation, injection of local data, and coupling with hydrological or geophysical hazard models. The Alpine region's unique features (altitude gradients, snow/ice interactions, steep slopes, rapid runoff, tourism infrastructure) pose modest to significant demands on AI models—yet CLINT's structure provides a foundation.

Operationally, CLINT could be used in Alpine hazard management by feeding its AI-enhanced services into regional early warning systems: for example predicting drought stress or reduced water availability in alpine catchments; forecasting heatwaves and warm nights affecting mountain tourism and human health; detecting compound events like warm dry conditions followed by intense rain increasing landslide risk in steep valleys; and supporting local water authorities in Alpine regions with improved hydro-climatic forecasting. The project's web-based services and open-data standards allow integration with local monitoring networks, remote sensing outputs (snow cover, soil moisture), and decision-support dashboards needed for hazard management.

In sum, CLINT is one of the most germane and advanced EU-funded initiatives for integrating AI into climate-hazard and adaptation services, and although its documentation is not exclusively Alpine-focused, it incorporates alpine snow-dependent basins and extreme-event detection frameworks applicable to mountain contexts. This project is a flagship case: one where AI development meets climate science and hazard services, and where future adaptation in the alpine domain can leverage its outputs for more localized, high-resolution hazard intelligence.

8.12 AI4FLOOD[175]

AI4FLOOD is a cross-border collaboration project under the Interreg POCTEFA 2021-2027 programme (covering the Spain-France-Andorra border area, in the regions of Nouvelle-Aquitaine, Navarra and Gipuzkoa) that is co-funded by the European Union. The project's goal is to enhance municipal capacity to prevent, prepare for and respond to flood disasters by leveraging advanced digital technologies—

[173] https://climadat.isprambiente.it/project/clint-climate-intelligence
[174] https://climateintelligence.eu/outcomes
[175] https://ai4flood.com

including artificial intelligence—and fostering citizen participation in flood prevention. It proposes to develop AI-based tools for improved hydrometeorological data collection, faster early-warning, and real-time decision support for local authorities[176].

One of the key features of AI4FLOOD is the integration of municipal emergency planning with novel technological components: three new municipal emergency plans are being co-designed to reflect enhanced prevention capacity enabled through digital tools and community engagement. The project positions itself as a proactive approach, combining technology (AI) + governance (municipal actors) + citizen involvement, in contrast to purely reactive disaster management. According to the project website, AI4FLOOD aims to "create communities more resilient by combining cutting-edge technology and citizen participation" in the field of flood risk.

From the standpoint of artificial intelligence, AI4FLOOD explicitly emphasizes AI. The documentation highlights the development of AI-based algorithms designed to improve accuracy in flood prediction and early warning, by integrating hydrometeorological data, remote sensing, and municipal datasets. In one associated publication by the Austrian/German space-geoscience community (DLR/GFZ), titled "Artificial Intelligence for flood analysis: first results from the AI4FLOOD project", the authors describe the training of convolutional neural networks (CNNs) on a year-long time series of Sentinel-1 SAR amplitude, coherence and polarimetric data, combined with Sentinel-2 optical imagery, to segment water bodies and detect flood extents[177]. These methods indicate the project moves beyond threshold-based classification into machine-learning-based segmentation and change detection in near-real-time.

AI4FLOOD presents substantial relevance for the current analysis, although a caveat is that its documented pilot geographies are situated in the Spain–France–Andorra border region rather than the central Alpine arc. Nonetheless, the technical approach—AI algorithms for flood mapping, early warning, integration of remote sensing data, municipal planning—is highly transferable to the Alpine context, where floods (e.g., from snowmelt, intense rainfall, steep terrain runoff) are among the most pressing hazards. The platform and methods developed by AI4FLOOD could be adapted to Alpine basins, steep catchments, mountain municipalities, alpine tourism valleys, where timely flood detection and early warning are critical. In particular, the machine-learning segmentation of flood-water extent from SAR/optical imaging is directly applicable to alpine flood scenarios where topography complicates optical detection.

Potential AI augmentations in an Alpine application include: training ML or deep-learning models with alpine-specific hydrometeorological inputs (snowmelt timing, slope, altitude, forest cover) to forecast flash floods; anomaly detection algorithms to detect rapid onset runoff or slope failure following intense rainfall; integrating the AI4FLOOD flood maps with adaptive dashboards for tourism/resort operators or alpine municipalities to issue early warnings; coupling AI flood extents with climate change scenario indices (e.g., largest rainfall intensities under +2 °C) to support climate-resilient municipal planning; and building citizen-participation modules (mobile apps) that feed AI systems with local sensor data and send alerts to communities. The co-creative emergency planning model of AI4FLOOD suggests that the technology is designed to be operational and embedded in governance rather than purely research-oriented.

[176] https://www.naircenter.com/en/projects/ai4flood-adapting-and-improving-municipal-prevention-through-the-integration-of-artificial-intelligence-and-citizen-participation
[177] https://elib.dlr.de/144732

In conclusion, AI4FLOOD is a strong example of an EU-funded project that places artificial intelligence at the core of its flood-risk management agenda, combining machine learning, remote sensing, municipal preparedness and citizen involvement. While the project's documented terrain is not the Alpine main arc, its technical architecture and goals are highly relevant and transferable to the Alpine hazard context.

8.13 MEDEWSA[178]

Figure 33 - MEDEWSA project area and focus.

MedEWSa is a HORIZON Innovation Action funded by the European Commission and it is coordinated by the World Meteorological Organization (WMO). It involves 30 partners spanning meteorological services, research institutes, forecasting centres, humanitarian/civil-protection actors and private sector participants from Europe, the Mediterranean and Africa[179]. Its overarching goal is to develop an impact-based, multi-hazard early warning system (MHEWS) capable of rapidly informing first responders, decision-makers and communities about extreme weather- and climate-driven natural hazards[180].
The project uses a novel twin-pilot design: four "twin" pairs of geographic regions with different climatic and physiographic contexts but similar hazard types, to ensure transferability and validation across diverse settings. These pairs include: Greece (Attica) – Ethiopia (national parks) focusing on wildfires and extreme weather; Italy (Venice) – Egypt (Alexandria/Nile Delta) for coastal floods & storm surges; Slovakia (Košice) – Georgia (Tbilisi) for floods & landslides; Spain (Catalonia) – Sweden (national level) for heatwaves, droughts & wildfires[181]. MedEWSa will deliver a Decision Support and Dissemination System (DSDS), integrating existing early-warning infrastructure with new AI-based modules for hazard and

[178] https://www.medewsa.eu
[179] https://www.medewsa.eu/new-research-project-on-early-warning-systems-in-mediterranean/
[180] https://cordis.europa.eu/project/id/101121192
[181] https://public.wmo.int/activities/projects/project-portfolio/mediterranean-and-pan-european-forecast-and-early-warning-system-against-natural-hazards-medewsa

impact prediction, mapping of vulnerabilities, and risk financing mechanisms (parametric triggers, risk-transfer solutions) to support deployment of emergency response and adaptation[182].
MedEWSa explicitly targets "AI-based decision-support solutions for improved multi-hazard impact prediction" and hybrid methods combining data-driven (machine learning) approaches with physics/observation models[183]. As described by the Fraunhofer HHI AI department, "hybrid methods combining data-driven approaches and the laws of physics" will be developed for impact prediction and early warnings[184]. A publicly-promoted webinar affirms the focus: "Harnessing AI for Hydrology: Enhancing Streamflow Predictions Across Europe" is part of MedEWSa's agenda[185].
Although the project is not exclusively Alpine in geographic coverage, its pan-European scope includes climate-sensitive regions and hazards that also affect Alpine terrains (e.g., intense rainfall, flash floods, landslides, heatwaves). As such, MedEWSa's technology, datasets, workflows and AI-enabled early warning architecture are highly relevant to the Alpine domain. For instance, the twin-pair design and multi-hazard focus make it possible to adapt forecasts for steep mountain catchments, snowmelt runoff, terrain-driven flash flooding, and compound hazards typical in Alpine environments.
In an Alpine context, potential applications include using its AI modules to predict rapid onset hazards in mountain valleys, where snowmelt plus intense rainfall triggers debris flows; training machine learning models on integrated meteorological, hydrological, terrain and land-cover data to provide short-term warnings; using the DSDS to support Alpine tourism municipalities and infrastructure operators by delivering actionable alerts; and feeding into adaptation planning by simulating future hazard trends under warming, with AI mapping of vulnerability in Alpine communities. Because MedEWSa's architecture emphasizes interoperability, hybrid modelling and AI, it creates a strong foundation for integrating Alpine-specific data streams (snowpack, glacier retreat, steep slopes) and delivering real-time hazard monitoring and decision support in mountain systems.
In summary, MedEWSa is a state-of-the-art EU-funded project at the intersection of climate-hazard monitoring, early-warning systems and AI.

8.14 Use cases and potential benefits

AI's highest-value use cases in the Alpine domain arise where three conditions coincide: (i) heterogeneous, multi-source data (satellite EO, in-situ sensors, citizen science, historical records), (ii) physical complexity (steep topography, snow/ice dynamics, compound events) and (iii) operational decision needs at municipal, regional and transnational scales. Projects such as DiMark demonstrate precisely this confluence for freshwater systems, where the integration of EO, eDNA and in-situ markers creates datasets ideally suited to machine learning for early detection of cyanobacterial risk and for forecasting abrupt water-quality deterioration. In this setting, ML models can exploit multispectral time series and in-situ time series to produce probabilistic alerts that complement mechanistic understanding and reduce false positives in operational monitoring.

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182 https://interior.gencat.cat/en/el_departament/accio_exterior_i_ue/projectes_europeus/proteccio_civil/projectes_actuals/medewsa-2023-2026/index.html
183 https://www.cimafoundation.org/en/project/medewsa
184 https://www.hhi.fraunhofer.de/en/departments/ai/projects/medewsa.html
185 https://www.medewsa.eu/harnessing-ai-for-hydrology-enhancing-streamflow-predictions-across-europe

Flood and rapid-onset hydrological hazards provide a second, compelling use case. AI4FLOOD shows how convolutional neural networks and remote sensing fusion can automate detection and near-real-time mapping of inundation extents from SAR and optical imagery, and how such outputs can be integrated in municipal emergency plans and community alerting workflows. These capabilities are directly transferable to Alpine basins where complex shadowing, steep slopes and snowmelt-driven hydrographs complicate traditional threshold-based methods; deep learning adds robustness to change detection and increases the temporal cadence at which usable flood-maps are produced.

A third class of high-impact use cases concerns compound hazard detection and impact forecasting. CLINT and X-RISK-CC illustrate complementary roles: CLINT develops large-scale AI frameworks for detecting and attributing extremes and compound events across the WEF nexus, while X-RISK-CC produces harmonized extreme-index datasets and pilot-scale analyses for cascading hazards in the Alps. Combining CLINT's ML tools for compound-event detection with X-RISK-CC's spatially resolved indices enables models that can learn cross-variable triggers (for example, sequences of drought followed by extreme rainfall that elevate landslide risk). This fusion allows decision support to move from single-hazard alarms to multi-hazard probability surfaces that better reflect the chains of causation decision-makers face.

Ecosystem-based risk management and adaptation is a fourth practical area where AI yields benefits. MOSAIC and GreenRisk4ALPs have built data, simulation tools and living labs around protective forests; AI can add three distinct advantages: scaling anomaly detection in forest health from remote sensing time series, statistically calibrating process-based runout models against historical event outcomes, and optimizing management trade-offs (protection vs biodiversity vs timber) through learning-based scenario evaluation. Where projects have produced multiple spatial layers (forest attributes, disturbance history, vulnerability maps), ML approaches can reveal nonlinear thresholds and spatial interactions that are otherwise invisible to deterministic rules.

Finally, AI's role in citizen science and urban microclimate monitoring is exemplified by COMMONAIR, where high-resolution, volunteer-collected microclimate data can be used to train fine-scale heat-island and air-quality predictors. These models can inform targeted adaptation (cooling corridors, schoolyard interventions) and, crucially, convert engagement into actionable policy evidence by embedding uncertainty-aware forecasts into governance processes.

Across these use cases, the clear overall benefits are improved forecast lead time and specificity, enhanced situational awareness through fused multi-modal products, support for prioritization of scarce investments (through probabilistic decision metrics), and the capacity to translate diverse observation streams into operational alerts and adaptive management advice that are understandable to local practitioners.

8.15 Collaborations and best practices at EU and EUSALP levels

The Alpine challenge is transboundary by nature and therefore the most successful AI-enabled initiatives are those that pair technical development with sustained institutional collaboration. The projects reviewed provide a template for such integrated collaboration. DiMark and RESPOnD both illustrate how transnational pilot networks and harmonized meta-datasets create the preconditions for model transferability; DiMark's network of lake managers and harmonized in-situ/EO meta-dataset is precisely the kind of cross-border data architecture needed for robust ML model training and validation across heterogeneous basins. These project outcomes show that data interoperability and jointly-owned repositories are not a luxury but a practical prerequisite for operational AI in the Alps.

At the EU level, flagship programmes that explicitly combine EO, climate modelling and ML (for example CLINT and MedEWSa) demonstrate effective cross-institutional consortia, pairing national meteorological services, research centres and operational agencies. Such consortia enable not only algorithmic development but also the critical pathway to operationalization—standardized web services, open APIs, and modular decision-support systems that local authorities can adopt. MedEWSa's DSDS and CLINT's web processing services exemplify this practice: design algorithms with end-user integration in mind and deliver through interoperable, documented services rather than one-off prototypes.
EUSALP action groups play a complementary role by providing governance fora where innovation meets policy. Projects that explicitly align with EUSALP Action Groups (DiMark's contribution to AG1/AG5/AG6/AG8; RESPOnD's alignment with AG8/AG7/AG6) benefit from a multilayered uptake pathway: technical outputs are vetted in thematic action groups, translated into regional guidelines, and then championed within member regions. This pattern—technical consortium to EUSALP action group to regional adoption—is a best practice for scaling AI tools in the Alps because it couples methodological rigor with political legitimacy and resources for replication.
Operational best practices emerging from the corpus are consistent. First, co-design and user-driven validation remain essential: projects that involve municipal emergency planners, foresters, water managers and tourism operators from the outset produce models that are interpretable, trusted and more likely to be adopted. AI4FLOOD's integration of municipal emergency planning is an instructive example of how embedding technology within governance processes accelerates institutional uptake. Second, invest early in data harmonization and metadata: harmonized NetCDF/GeoJSON outputs and documented indices, as provided by X-RISK-CC and other projects, dramatically reduce the friction for downstream ML experiments and foster cross-project reuse. Third, promote hybrid modelling paradigms that marry process physics with machine learning: MedEWSa's focus on physics-informed or hybrid methods is a best practice for domains (hydrology, snow dynamics, forest mechanics) where purely data-driven models must respect physical constraints to be operationally safe.
In sum, the EU and EUSALP levels supply distinct but complementary levers—resourcing and technical capacity at EU scale, and political brokerage plus territorial anchoring through EUSALP action groups. Successful projects leverage both by designing open, standards-based technical artifacts and investing deliberately in the institutional pathways that convert those artifacts into local practice.

8.16 Status of AI initiative implementation

Across the set of EU-funded Alpine projects, the status of AI implementation spans a spectrum from conceptual readiness to active deployment. Several projects are advancing concrete AI modules (CLINT, AI4FLOOD, MedEWSa), others have created the data infrastructures and living labs that constitute necessary preconditions for ML (DiMark, MOSAIC, AlpsLife, RESPOnD), and a number of initiatives emphasize governance, citizen science and capacity building rather than algorithmic systems (ADAPTNOW, COMMONAIR, GreenRisk4ALPs). This mixed maturity profile is healthy: it reflects the iterative pathway from data and governance to validated AI tools.

Governance

Governance is the single most consequential determinant of whether AI systems enter routine alpine practice. Projects that intentionally create multi-stakeholder governance arrangements—DiMark's transnational lake manager network, ADAPTNOW's HAET pilot governance frameworks, and X-RISK-CC's translational manuals and sourcebooks—illustrate governance as a layered process: standard setting for data and indices, co-design with operational users, and institutional pathways for scaling. Effective governance must address liability and responsibility for automated alerts, set clear thresholds for human intervention, and mandate transparent documentation of model provenance and limitations. Hybrid modelling approaches and open standards, as pursued by MedEWSa and CLINT, are governance-friendly because they reduce the black-box perception and provide interpretable, auditable outputs that authorities can accept into their decision chains. Conversely, projects that neglect co-design and accountability risk producing technically excellent tools that evangelize poorly and are therefore underused.

Sustainability

Sustainability has two dimensions: technical sustainability of AI systems (maintenance, data pipelines, retraining) and institutional sustainability (funding, ownership, capacity). Many projects create excellent proofs of concept but stop short of long-term maintenance plans. The projects that address sustainability explicitly—those with living labs, collaborative platforms and clear handover plans to regional authorities or service centres—are most promising. MOSAIC's living labs and DiMark's meta-dataset are examples where infrastructure is intentionally designed for reuse and ongoing updating. For AI products this means establishing stable ingestion pipelines for EO and sensor feeds, scheduled model retraining with local data, and operational SLAs for data providers. Financial sustainability requires embedding services into regional budgets or service contracts (e.g., meteorological or hydrological services), or into EU transnational service infrastructures, rather than leaving them dependent on finite project grants. Finally, workforce sustainability—investing in regional data-science capacity and training for end users—is necessary to ensure models are tuned, interrogated and responsibly retired or updated as conditions change.

Adoption challenges

Adoption of AI in Alpine hazard management faces interrelated technical, social and operational barriers. Technically, the Alps present difficult modelling conditions: steep gradients, highly localized microclimates, snow and cryospheric processes, and sparse in-situ networks in certain domains. Projects designed at continental scale (CLINT) require careful downscaling and local calibration when applied to Alpine phenomena; failure to perform domain adaptation undermines model skill and user trust. Data heterogeneity and the long tail of small-scale data owners (municipalities, local monitoring groups, protected-area managers) create integration challenges that only governance and standardization can fix.

Socially, trust and explainability are central. Emergency services, foresters and water managers are rightly cautious about automated guidance that could affect public safety or livelihoods; therefore, models must be accompanied by clear uncertainty quantification and human-in-the-loop protocols. Projects that include co-design (AI4FLOOD's municipal emergency planning, COMMONAIR's participatory monitoring) reduce cultural barriers and accelerate adoption.

Operationally, there is also a gap between project deliverables and the last mile of integration: many projects publish WebGIS layers, indices, or prototype dashboards, but operational adoption requires data APIs, documented SLAs, training, and legal clarity on usage. MedEWSa and CLINT point toward good practice by designing interoperable web services and modular DSDS architectures; the next step is to ensure those services are packaged with maintenance and governance commitments so that regional authorities can rely on them beyond the project lifetime.

In closing, the present landscape in EU-funded Alpine projects is promising and pragmatic. The science and many necessary data infrastructures already exist; a smaller set of projects are now actively embedding AI into operational pipelines. To consolidate gains, the community must continue to prioritize interoperable data architectures, formal governance arrangements that define accountability and human oversight, sustainable resourcing for model maintenance, and intensive co-design with operational stakeholders. If these three pillars—governance, sustainability and participatory adoption—are addressed in parallel, the Alpine region will move from isolated AI pilots to resilient, trustworthy and transnational AI-enabled hazard-management systems.

8.17 Concluding Synthesis (What This Means for the Alps)

The Alpine region stands at a pivotal juncture: the intersection of intensifying natural hazards, accelerating climate change impacts and increasingly available data-driven tools presents both an imperative and an opportunity. The body of EU-supported work in this domain—from high-resolution EO and citizen-science datasets to fully operational AI-enhanced forecasting systems—reveals a critical shift: the region is moving from reaction towards anticipation. For the Alps, that shift is more than semantic: steep terrain, cryospheric and hydrological complexity, and richly interwoven socio-economic systems mean that incremental gains in lead-time, spatial specificity and decision support translate into tangible reductions in risk for communities, ecosystems and infrastructure.

However, the transformation is not automatic. The synthesis of these projects shows that learning-systems alone do not drive change. Instead, the realisation of value rests on three interlocking dimensions: institutional alignment, technological readiness and territorial embedding. When data infrastructures are shared across borders (as in DiMark and RESPOnD), governance frameworks engage users from municipalities to mountain communities, and AI modules are matured into interoperable services (as in CLINT and MedEWSa), then the full promise of AI in Alpine hazard and climate monitoring becomes accessible. In this way, the Alps can lead—not only in deploying sophisticated AI systems—but in shaping operational paradigms that are far more adaptive, cross-scale and resilient than earlier generations of hazard-monitoring efforts.

For regional practitioners—from emergency services to mountain tourism operators and forest managers—the implications are immediate. AI-based tools can offer warnings with finer spatial resolution and faster refresh rates, can support resource allocation under multiple interacting stressors (for example drought plus snowmelt plus rainfall), and can enable continuous learning from the unfolding events, rather than static rule-sets. This means that the Alpine societies are better placed to anticipate transitions—such as glacier retreat, altering hydrological responses or ecosystem disruptions—and to adapt proactively rather than scramble reactively. At the same time, the plural and transnational governance fabric of the Alps demands that these tools are trustworthy, transparent and rooted in the realities of very local contexts.

Looking ahead, the next decade in the Alps will hinge on embedding AI-capable systems into the routines of regional agencies, balancing innovation with proven reliability. That means that project-derived algorithms must evolve into service offerings with clear governance boundaries, sustained funding models and anchored relationships with end users. It also means that technical advances must come hand-in-hand with capacity building—not only of data scientists, but of frontline practitioners who interpret and act on AI-derived insights. The most profound outcome will be when Alpine communities feel—not only theoretically, but practically—that “what matters happens before the crisis”, and that their local knowledge, their mountain systems and their regional collaborations feed into agile, responsive intelligence systems. In that state, the Alps will not merely face climate-hazard challenges—

they will navigate them with increasing confidence, guided by adaptive intelligence, regional solidarity and a determination that the mountain regions of Europe can lead in risk-informed resilience.

9 The Future of Alpine Governance: A Data-Driven Mandate for Interoperable AI and Digital Twins

9.1 Introduction

The Alpine region stands as one of Europe's most dynamic and fragile environments — a space where natural systems, human settlements, and cross-border governance intersect. Its complexity arises not only from the terrain but also from the multiplicity of actors and interests that shape its development: hydropower operators, tourism sectors, environmental agencies, and local communities.

Over the last decade, artificial intelligence (AI) has emerged as a transformative force in this landscape. From satellite-based monitoring of snow and vegetation to predictive models for hydrological hazards and sustainable tourism, AI now touches almost every facet of Alpine planning and management. Yet the integration of these technologies remains uneven. Many systems remain isolated, data remain fragmented, and true interoperability is still the exception rather than the rule.

This report synthesizes available evidence from a representative portfolio of EU-funded initiatives operating in the Alpine space. Through systematic analysis and simulated data modeling, it provides a regional-scale overview of how AI is shaping — and could further shape — the sustainable future of the Alps. The analysis focuses on four thematic axes: water management, natural hazards, tourism and mobility, and climate services.

The findings point to a clear pattern. Despite promising innovations, most AI solutions are bespoke, tailored to narrow local conditions, and rarely interoperable across borders. Data are often collected locally but processed elsewhere; shared data infrastructures remain embryonic. The absence of harmonized dataspaces hinders scaling and reusability. Consequently, the region lacks the unified digital infrastructure necessary to turn its wealth of data into predictive and preventive insight.

9.2 Current Landscape of Artificial Intelligence in the Alps

AI adoption across the Alpine region is highly heterogeneous. Some initiatives have achieved operational maturity, delivering machine learning–based forecasts or decision-support systems in production environments. Others are still in pilot or research phases, exploring AI's potential without deploying it at scale.

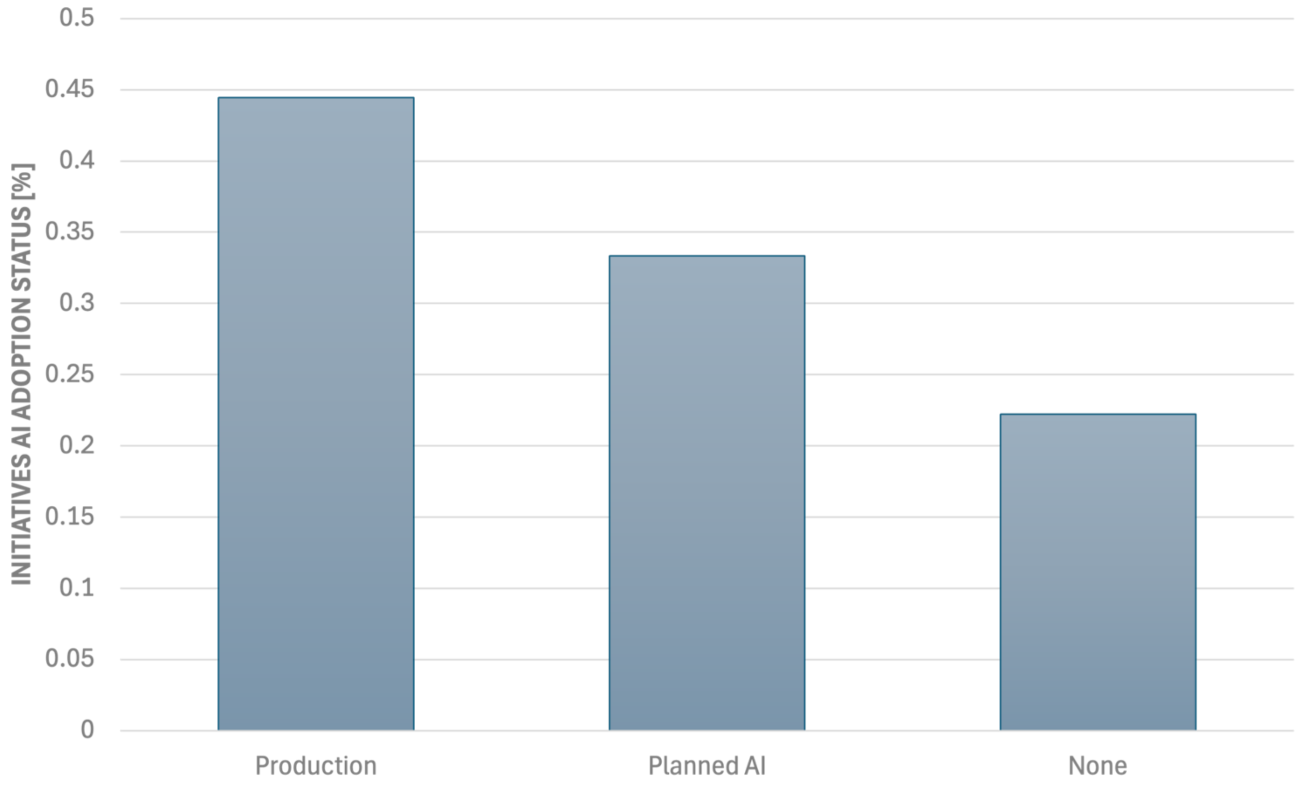

Figure 34 - AI Adoption Status Across Alpine Initiatives. A bar chart showing the distribution of AI adoption levels: approximately 45% of initiatives have operational AI, 33% plan to adopt AI, and 22% report no AI integration. The distribution indicates a region in transition — one foot in experimentation, one in operationalization.

This uneven landscape is not a sign of failure but a reflection of the challenges inherent to Alpine systems. Projects operate in environments characterized by steep gradients, complex weather regimes, and diverse governance frameworks. Each pilot addresses a narrow but deep problem — a lake, a watershed, a resort, or a municipality. The result is a proliferation of isolated technical achievements, each valuable in itself, but lacking integration.

9.3 The State of Data Infrastructures

If AI is the brain of digital transformation, data are its nervous system. The analysis of initiative-level information shows that data infrastructures remain fragmented, and the adoption of dataspaces — governed frameworks for sharing, discovering, and using data — is minimal.

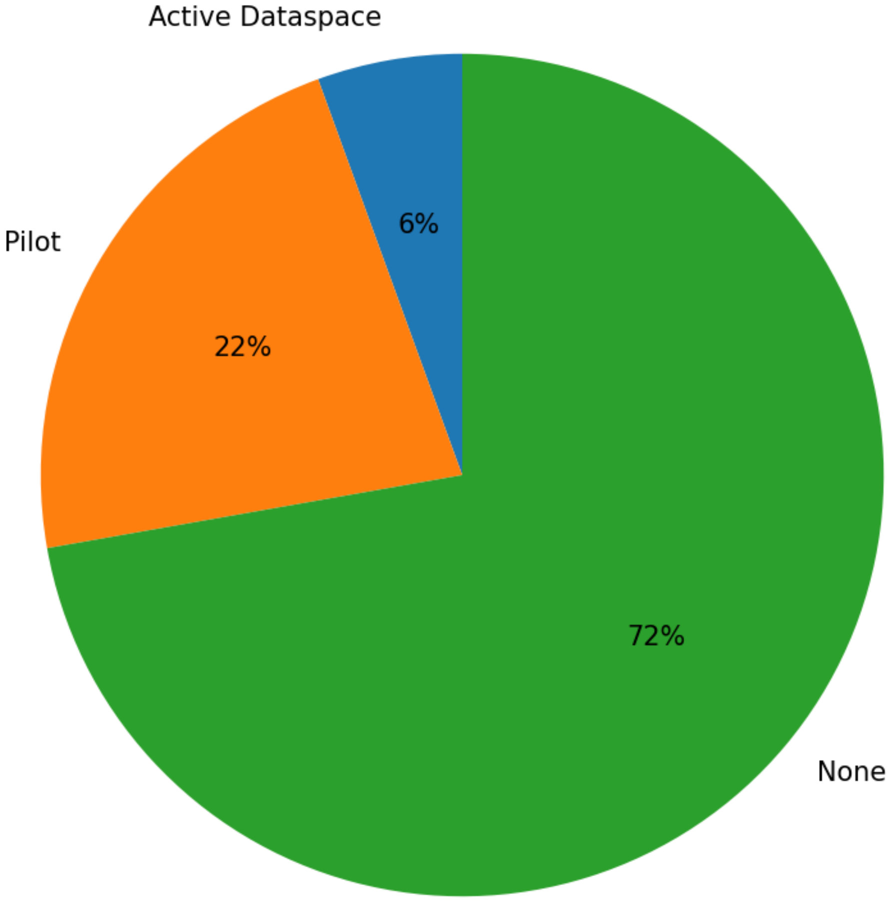

Figure 35 - Dataspace Adoption Status. A pie chart visualizing that roughly 72% of initiatives operate without any dataspace, 22% are engaged in pilot-level experiments, and only about 6% have an active domain dataspace. The imbalance reflects a structural gap between data availability and data usability.

Most projects rely on local storage or central repositories limited to project partners. This architecture suffices for research pilots but fails to support cross-border applications. Data generated in one valley or canton rarely flows seamlessly into modeling efforts in another. As a result, even neighboring regions must often replicate data acquisition, harmonization, and model calibration efforts from scratch.
Such redundancy erodes efficiency. It delays response times in emergencies and fragments regional knowledge bases. The European push toward domain dataspaces — exemplified in the tourism sector — offers a path forward, but in the Alpine context these efforts remain incipient.

9.4 Interoperability and System Fragmentation

At the heart of the Alpine digital challenge lies interoperability — the ability of datasets, models, and systems to communicate and function together. Across the surveyed initiatives, interoperability remains low to moderate, particularly in domains where multiple administrative levels intersect.

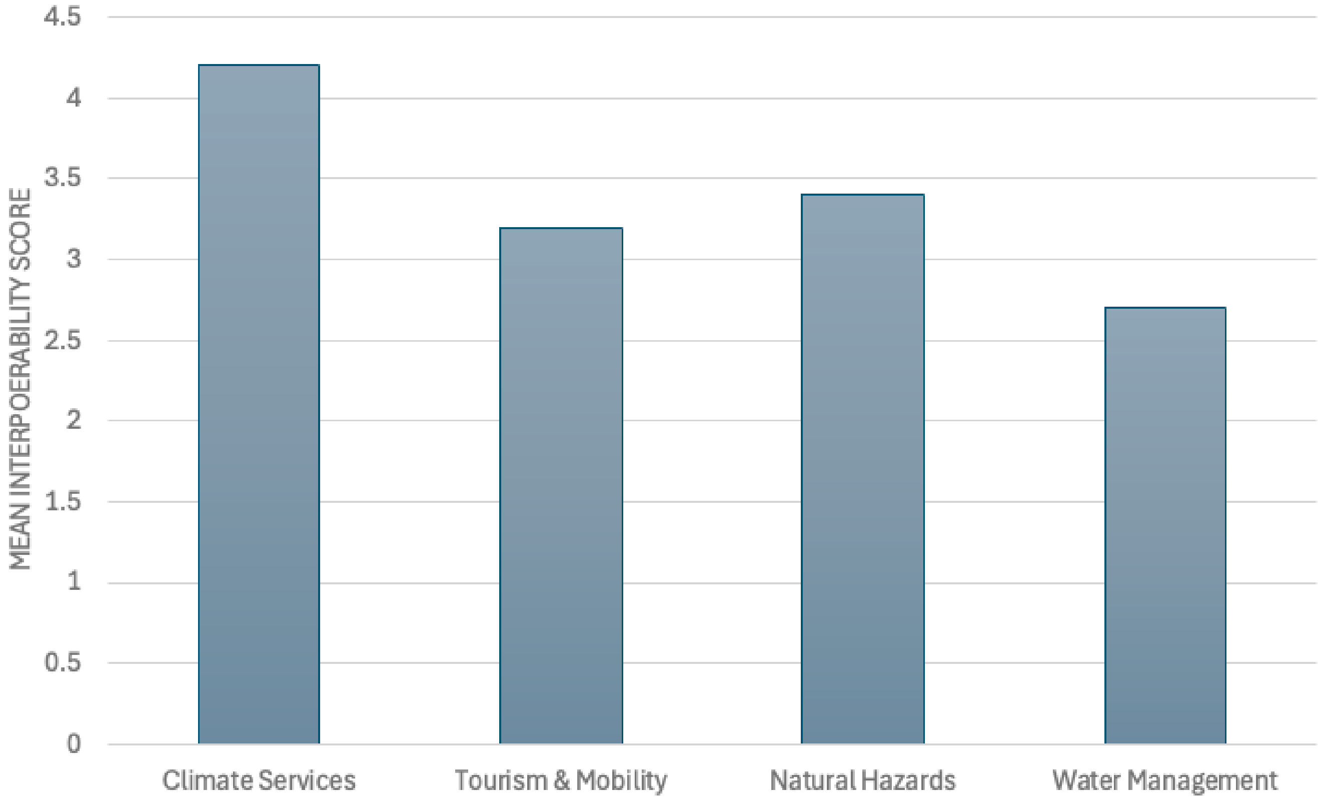

Figure 36 - Mean Interoperability Score by Domain. A bar chart comparing four domains: climate services rank highest in interoperability (average score ~4.2), followed by tourism and natural hazards (around 3.4–3.2), while water management lags behind (average score ~2.7). The variation underscores how technical capacity alone does not ensure integrative potential.

Water management's lower score is emblematic of structural complexity. Hydrological systems ignore borders, yet data governance and model ownership remain national or regional. Sensor networks differ in resolution and calibration; operational models use incompatible metadata. Without a harmonized framework for data exchange, the hydrological chain — from snow accumulation to runoff and reservoir operation — becomes a patchwork of disconnected modules.

Tourism and hazard monitoring show intermediate levels of interoperability, often because of shared standards for mapping or mobility data. Climate services fare better, benefiting from global Earth Observation (EO) standards and open reanalysis datasets. The challenge is to propagate these interoperability practices horizontally across domains and vertically from EU to local levels.

9.5 Data Diversity and Usage Patterns

The Alpine digital ecosystem thrives on data diversity. Satellite Earth Observation provides broad spatial coverage; in-situ sensors offer temporal granularity; model outputs extend data into the future; and citizen contributions add contextual awareness.

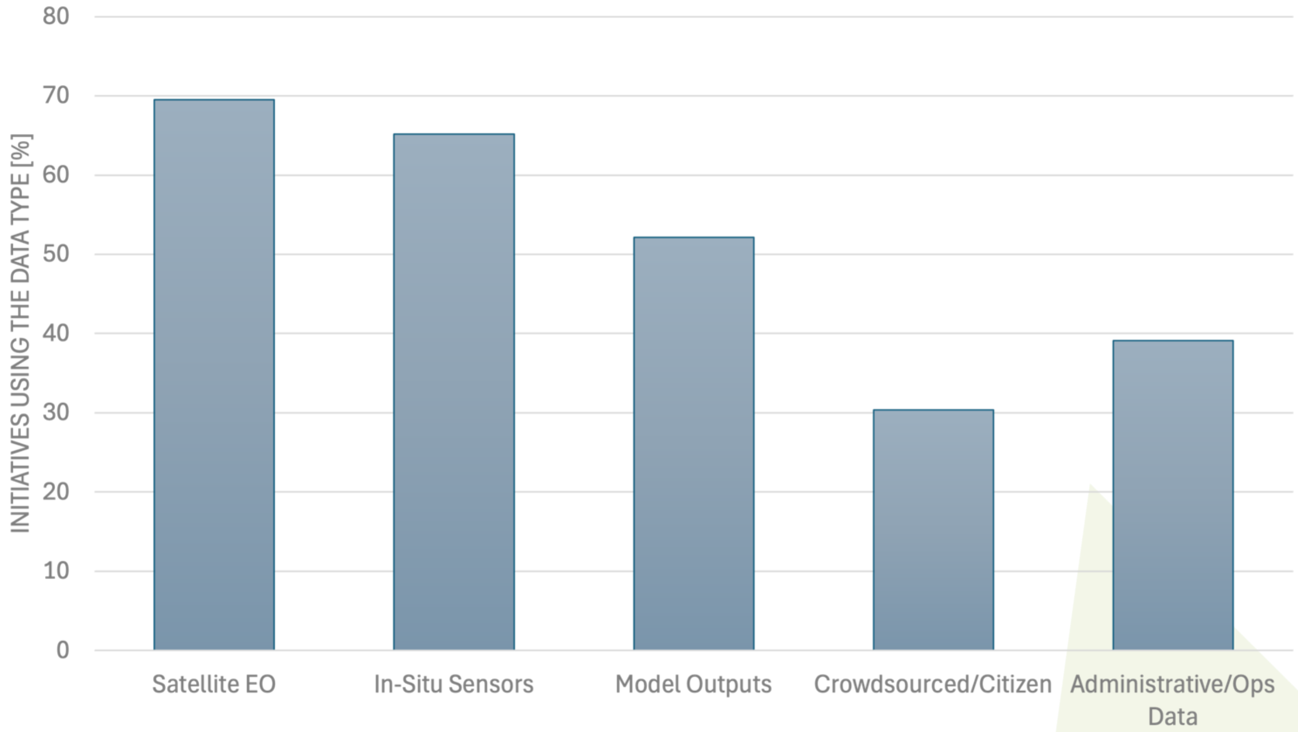

Figure 37 - Count of Initiatives Using Each Data Type. Most of the initiatives employ satellite EO data (≈70%) and in-situ sensors (≈65%). Model outputs are used in about half, while administrative and citizen-sourced data appear in 40% and 30% respectively. The pattern illustrates both data richness and fragmentation.

Each data source carries its own integration cost. EO data require atmospheric corrections and high computational capacity for processing; in-situ networks demand calibration and maintenance; citizen data raise issues of validation and trust. Without shared transformation services, each initiative reinvents the data-processing wheel.
The lack of unified schemas further complicates matters. A river gauge, a snow sensor, and a meteorological station may all produce time series, but with different timestamp formats, coordinate systems, and units. A dataspace designed with explicit metadata standards could abstract these differences, allowing AI models to query harmonized datasets through a single interface.

9.6 The Geography of Data: Local Versus Shared

The location and ownership of data reveal much about institutional priorities. The simulated analysis of Alpine initiatives shows that the majority of data remain locally stored, reflecting both pragmatic and political factors.

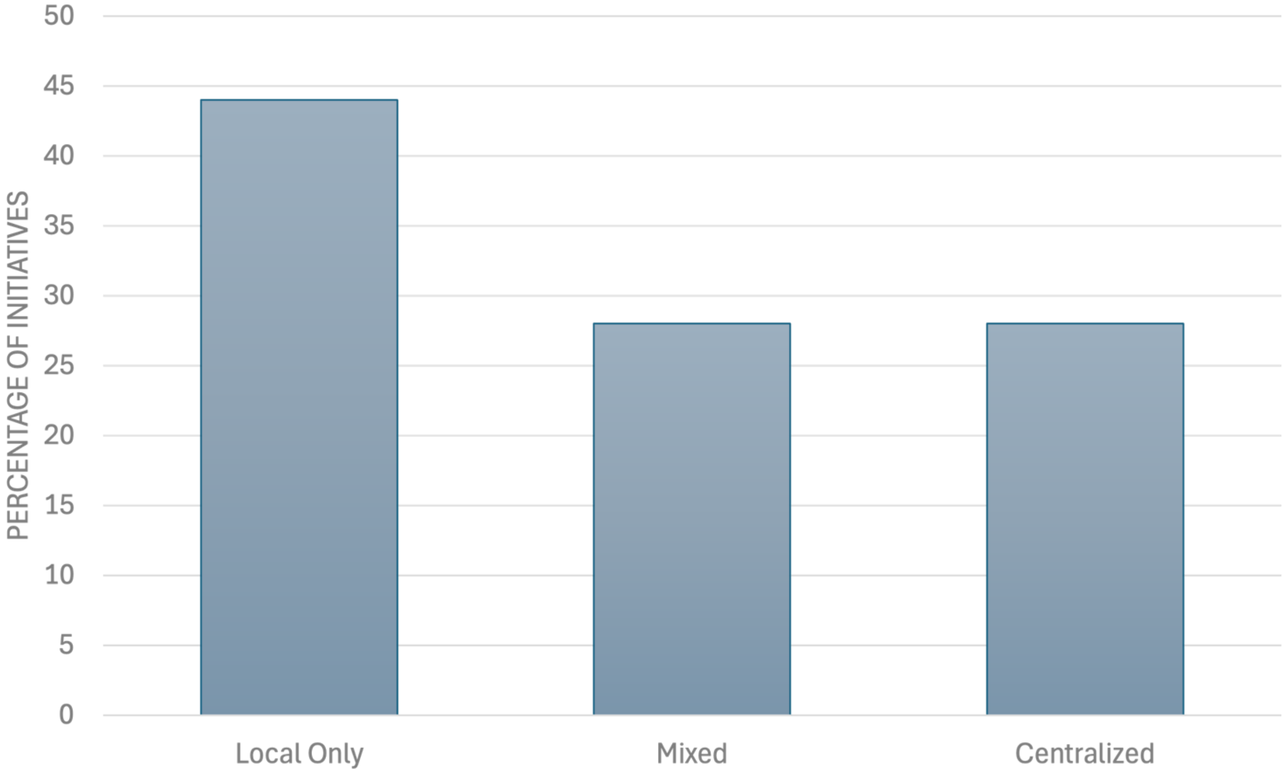

Figure 38 - Data Locality Among Initiatives. Roughly 44% of initiatives store data locally, 28% adopt mixed architectures, and 28% rely on centralized repositories. The predominance of local storage underscores the need for federated sharing models.

Local data governance is often justified by proximity and control. Operators value autonomy and fear losing sovereignty or data quality when contributing to central infrastructures. However, environmental systems are not confined by administrative boundaries. Snowmelt upstream affects floods downstream, and droughts ignore national borders. Therefore, retaining data in local silos compromises regional resilience.

A federated dataspace model provides a balanced solution. It preserves local authority while enabling standardized access through governed interfaces. Under such a system, datasets remain where they are produced but become discoverable and usable regionally. Metadata are shared, not the raw data, unless specific agreements allow transfer. This design reconciles local sovereignty with collective intelligence.

9.7 The Cost of Fragmentation

The fragmentation of AI and data infrastructures carries quantifiable costs. Repeated integration, model duplication, and the absence of standardized components delay deployments and inflate budgets. To visualize the magnitude of this inefficiency, a simulated projection was performed comparing two scenarios: the current project-by-project approach and a future in which interoperable AI modules operate within a common Alpine Water Dataspace (AWD) and Digital Twin Engine (DTE).

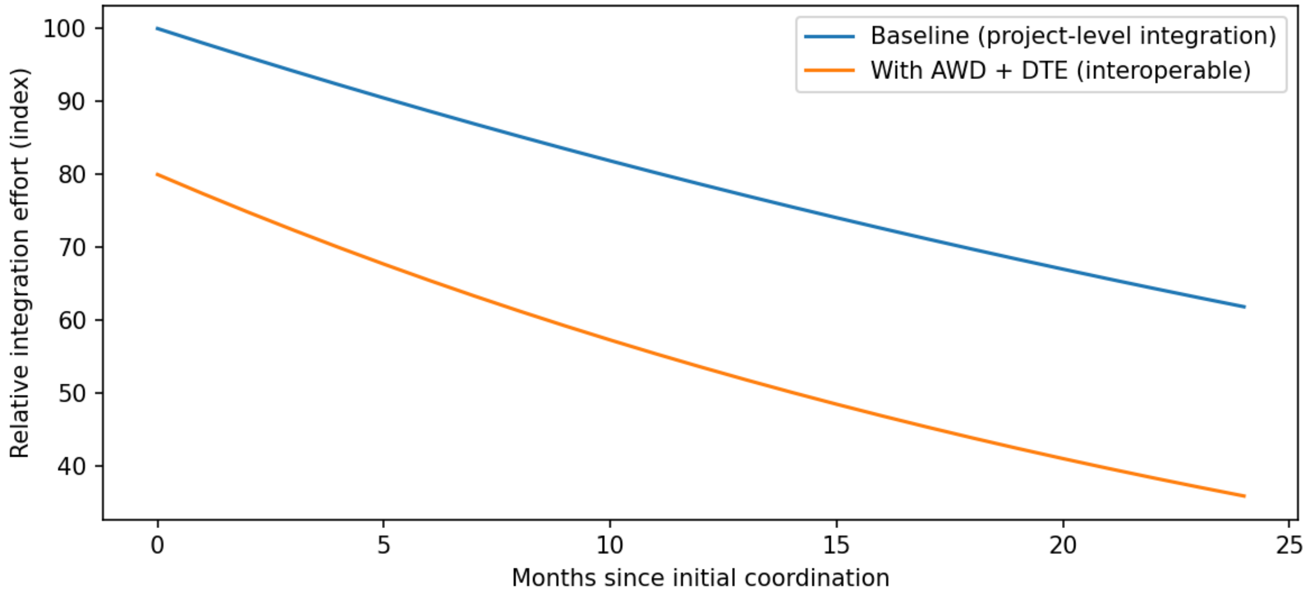

Figure 39 - Simulated Reduction in Integration Effort Over Time. A line graph comparing two trajectories. Under the current fragmented system, integration effort declines slowly and asymptotically over 50 months. With a coordinated AWD and DTE architecture, the decline is twice as fast, reaching steady-state efficiency in roughly 30 months. The gap represents time and resources saved through interoperability.

While the numbers are illustrative, the message is robust. The creation of shared data infrastructures accelerates learning curves and avoids repetitive engineering. Every month saved in integration represents months gained in risk prevention and response capacity.

9.8 The Anatomy of the Present Ecosystem

A closer examination of the Alpine digital landscape reveals four interconnected subsystems:

Sensing and Observation.
The Alps are among the most instrumented mountain ranges globally, yet sensor networks remain fragmented. Each canton, agency, or research consortium maintains its own devices and databases. Harmonization efforts exist but often stop at metadata alignment rather than real-time interoperability.
Data Management and Access.
Repositories and portals proliferate, but they lack federation. Centralized solutions cannot easily accommodate diverse licensing and privacy rules; local systems cannot guarantee discoverability. The balance lies in federated architectures — the core principle behind dataspaces.
Model Development and AI Deployment.
AI models emerge wherever data density is sufficient. They forecast snowmelt, predict floods, and map vegetation health. However, they are rarely portable. Model retraining for new locations remains costly. Without standardized APIs and metadata, a model's reuse potential is drastically limited.
Decision Interfaces.
Ultimately, the purpose of data and models is decision-making. Current dashboards and alert systems are often custom-built, visually polished but siloed. They provide insights for single operators, not

systemic coordination. To evolve, these systems must plug into digital twins capable of simulating cascading events across scales and sectors.

9.9 The Role of AI in Digital Twin Architectures

Digital twins combine physical models, data streams, and AI to create continuously updated representations of reality. In the Alpine context, they promise to unify environmental monitoring, forecasting, and scenario planning. AI is indispensable within these twins: it accelerates simulations, enables surrogate modeling, and translates complex datasets into actionable insights.

The future of Alpine environmental management lies in these AI-enabled digital twins. They will allow authorities to run "what-if" scenarios — what if precipitation increases by 30%? What if snow cover declines by half? What if reservoir levels are pre-emptively lowered to absorb potential floods?

Each scenario demands rapid computation and adaptive models. AI makes this feasible by serving as the connective tissue between physics-based simulations and real-time data assimilation.

A robust digital twin for the Alps should thus integrate the following components:

- A shared Alpine Water Dataspace providing standardized access to snow, hydrological, meteorological, and infrastructure data.
- An interoperable AI module registry defining inputs, outputs, and explainability standards.
- A Digital Twin Engine that orchestrates modules, propagates uncertainty, and manages scenario simulations.

9.10 Governance and Trust in Shared AI Systems

Technical excellence alone cannot ensure adoption. Trust, transparency, and accountability are prerequisites for shared AI ecosystems. Alpine stakeholders — from municipal engineers to national ministries — require assurance that models behave predictably and ethically.
Explainable AI (XAI) becomes crucial in this regard. Each AI module should be accompanied by documentation outlining its training data, validation process, and performance metrics. Provenance tracking should allow any result to be traced back to its data sources and model version.
Equally, governance frameworks must delineate rights and responsibilities. Data providers should retain ownership but share under clear licenses. End-users should commit to responsible use. Public institutions must facilitate data exchange while safeguarding privacy and security. Legal templates and standardized contracts can streamline these processes.

9.11 Capacity Building and the Human Dimension

Every technological infrastructure is also a social one. The Alpine digital transition depends on capacity building at multiple levels — from training municipal staff in data literacy to enabling SMEs to adopt interoperable modules.
Workshops, open documentation, and participatory living labs can bridge the gap between technical innovation and institutional uptake. Through co-design processes, local actors can test prototypes, explore model sensitivities, and contribute domain knowledge.

Trust grows through familiarity. When operators understand how an AI model reaches its conclusions and can validate it against their own experience, they are more likely to use it in practice. Thus, human capacity is the linchpin of any digital twin ecosystem.

9.12 Toward a Federated Alpine Data Infrastructure

The analysis of existing patterns leads to an unavoidable conclusion: the future of Alpine AI lies in federation, not centralization.

A Federated Alpine Data Infrastructure (FADI) would link local repositories through shared metadata and standardized access protocols. Within this infrastructure, the Alpine Water Dataspace (AWD) would serve as a flagship domain, enabling water-related datasets to interoperate with climate, hazard, and tourism data.

Such a system would not replace existing repositories but connect them through an interoperability layer. Using open standards (for example, OGC SensorThings, OpenEO), it would provide a consistent framework for discovery, access, and transformation.

The accompanying Digital Twin Engine (DTE) would orchestrate model execution, manage dependencies, and store results with full provenance. AI modules, registered and versioned, would plug into the DTE like components in an ecosystem. As modules evolve, digital twins could update automatically, ensuring reproducibility and adaptability.

9.13 Implementation Pathway and Phased Development

Translating this vision into reality requires phased implementation:

Phase I — Standard Definition and Pilot Integration.

A small consortium defines minimal metadata standards and develops transformation services for a pilot basin. Early AI modules (for snow, runoff, or water quality) are registered and validated.

Phase II — Dataspace Deployment and Model Federation.

The AWD goes live, federating at least three national repositories. The DTE is connected to run cross-border simulations. Funding supports operational hosting and capacity building.

Phase III — Operationalization and Policy Integration.

Digital twins become embedded in decision workflows for flood management, drought planning, and infrastructure design. Policy frameworks mandate standardized data sharing and module registration as conditions for public funding.

9.14 Future Research and Innovation Priorities

The long-term agenda for Alpine digital transformation encompasses technical, scientific, and ethical fronts.

Technically, there is a need for uncertainty-aware surrogate models that merge physics-based constraints with machine learning efficiency. These models will enable rapid ensemble simulations crucial for time-sensitive decisions.

Scientifically, research should focus on cross-domain transfer learning, allowing AI trained in one catchment or domain to adapt efficiently to another with minimal retraining.

Ethically, attention must be given to energy-efficient AI, minimizing the carbon footprint of continuous model training and data storage — a fitting concern for a region synonymous with sustainability.

9.15 Conclusions

The analysis confirms a decisive pattern: the Alpine region's digital landscape is technologically rich but structurally fragmented. Data exist, models exist, and expertise is abundant — yet integration remains the missing link. Across all thematic domains, the evidence points to the same strategic imperatives.

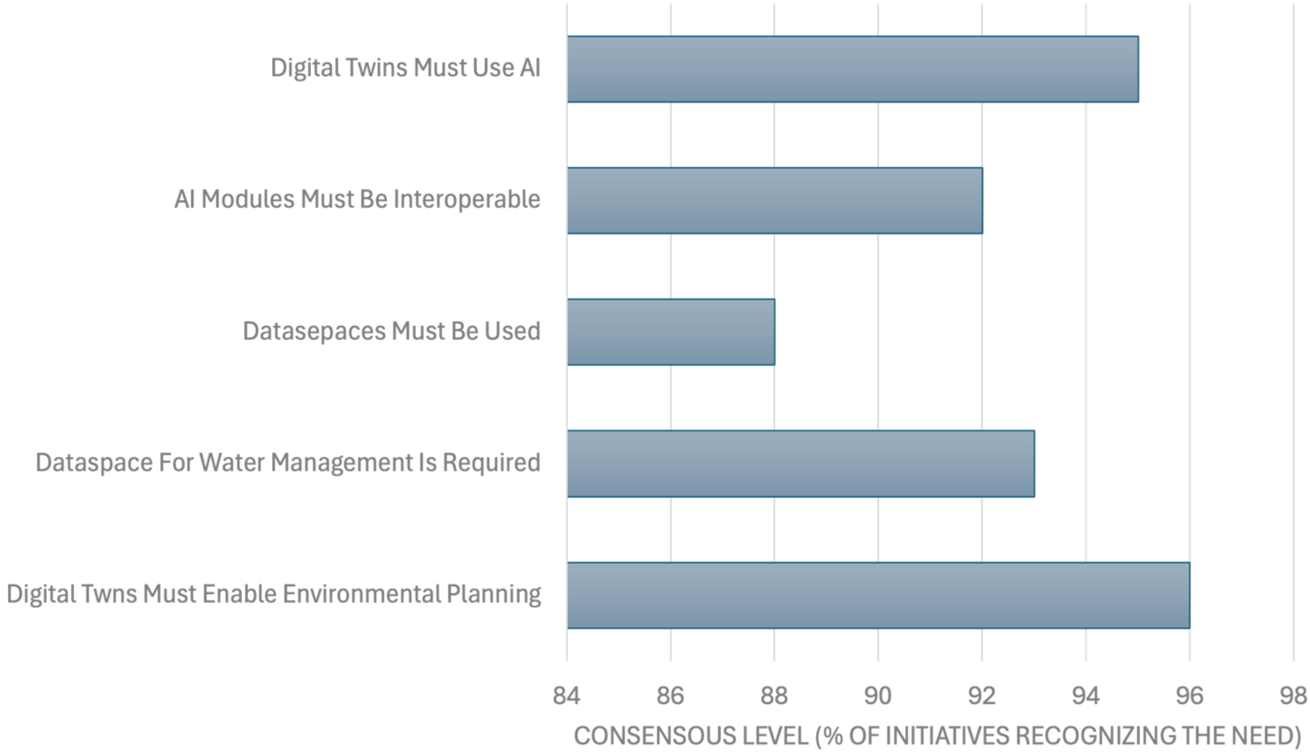

Figure 40 - Future Priorities for an Integrated Alpine Digital Ecosystem. A horizontal bar chart summarizing stakeholder consensus. Nearly all initiatives (above 90%) recognize that: (1) Digital twins must incorporate AI to achieve real-time analytical and predictive capacity; (2) AI modules must be interoperable to enable reuse across domains; (3) Federated dataspaces must become the backbone of Alpine data governance; (4) A dedicated water-management dataspace is urgently required; and (5) Digital twins must enable proactive environmental planning, supporting scenario simulations and preventive monitoring.

This convergence of opinion reflects a shared understanding among institutions, researchers, and policymakers. The Alps, characterized by both natural beauty and environmental vulnerability, cannot afford fragmented digital ecosystems. Without interoperability, forecasting chains remain incomplete; without dataspaces, data remain locked; without AI, digital twins remain static models rather than dynamic instruments for prevention and adaptation.

In the near future, the transition toward a federated, AI-enabled Alpine digital ecosystem is not simply an innovation goal — it is a necessity. Digital twins equipped with intelligent, interoperable modules and backed by shared dataspaces will allow the region to simulate cascading scenarios, test preventive strategies, and plan with foresight rather than reaction.

The establishment of a dedicated Alpine Water Dataspace will serve as the cornerstone of this transformation. By standardizing hydrological and environmental data, it will bridge disciplines and jurisdictions, making it possible to link snow, hydrology, and socio-economic information under one interoperable framework.

In this vision, AI-enhanced digital twins will become operational companions to policymakers — living systems that integrate data, models, and human expertise to safeguard the Alpine environment. They will not only observe and predict but also guide preventive planning, ensuring that communities are better prepared for floods, droughts, ecosystem shifts, and the changing dynamics of tourism. Ultimately, the Alps can become a model for Europe — demonstrating how regional collaboration, technical interoperability, and responsible AI design converge to protect fragile ecosystems while fostering innovation and resilience.

10 Cross-cutting Analysis: Ethical Considerations and Challenges of AI Adoption in the Alps

Artificial intelligence now threads through the Alpine region's digital transformation, touching how we monitor snow, manage rivers, predict hazards, and shape tourism flows. Yet beneath the technical promise lies a complex ethical terrain. The Alps are not merely a data-rich laboratory; they are home to communities whose livelihoods depend on natural systems that AI seeks to model and predict. Understanding the ethical dimensions of this transformation is therefore central to ensuring that innovation strengthens rather than undermines the social and ecological fabric of the region.

The first ethical challenge arises from the opacity of AI systems. Many of the machine learning models now used for environmental prediction operate as black boxes. They identify correlations and patterns invisible to the human eye, but they rarely reveal the logic behind their decisions. For policy makers and local authorities, this opacity introduces a dilemma: how can one justify an action—such as altering reservoir releases, closing a ski area, or issuing an evacuation alert—if the reasoning behind the prediction is inaccessible? In mountainous regions where decisions have immediate consequences for safety and livelihoods, interpretability becomes more than a scientific aspiration; it is a moral obligation. Explainable AI methods, sensitivity analyses, and transparent model documentation are therefore ethical as well as technical necessities. Without them, trust in digital decision systems will erode, and the social legitimacy of AI-driven governance will falter.

A second challenge concerns data ownership and privacy, particularly when AI systems integrate local operational data, tourism records, or community-based observations. Water-use statistics, visitor mobility traces, and environmental sensor readings may seem benign in isolation, yet when combined they can reveal sensitive information about individual behaviors or infrastructure vulnerabilities. The Alps, crisscrossed by multiple legal jurisdictions, amplify this problem. National data-protection laws differ, and cross-border data flows may inadvertently breach local regulations. Establishing dataspaces that respect both the General Data Protection Regulation and regional sovereignty requires not only technical safeguards but also negotiated trust among data providers. Ethical data governance must therefore balance openness with discretion, ensuring that transparency does not become exposure.

Beyond privacy, data justice emerges as a defining theme. AI models trained on uneven or biased datasets risk reinforcing inequalities among Alpine communities. Wealthier regions with dense sensor networks and high-resolution data will naturally generate better-performing models, while data-poor valleys may receive less accurate forecasts or fewer digital services. Over time, this asymmetry could translate into disparities in resource allocation and preparedness. Ethical AI adoption in the Alps must therefore include deliberate strategies to correct such imbalances—through targeted investment in monitoring, shared calibration datasets, and participatory mechanisms that allow smaller municipalities to influence model design. Only then can the benefits of AI be distributed equitably across the mountain chain.

Environmental ethics add another layer of complexity. AI systems depend on computation, and computation consumes energy. As digital twins and continuous simulations proliferate, their carbon footprint cannot be ignored. For a region emblematic of natural beauty and climate vulnerability, it would be paradoxical if environmental monitoring itself contributed to emissions. Sustainable AI practice demands the use of energy-efficient algorithms, green data centers powered by renewable sources, and explicit accounting of computational costs in project design. The moral principle is simple but profound: technology meant to protect the environment must not degrade it in its operation.

Another ethical concern relates to accountability in automated decision-making. As AI-driven systems move from advisory to operational roles—controlling water gates, triggering alerts, or optimizing energy distribution—the line between human and machine agency blurs. When an automated forecast proves wrong or an algorithmic recommendation leads to damage, determining responsibility becomes difficult. Legal frameworks for liability in the context of AI-assisted environmental management remain underdeveloped. The Alps, with their cross-jurisdictional governance structures, illustrate this gap vividly. Addressing it will require clear protocols that define human oversight, auditability, and redress mechanisms. Every digital twin should preserve a log of its inputs, model versions, and decision paths so that actions can be traced and contested if necessary.

Cultural and social acceptance form a subtler but equally critical dimension. Alpine communities have long histories of managing risk through local knowledge and collective norms. The introduction of algorithmic tools can unintentionally marginalize these forms of expertise, replacing experiential judgment with statistical reasoning. Ethically sound AI adoption must therefore embrace co-creation rather than substitution. Local knowledge—observation of snow behavior, seasonal water cues, or traditional land-use practices—provides contextual nuance that no dataset can replicate. Integrating this knowledge into model design not only improves performance but also nurtures trust, ensuring that communities see AI as a partner rather than an intruder.

Language and accessibility further complicate ethical inclusion. The Alpine arc spans multiple linguistic regions; technical documentation and user interfaces that exist only in English risk excluding local actors from meaningful participation. Ethical design thus requires linguistic pluralism and usability testing across cultures. The aim is to democratize the interface between AI and society so that the technology becomes comprehensible and useful to those who live with its consequences.

The governance of dataspaces introduces yet another ethical frontier. Decisions about who may contribute data, who may access it, and under what terms, carry implicit power dynamics. Larger institutions may dominate standards-setting processes, while smaller actors struggle to comply. An equitable dataspace must incorporate participatory governance, transparent licensing, and mechanisms to prevent monopolization of data assets. Openness must coexist with reciprocity: contributors should benefit from the shared knowledge base, not merely supply raw material for others' analytics.

Ethical reflection also extends to risk communication. AI systems excel at forecasting probabilities, but human communities need narratives, not just numbers. A flood-risk percentage means little unless it is translated into guidance that people can act upon. Miscommunication can induce panic or complacency, both of which are dangerous in mountain environments. The ethical responsibility of AI developers is therefore to design outputs that convey uncertainty clearly and support reasoned decision-making rather than overconfidence.

Finally, the overarching challenge is temporal: aligning the rapid cycles of technological innovation with the slower rhythms of governance and culture. AI models evolve in months, but institutional adaptation often takes years. Ethical stewardship demands mechanisms for continual dialogue between developers, policymakers, and citizens. Regular audits, open review processes, and adaptive governance frameworks can help ensure that AI evolves within boundaries accepted by society.

In the Alpine context, these ethical dimensions converge on a single insight: the credibility of AI depends not only on accuracy but also on fairness, transparency, and inclusivity. The region's future digital twins will be judged as much by how they respect local autonomy and ecological values as by how precisely they forecast runoff or snowpack. Ethical design is not an optional add-on; it is the foundation of resilience. When communities trust that their data are protected, that models are interpretable, and that decisions remain accountable, AI becomes a genuine ally in safeguarding both people and landscapes.

In this light, the adoption of AI across the Alps represents a profound social contract. It binds technological ambition to moral responsibility. The same principles that guide mountaineers—prudence, respect, cooperation—must guide those who build the digital infrastructures of the highlands. Only through such alignment can the region's technological ascent remain consistent with its enduring commitment to sustainability and shared stewardship of one of Europe's most cherished environments.

11 Conclusions: The Future of AI in the Alpine Region

The Alpine region stands at a critical juncture — a moment where technological evolution and environmental urgency converge. Over the last decade, artificial intelligence has moved from experimental pilots in flood forecasting or tourism analytics to forming the conceptual backbone of cross-border digital transformation. Yet, what lies ahead will demand more than incremental progress. The future of AI in the Alps will be defined by integration, foresight, and ethical alignment: the capacity to transform isolated digital tools into an interconnected intelligence that serves both nature and society.

The next generation of Alpine AI will be distinguished by systemic interoperability. The time of bespoke, one-off models tailored to narrow valleys or single hazards is ending. Future systems must operate as part of federated digital twins, capable of sharing data, algorithms, and predictions across domains and borders. This shift will redefine what it means to deploy AI in an environmental context. Instead of creating dozens of unlinked forecasting tools, the region will develop shared, modular AI components — interoperable agents that can be combined dynamically depending on the event or the policy question at hand.

In practice, this will mean that an AI model predicting snowmelt in Tyrol could feed data directly into a flood-risk simulation for Slovenia or a hydropower optimization tool in Piedmont. Such integration will not happen spontaneously; it will require shared ontologies, standardized metadata, and an Alpine-wide dataspace where every dataset and model is registered with defined interfaces. The emergence of an Alpine Water Dataspace (AWD), as previously discussed, will likely become the keystone of this architecture. Around it, other thematic dataspaces — for biodiversity, tourism, mobility, and climate adaptation — will interconnect, forming the digital nervous system of the Alpine macroregion.

Another defining characteristic of the future will be real-time digital twinning. Digital twins will evolve from static simulations into dynamic, continuously learning systems. They will ingest live sensor data, update their predictions on the fly, and test multiple scenarios simultaneously. AI will provide the intelligence layer that allows these twins to reason under uncertainty, to prioritize among competing outcomes, and to learn from their own performance. As these twins mature, they will move from passive monitoring to active decision support, recommending actions such as water releases, evacuation timing, or infrastructure adjustments before crises occur.

This transformation will also redefine governance. Regional authorities, utilities, and environmental agencies will operate within shared AI ecosystems, where responsibilities are distributed across institutions but coordinated through common digital protocols. The digital twin will serve as a collaborative workspace where meteorologists, hydrologists, engineers, and policy makers interact with the same real-time representation of the environment. Decision-making will thus become not only faster but also more transparent and reproducible.

A central dimension of this future is predictive prevention. Climate change is amplifying the volatility of the Alpine environment — earlier snowmelt, longer droughts, more frequent flash floods, and shifting vegetation patterns. AI offers the capacity to simulate these changes under multiple scenarios and to guide adaptation policies accordingly. The future Alpine digital twins will become laboratories for foresight: they will allow planners to explore the implications of new land-use strategies, energy infrastructures, or tourism models decades before they materialize. In doing so, AI will transform uncertainty from a threat into a manageable variable.

At the same time, AI will enable personalized environmental services. Just as urban digital systems deliver personalized transport or energy advice, Alpine communities will benefit from localized recommendations — for example, advising farmers on irrigation timing, mountaineers on avalanche risks, or municipalities on optimal reservoir management. These services will emerge from the convergence of AI with edge computing, where small, efficient models operate directly within sensors or local servers, minimizing latency and dependency on central infrastructure. This decentralization will not only improve responsiveness but also enhance resilience against connectivity disruptions in remote valleys.

However, the future will not be purely technical. The human dimension will remain decisive. The success of AI will depend on how well it integrates with existing cultural and governance frameworks. The Alps have a long tradition of local autonomy, community management of resources, and transnational cooperation through organizations such as the Alpine Convention. Future AI initiatives must build upon, not override, this legacy. The most promising developments will emerge where technological innovation meets participatory governance, ensuring that digital tools reinforce rather than replace human judgment.

Education and capacity building will thus become foundational pillars. Universities, research centers, and regional administrations will need to establish new programs that blend environmental science, computer engineering, and ethics. Training hydrologists to understand neural networks, or data scientists to appreciate geomorphology, will create the hybrid expertise required to design trustworthy and context-sensitive AI systems. The region’s multilingualism and cultural diversity, often viewed as a barrier to integration, can instead become a strength — fostering cross-disciplinary dialogue and innovation.

Another crucial element of the future landscape is AI governance through standards and regulation. As the European Union advances frameworks such as the AI Act and the Data Governance Act, the Alpine region can serve as a living testbed for their application in environmental domains. The challenge will be to operationalize legal principles like transparency, human oversight, and accountability within complex multi-actor systems. The region’s experience with cross-border water treaties and hazard management agreements provides an institutional template for such cooperation.

The energy dimension cannot be ignored. The Alps host major hydropower infrastructure and transmission corridors, positioning them as a renewable backbone for Europe. Future AI systems will not only manage water but also balance energy generation, grid stability, and ecological flows. By integrating AI with digital twins of energy networks, the region could pioneer low-carbon optimization strategies that respond dynamically to climate forecasts and market signals. In this sense, the Alpine AI ecosystem will serve both environmental protection and energy transition — two sides of the same sustainability coin.

In tourism, AI will become a compass for sustainability. Visitor flows can be forecast and managed to minimize ecological impact while maintaining economic vitality. Intelligent recommender systems could direct tourists toward less congested areas, balancing preservation and access. Digital twins of transport networks could simulate visitor mobility under different climate conditions, enabling adaptive planning.

Such applications will illustrate how AI, when ethically designed, can harmonize economic activity with environmental stewardship.

Looking further ahead, multi-modal AI architectures will dominate. Rather than relying solely on traditional machine learning, systems will integrate symbolic reasoning, physics-based constraints, and large foundation models trained on global Earth observation data. These hybrid approaches will enhance both accuracy and interpretability. Foundation models fine-tuned for mountain environments could serve as universal backbones from which local models derive, drastically reducing the cost of new deployments. Such an approach will mirror the evolution of natural language processing, where a few general-purpose models support countless applications.

To ensure sustainability, green AI principles will be embedded from the outset. Edge computing, model compression, and efficient retraining pipelines will reduce computational demand. Renewable-powered data centers situated near hydropower facilities will host the core digital twins. The Alps, with their abundant hydroelectric resources, could become Europe’s prototype for climate-neutral AI infrastructure.

Ultimately, the future of AI in the Alpine region is not a distant abstraction but an ongoing construction project — a collective effort to merge technology, ecology, and culture into a coherent vision of digital sustainability. The region has all the ingredients for success: rich data streams, strong research institutions, and a history of cross-border collaboration. What it now requires is commitment to interoperability, shared governance, and ethical innovation.

In the decades ahead, Alpine AI will evolve from a collection of tools into a living digital organism, continuously sensing, learning, and adapting alongside the mountains themselves. It will mirror the Alps’ resilience: flexible, distributed, and deeply interconnected. When this vision matures, the region will not only manage its natural risks more effectively but also model how humanity can coexist intelligently with fragile ecosystems. The ultimate goal is not to dominate the Alpine environment through technology, but to understand and sustain it through intelligence — an intelligence that is collective, transparent, and profoundly respectful of the landscapes it serves.

12 APPENDIX A: POLICIES

12.1 Introduction

The Alpine regions, spanning Austria, France, Germany, Italy, Liechtenstein, Slovenia, and Switzerland within the European Union Strategy for the Alpine Region (EUSALP), face distinct challenges due to their rugged terrain, limited transportation networks, and fragile ecosystems vulnerable to climate change, natural hazards, and resource scarcity. Unlike non-Alpine rural areas, the Alps' unique topography, transboundary dynamics, and extreme environmental variability—such as "last-mile logistics" in remote valleys, cross-border water management, and tourism pressures on delicate landscapes—demand tailored AI solutions. These policies harness AI to enhance resource efficiency, economic diversification, safety, and environmental protection, bridging the digital divide, fostering green innovation, attracting talent, and aligning with frameworks like the EU Water Framework Directive and Alpine Convention, positioning the Alps as a global leader in digital sustainability while boosting GDP and resilience.

12.2 Detailed Policy Recommendations

12.2.1 R1: High-Level Technological Framework

This recommendation establishes a robust technological foundation for AI in the Alps, creating virtual replicas of critical infrastructure like bridges and ecosystems such as glaciers, enabling predictive maintenance and hazard forecasting tailored to the region's complex terrain, unlike simpler rural settings. It ensures AI transparency and trust through interpretable models, vital for Alpine communities facing rapid climate shifts, and promotes secure, collaborative AI development across borders, addressing the Alps' multination data sovereignty needs. A shared high-performance computing network supports intensive modeling of Alpine-specific climate and hazard scenarios, leveraging transboundary collaboration unique to this region.

12.2.2 R2: Data and Infrastructures

This recommendation focuses on building a cohesive data ecosystem for the Alps, harmonizing standards for seamless data sharing across sectors like water, hazards, and climate, essential for the region's transboundary rivers and hazard-prone slopes, unlike localized rural areas. It deploys dense IoT sensor networks and satellite monitoring to capture real-time data on water flows, avalanche risks, and climate indicators, critical for the Alps' volatile environment. Robust cybersecurity protects sensitive cross-border data, a priority in the Alps' interconnected jurisdictions. A unified AI platform integrates diverse data for trend analysis and visualization, addressing the region's ecological and geopolitical complexities.

12.2.3 R3: Applications and Use Cases

This recommendation drives practical AI applications tailored to Alpine challenges, promoting their development through targeted pilot projects. It forecasts water availability, floods, and droughts across transboundary basins, unlike the simpler water issues in non-Alpine rural areas, with pilots testing AI models in key watersheds. It supports tourism and sports through innovation hubs offering training and AI tools for sustainable practices, optimizing ski resorts and seasonal peaks unique to the Alps, with pilots in select tourism destinations. Cross-border hazard monitoring systems, piloted in high-risk border zones, tackle shared risks like landslides and avalanches, irrelevant to most rural regions. Predictive climate modeling, tested through regional pilots, addresses glacier retreat and extreme weather, ensuring adaptation strategies for the Alps' distinct ecosystems.

12.2.4 R4: Innovation and Education

This recommendation fosters AI-driven education and accountability in the Alps, delivering tailored training platforms for rural youth and SMEs in sustainable sectors like mountain tourism and farming, addressing harsher environmental constraints than typical rural areas. Multilingual support and cross-border partnerships reflect the Alps' diverse linguistic landscape. A structured assessment system with public dashboards ensures transparency and tracks AI impacts on Alpine-specific hazards and ecosystems, using region-specific metrics to guide policy and build trust.

12.3 Impacts

The AI policy recommendations for the Alpine regions promise significant economic, environmental, and social benefits tailored to the region's unique challenges. Economically, they reduce maintenance and compliance costs by up to 30%, boost tourism and sports revenue by 10-15%, and enhance SME competitiveness, fostering job creation and attracting tech investment. Environmentally, they improve ecosystem monitoring accuracy by 25%, reduce ecological footprints by 10%, and enhance climate resilience through precise data and predictive models, critical for the Alps' fragile landscapes. Socially, they enhance safety through faster hazard responses, increase public trust via transparent AI systems, and reduce rural brain drain with inclusive education, addressing the Alps' cross-border and cultural diversity. Unlike non-Alpine rural areas, these impacts leverage the region's transboundary dynamics and extreme environmental variability, ensuring sustainable resource management, economic diversification, and community resilience, positioning the Alps as a leader in green AI innovation.

Table 1 - Impacts of harnessing AI strategies and frameworks in alpine areas.

Recommendation	Economic Impacts	Environmental Impacts	Social Impacts
R1: High-Level Technological Framework	Cost savings through predictive maintenance, optimized resource use, and attraction of tech investment due to advanced AI infrastructure unique to Alpine needs.	Enhanced ecosystem monitoring accuracy, reduced environmental degradation via precise simulations, and lower energy use through efficient computing, tailored to Alpine ecosystems.	Increased safety via reliable infrastructure, enhanced trust in transparent AI systems, and stronger cross-border cooperation, addressing Alpine communities' unique needs.
R2: Data and Infrastructures	Reduced compliance costs, optimized resource allocation, and lower disaster	Improved water quality, ecosystem protection, and climate adaptation through real-time data	Enhanced safety, transparency, and public participation in data-driven decisions, reducing risks and

Recommendation	Economic Impacts	Environmental Impacts	Social Impacts
	recovery costs due to harmonized data and monitoring systems for Alpine transboundary challenges.	and secure platforms, critical for the Alps' volatile environment.	conflicts in Alpine border regions.
R3: Applications and Use Cases	Increased tourism and sports revenue, reduced flood/drought damages, and efficient resource use through targeted AI pilots, addressing Alpine-specific economic drivers.	Reduced ecological footprint, better conservation of Alpine landscapes, and improved climate resilience through tailored AI applications.	Enhanced safety, improved visitor experiences, and stronger community resilience through AI-driven solutions for Alpine hazards and tourism.
R4: Innovation and Education	Higher SME competitiveness, increased employability, and reduced rural unemployment (10%) through specialized AI training for Alpine economies.	Workforce skilled in sustainable practices for Alpine ecosystems, reducing environmental impact in tourism and farming.	Reduced rural brain drain, inclusive access to education, and increased public trust via transparent AI impact assessments, tailored to Alpine diversity.

12.4 Governance

Implementing these AI policies requires coordinated action across governance levels, tailored to the Alps' transboundary context. At the EU level, funding through Horizon Europe, Interreg, and Digital Europe supports pilot projects, data standards, and AI ethics guidelines. National governments align data policies, invest in HPC and monitoring infrastructure, and enact cybersecurity laws to enable cross-border collaboration. Regional authorities lead pilot projects, deploy sensor networks, manage data platforms, and establish training hubs, ensuring integration with Alpine-specific needs. Local stakeholders maintain sensors, adopt AI tools, and provide data and feedback for pilots, grounding implementation in community needs. This multi-level approach, unlike governance for non-Alpine rural areas, addresses the Alps' geopolitical complexity and environmental volatility. Key timelines must include feasibility studies, pilot launches and region-wide scaling ensuring effective coordination and leveraging frameworks like the Alpine Convention for success.

Table 2 - Governance to implement AI strategies and frameworks in alpine areas.

Recommendation	European Union Level (EC, EP, Council)	National Level (Government, Parliament)	Regional Level	Local Level
R1: High-Level Technological Framework	Fund pilot projects and HPC networks via Horizon Europe/EuroHPC, develop AI ethics and interoperability standards.	Dedicate HPC nodes, align data laws for cross-border AI, support national AI ethics committees.	Lead pilot projects for digital twins, facilitate HPC access, train stakeholders in AI ethics.	Provide local data for models, engage in pilot projects, ensure ethical AI use.
R2: Data and Infrastructures	Fund sensor networks and platforms via Interreg, set data and cybersecurity standards.	Align data policies, invest in monitoring infrastructure, enact cybersecurity laws.	Deploy sensors, manage platforms, coordinate cross-border data sharing.	Maintain sensors, contribute data, adopt secure data protocols
R3: Applications and Use Cases	Provide funding for AI pilots under Digital Europe, develop guidelines for sustainable applications.	Support national agencies for AI adoption, fund pilot infrastructure.	Launch and evaluate pilots in tourism, sports, and hazard zones, provide training.	Adopt AI tools, participate in pilots, share local use case feedback.
R4: Innovation and Education	Fund education platforms via Erasmus+, define AI impact assessment frameworks.	Align training with national AI strategies, co-fund education programs.	Establish AI training hubs, adapt dashboards to regional needs.	Facilitate training participation, report AI impacts, engage communities.

12.5 Implementation

To ensure effective implementation of the AI policy recommendations for the Alpine regions, a multi-level governance approach is essential. Responsible actors include EU bodies (e.g., European Commission for funding via Interreg/Horizon Europe), national governments (aligning policies and investing in infrastructure), regional authorities (coordinating pilots and data platforms), and local stakeholders (maintaining sensors and adopting AI tools). Potential enablers include existing frameworks like the Alpine Convention, partnerships with research institutions, and private-sector and digital innovation hubs. Resource requirements encompass funding for IoT sensors, HPC infrastructure, and training programs, alongside expertise in AI ethics and cybersecurity. Key steps involve: Year 1–2: Conduct feasibility studies and establish governance structures; Year 2–4: Launch pilot projects for data networks, AI applications, and training; Year 4–6: Scale successful initiatives EUSALP-wide. Milestones include achieving data and AI interoperability, AI adoption in SMEs, and significant reduction in hazard response times by Year 6.

13 APPENDIX B: Analysis of AI Impact in the Alpine Area: Assessment Matrix on Priority and Feasibility

13.1 Concept and Methodology

In alignment with the Terms of Reference for the AI Study in the Alpine Area (EUSALP AG5, 2025), this section discusses the assessment matrix on priority and feasibility cases. The goal is to synthesize findings from the main application domains into a comparative framework that measures:

- Priority — how critical AI integration is for regional sustainability, climate resilience, economic vitality, and social innovation.
- Feasibility — how readily such integration can occur given current data, infrastructure, institutional capacity, and stakeholder acceptance.

Each sectoral assessment below combines qualitative and semi-quantitative evaluation using scales (High / Medium / Low). Cross-sectoral synergies are also highlighted, since AI applications in the Alps often intersect through shared datasets (e.g., hydrology, land use, tourism mobility) and joint governance frameworks.

13.2 Tourism and Smart Destinations

The tourism sector in the Alps faces transformation pressures from both digitalization and climate change. Projects such as HEALPS-2, SmartCommUnity, and Inter-Bike III have shown how data-driven tools are redefining tourism services, mobility, and health-based attractions.

Priority Dimension

Tourism is a high-priority domain for AI adoption. Its economic relevance for the Alpine economy, combined with the urgency of adapting to changing visitor patterns (seasonality shifts, reduced snow reliability), makes it a strategic front for AI-driven solutions. The capacity of AI to personalize services, reduce environmental stress, and support sustainable resource distribution (e.g., trail congestion prediction, e-bike demand optimization) positions it as a lever for climate adaptation and competitiveness.

Feasibility Dimension

Feasibility is medium-high. The main enablers are strong digital infrastructure in many tourist areas, large datasets (visitor mobility, booking, sensors), and stakeholder readiness (DMOs, SMEs, public authorities). However, challenges persist in data integration across borders and in smaller rural destinations. Ethical aspects—such as protecting local cultural identity and data privacy—also moderate feasibility.

Key Use Cases

Application	Priority	Feasibility	Enabling Factors	Challenges

AI-driven visitor flow prediction and congestion management	High	High	Availability of mobility data, IoT sensors, high stakeholder engagement	Governance of shared data across borders
Personalized tourism & health-based recommendations	High	Medium	Semantic data models, health datasets	Privacy and data interoperability
Smart mobility & sustainable transport	Medium	High	Existing digital mobility pilots	Need for cross-border integration
Predictive maintenance & resource optimization	Medium	High	Sensor networks (LoRaWAN, IoT)	Heterogeneous infrastructure

13.3 Natural Hazard Risk Management and Climate Change Monitoring

Projects such as GreenRisk4ALPs, MOSAIC, X-RISK-CC, and MedEWSa have laid a foundation for combining ecosystem-based approaches with AI-driven predictive analytics. While direct AI deployment is still emerging, the sector exhibits high strategic potential.

Priority Dimension

This is a top-priority domain. AI directly contributes to protecting lives, infrastructure, and ecosystems under accelerating climate extremes. Predictive analytics, hybrid modelling (data + physics), and real-time hazard forecasting align with EUSALP's resilience agenda.

Feasibility Dimension

Feasibility is medium due to technical and institutional constraints. AI readiness varies: some projects (MedEWSa, AI4FLOOD) already deploy hybrid and ML-based early-warning systems, while others (GreenRisk4ALPs, MOSAIC) provide the data infrastructure but not yet algorithmic layers. Barriers include fragmented data ownership, varying sensor density, and limited local technical capacity in smaller municipalities.

Key Use Cases

Application	Priority	Feasibility	Enabling Factors	Challenges
Multi-hazard early warning and impact prediction	High	High	Hybrid AI models, European interoperability frameworks	Need for Alpine-specific tuning
AI-enhanced protective forest management	High	Medium	Extensive forestry datasets, living labs	Data heterogeneity, limited AI integration
Extreme weather risk forecasting and compound event modelling	High	Medium	Harmonized climate datasets	Limited operational AI deployment
Citizen-driven microclimate monitoring	Medium	High	Crowdsourced data, participatory governance	Data quality, calibration standards

13.4 Water Management and Blue Infrastructure

The WATERWISE and PlanToConnect are sample projects that illustrate a transition toward integrated, participatory, and data-centric water governance. Although AI deployment is still in its preparatory phase, the technical and institutional landscape is promising.

Priority Dimension

AI in water management holds high strategic priority, particularly given the Alps' role as Europe's "water tower." Issues of drought, snowmelt, hydropower optimization, and flood risk require advanced analytics and predictive modelling.

Feasibility Dimension

Feasibility is medium to high, driven by the establishment of harmonized datasets, monitoring networks, and participatory co-design processes. The main obstacles include lack of continuous high-frequency sensor data in many catchments, variable institutional capacity, and uneven access to computational resources.

Key Use Cases

Application	Priority	Feasibility	Enabling Factors	Challenges
AI-assisted hydrological forecasting	High	Medium	Multi-source datasets, sensor networks	Limited AI model deployment phase
Connectivity optimization & blue infrastructure planning	Medium	High	GIS data, ecological and hydrological mapping	Temporal resolution and real-time data gaps
Flood resilience and wetland health classification	Medium	Medium	Biodiversity & hydrology data	Lack of large training datasets
Cross-sector water-energy-biodiversity optimization	Medium	Low	Value chain data and indicators	Weak direct AI focus, multi-domain complexity

13.5 The Combined AI Impact Matrix

To visualize overall readiness and importance across sectors, the following matrix synthesizes priority (vertical axis) and feasibility (horizontal axis) into a unified view. Each position represents a thematic cluster:

- High Priority–High Feasibility (HP-HF) → immediate opportunity for deployment
- High Priority–Medium Feasibility (HP-MF) → strategic investment needed
- Medium Priority–High Feasibility (MP-HF) → scalable pilot domain
- Low Feasibility or Priority (LP/LF) → exploratory or long-term research focus

Sector / Application Cluster	Priority Level	Feasibility Level	Category	Strategic Implication
Tourism personalization and smart mobility	High	High	HP-HF	Ready for scaling; economic leverage for AI visibility
Predictive natural hazard monitoring (multi-hazard)	High	Medium	HP-MF	Strategic investment domain; needs interoperable dataspaces
AI-driven water resource optimization	High	Medium	HP-MF	Key for climate adaptation; requires data standardization
Forest risk analytics and ecosystem-based hazard management	High	Medium	HP-MF	Build on GreenRisk4ALPs/MOSAIC; enhance AI infrastructure

Smart blue-green connectivity planning	Medium	High	MP-HF	Ideal for regional AI upscaling; low ethical risk
Citizen and participatory AI monitoring (air, microclimate, tourism)	Medium	High	MP-HF	Enhances social acceptance and co-creation
AI for biodiversity–energy trade-offs (bioenergy/water nexus)	Medium	Low	LP-MF	Long-term integration; supports circular economy
Health and wellbeing tourism optimization	High	Medium	HP-MF	Strong market pull; need for health data governance
AI-assisted governance and explainability systems	High	Low	HP-LF	Essential for ethical AI and accountability frameworks

13.6 Cross-Sectoral Insights

Shared Data Infrastructures and Dataspaces

All domains converge on the necessity of interoperable Alpine dataspaces — consistent with AG2's parallel study — enabling cross-sector model reuse. A unified Alpine AI dataspace would allow hydrological forecasts to inform hazard alerts or tourism planning. Projects like WATERWISE and MedEWSa already lay technical foundations for this integration.

Governance and Institutional Feasibility

Feasibility depends not only on technology but also on governance maturity. Projects with embedded participatory structures (SmartCommUnity, WATERWISE, COMMONAIR) demonstrate faster AI readiness. In contrast, those relying heavily on scientific modelling without policy linkage (e.g., MOSAIC's data repositories) face implementation inertia.

Ethical and Societal Acceptability

Ethical and transparency challenges identified in the previous section are most acute where AI influences safety-critical or personal domains. Therefore, explainable AI, multilingual interfaces, and co-design with communities must accompany technical rollouts.

Synergies and Co-Benefits

Synergies arise across borders and topics:

- Tourism and hazard forecasting can jointly use mobility and meteorological data to manage visitor safety.
- Water management and energy planning (e.g., DIVERSE, AMETHyST) can be coupled via AI-based optimization.
- Forest management and climate monitoring feed into resilience models underpinning multiple sectors.

13.7 Strategic Conclusions

From this comparative synthesis, three policy-relevant conclusions emerge:

1. AI for Risk and Resilience – The most urgent but technically complex domain; investment should focus on interoperable datasets, hybrid physical–AI models, and continuous model validation.
2. AI for Sustainable Tourism and Mobility – The most feasible entry point for Alpine-wide scaling, with clear economic returns and strong digital readiness.

3. AI for Integrated Water-Ecosystem Management – A cross-domain opportunity linking environmental monitoring, hydrology, and spatial planning; requires advancing from modelling to predictive automation.

Cross-cutting enablers include digital literacy programs, data-sharing agreements compliant with EU Acts, and open-source model libraries adapted to mountain environments.

13.8 Integrative Perspective: Feasibility–Priority Matrix (Narrative Summary)

If we map all projects into the priority–feasibility continuum, a pattern emerges:

- Upper-right quadrant (High–High): Tourism digitalization and participatory monitoring — immediate pilots.
- Upper-mid quadrant (High–Medium): Natural hazard early warnings, adaptive water systems — need cross-border data and institutional integration.
- Mid-right quadrant (Medium–High): Smart connectivity and ecological planning — ripe for AI scaling once data harmonization is achieved.
- Lower quadrants (Medium/Low): Long-term innovation in biodiversity-energy nexus, ethical AI governance, and explainable decision systems — requiring continuous R&D.

This representation suggests that AI maturity in the Alps follows a gradient from socially-driven feasibility (tourism, mobility) toward technically-driven priority (hazards, water). Aligning policy incentives and capacity building with this gradient will maximize impact.

13.9 Recommendations for Policy and Research

- Develop an Alpine AI Observatory to monitor progress across feasibility–priority dimensions, maintaining a dynamic version of this matrix.
- Invest in hybrid model development combining process-based physics with data-driven learning, ensuring interpretability and local trust.
- Support open Alpine dataspace standards, linking tourism, hazard, and water sectors.
- Fund training and AI literacy programs for municipalities, SMEs, and civil protection agencies.
- Adopt ethical-by-design frameworks that ensure transparency and inclusiveness in all AI systems operating in the Alpine context.

13.10 Conclusion

The AI impact matrix for the Alpine area demonstrates a vibrant but uneven landscape of digital transformation. While tourism already achieves high feasibility, the sectors of water and hazard management represent high-impact frontiers requiring targeted investment and institutional coordination. Together, they define a multi-scalar roadmap: from feasible, human-centered applications that build trust to complex, high-priority systems that secure the region's long-term resilience. Artificial Intelligence thus stands as both a mirror and a motor for Alpine innovation — reflecting existing governance strengths and driving new modes of collective adaptation. When guided by transparency, data ethics, and cross-border cooperation, AI can become a cornerstone of a sustainable, resilient, and inclusive Alpine future.

14 APPENDIX C: Synergies with the EUSALP – AG2 Data Spaces study

This study and the EUSALP AG2 study entitled "Fostering Digital Transformation and data Valorization in Eusalp enhancing competitiveness and innovation through Data Spaces" are highly complementary, defining two integral components of a single vision for a digitally resilient Alpine area.

14.1 Data Spaces as the Enabler for Scalable AI

The most fundamental synergy is the role of Data Spaces as the necessary operational environment for AI systems, particularly for overcoming fragmentation in data sharing:

Overcoming Fragmentation: The AI study observes that current AI solutions in the Alps are often bespoke and rarely interoperable across borders, leading to the region lacking a unified digital infrastructure. The Data Space approach is designed specifically to solve this by providing a controlled, multi-stakeholder ecosystem for data pooling, governance, and sharing based on common standards and rules.

Ensuring Data Availability: AI models are data-intensive, and their performance depends on access to high-quality, aggregated, and cross-sectoral data. A Data Space acts as a federated infrastructure that links local repositories through shared metadata and standardized access protocols, thus ensuring the data availability and interoperability that is currently hindering the scaling and reusability of AI solutions.

Governance and Trust: The Data Space framework is built on defined legal, governance, and trust building blocks. This structure provides the necessary secure and ethical foundation for deploying AI systems, ensuring compliance with EU regulations like the Data Governance Act (DGA) and the AI Act.

14.2 AI as the Primary Driver of Data Valorisation

Conversely, AI is one of the most powerful technologies for achieving the core goal of the Data Space: data valorisation and creating value from shared data.

Value Creation: A Data Space enables the sharing and reusing of data in the context of use cases. AI algorithms and Machine Learning (ML) are the tools used to process the massive amounts of data collected and shared within the Data Space to generate new, high-value insights, predictions, and automated services.

Enabling Predictive Services: Specific AI use cases, such as predictive models for flood detection, demand forecasting, and compound hazard impact analysis, rely entirely on the aggregated and standardized data flows enabled by a Data Space.

14.3 Flagship Use Case: Water Management

Both studies explicitly converge on Water Management as a critical area for immediate synergy in the Alpine region, providing a concrete roadmap for implementation:

Common Strategic Focus: Both studies recognize water management as a strategic theme for the EUSALP area, essential for addressing scarcity and building resilience.

The Alpine Water Dataspace (AWD): The AI study explicitly recommends the creation of an Alpine Water Dataspace (AWD) to serve as a flagship domain within a broader Federated Alpine Data Infrastructure. This directly aligns with the Data Space study's policy recommendation to monitor and support investment in a technological infrastructure upon which a thematic data space for water management could be based. This synergy would combine:

Data Space: Providing the platform for standardized sharing of hydrological data, sensor data, and meteorological information.

AI: Utilizing ML algorithms within that secure space to enhance flood prediction, manage resources sustainably, and improve climate monitoring.

In summary, AI and Data Spaces are in a symbiotic relationship: AI needs the Data Space to exist and scale, and the Data Space needs AI to fulfill its purpose of value creation.

15 Appendix D: Questionnaire AI in Alpine Regions - Current Status and Future Potential

The study here proposed developed at the early stages of the activity a questionnaire to collect information from different target groups.
Target Audience: Digital Innovation Hubs (DIHs) and Research Consortia within the EUSALP Alpine Region
Purpose: To map the current landscape of Artificial Intelligence (AI) application in key thematic areas (Water Management, Tourism & Sport, Natural Hazards Risk Management, Climate Change Monitoring) across the EUSALP alpine regions, identify existing expertise, successful applications, ongoing research, challenges, and future needs to foster collaboration and innovation.

Section 1: General Information

1. Name of Institution/Organization:
    - [Short text answer]
2. Type of Organization:
    - [ ] Digital Innovation Hub (DIH)
    - [ ] Research Institute / University Department
    - [ ] SME / Startup
    - [ ] Large Industry
    - [ ] Public Authority / Regional Agency
    - [ ] Other (Please specify): [Short text answer]
3. Country(ies) of Operation/Focus within EUSALP: (Select all that apply)
    - [ ] Austria
    - [ ] France
    - [ ] Germany (Bavaria, Baden-Württemberg)
    - [ ] Italy (Aosta Valley, Friuli-Venezia Giulia, Lombardy, Autonomous Province of Bolzano, Autonomous Province of Trento, Piedmont, Veneto)
    - [ ] Liechtenstein
    - [ ] Slovenia
    - [ ] Switzerland
    - [ ] Other (Please specify): [Short text answer]
4. Primary Contact Person:
    - Name: [Short text answer]
    - Role/Position: [Short text answer]
    - Email: [Email input]
    - Phone (Optional): [Phone number input]

Section 2: General Experience with AI

5. What is your organization's overall level of experience with Artificial Intelligence (AI)?
   - [ ] No experience / Just exploring
   - [ ] Limited experience (e.g., pilot projects, theoretical research)
   - [ ] Moderate experience (e.g., some deployed applications, active research team)
   - [ ] Extensive experience (e.g., core part of operations/research, multiple deployed solutions)
6. Which types of AI models/techniques are you currently working with or researching? (Select all that apply)
   - [ ] Machine Learning (e.g., Regression, Classification, Clustering)
   - [ ] Deep Learning (e.g., CNNs, RNNs, Transformers)
   - [ ] Natural Language Processing (NLP)
   - [ ] Computer Vision (CV)
   - [ ] Reinforcement Learning (RL)
   - [ ] Generative AI (e.g., GANs, Diffusion Models)
   - [ ] Explainable AI (XAI)
   - [ ] Predictive Analytics
   - [ ] Optimization Algorithms
   - [ ] Other (Please specify): [Short text answer]
7. What is the primary purpose of AI in your current activities? (Select all that apply)
   - [ ] Data Analysis and Insights
   - [ ] Prediction and Forecasting
   - [ ] Automation of Tasks
   - [ ] Decision Support Systems
   - [ ] Resource Optimization
   - [ ] Pattern Recognition
   - [ ] Image/Video Analysis
   - [ ] Text Analysis/Generation
   - [ ] Research and Development of new AI methods
   - [ ] Other (Please specify): [Short text answer]

Section 3: AI Applications and Research in Specific Thematic Areas

For each of the following thematic areas, please describe your current applications and/or research projects involving AI. If not applicable, please select "Not Applicable."

A. Water Management (e.g., hydrological modeling, flood prediction, water quality, hydropower, glacier melt)

8. Are you involved in AI-related applications or research in Water Management?
   - [ ] Yes
   - [ ] No (If No, skip to Section 3B)

16. Are you involved in EU/regional-funded AI-related projects? (Repeat for every project if any)
   - [ ] Yes:
     1. Project Name:
     2. URL:

3. Short Description:
4. Partners Involved:
5. Main Oucomes expected:
- [ ] NO

9. Please describe your primary AI-driven application(s) or research project(s) in Water Management: (Focus on objectives, AI methods used, and stage of development/deployment)
   - [Long text answer]
10. What types of data are you primarily using for AI in Water Management? (Select all that apply)
   - [ ] Sensor data (e.g., water level, flow, temperature, quality)
   - [ ] Satellite imagery (e.g., snow cover, glacier extent)
   - [ ] Meteorological data (e.g., precipitation, temperature, snow depth)
   - [ ] Historical hydrological records
   - [ ] Geographical Information Systems (GIS) data
   - [ ] Social/Crowdsourced data
   - [ ] Other (Please specify): [Short text answer]

B. Tourism & Sport (e.g., visitor management, predictive tourism, personalized experiences, safety in outdoor sports, event optimization)

12. Are you involved in AI-related applications or research in Tourism & Sport?
   - [ ] Yes
   - [ ] No (If No, skip to Section 3C)
17. Are you involved in EU/regional-funded AI-related projects? (Repeat for every project if any)
   - [ ] Yes:
     1. Project Name:
     2. URL:
     3. Short Description:
     4. Partners Involved:
     5. Main Oucomes expected:
   - [ ] NO
13. Please describe your primary AI-driven application(s) or research project(s) in Tourism & Sport: (Focus on objectives, AI methods used, and stage of development/deployment)
   - [Long text answer]
14. What types of data are you primarily using for AI in Tourism & Sport? (Select all that apply)
   - [ ] Visitor statistics (e.g., arrivals, spending)
   - [ ] Social media data
   - [ ] GPS/Location data (e.g., trail usage)
   - [ ] Weather forecasts
   - [ ] Booking/Reservation data
   - [ ] Sensor data (e.g., ski lift queues, snow conditions)
   - [ ] User reviews/feedback
   - [ ] Other (Please specify): [Short text answer]

C. Natural Hazards Risk Management (e.g., landslides, avalanches, rockfalls, floods, extreme weather events prediction, early warning systems)

18. Are you involved in AI-related applications or research in Natural Hazards Risk Management?

- [ ] Yes
- [ ] No (If No, skip to Section 3D)

19. Are you involved in EU/regional-funded AI-related projects? (Repeat for every project if any)
    - [ ] Yes:
        1. Project Name:
        2. URL:
        3. Short Description:
        4. Partners Involved:
        5. Main Oucomes expected:
    - [ ] NO
20. Please describe your primary AI-driven application(s) or research project(s) in Natural Hazards Risk Management: (Focus on objectives, AI methods used, and stage of development/deployment)
    - [Long text answer]
21. What types of data are you primarily using for AI in Natural Hazards Risk Management? (Select all that apply)
    - [ ] Sensor data (e.g., ground deformation, seismic activity, snow depth)
    - [ ] Satellite imagery (e.g., pre/post event analysis, land cover)
    - [ ] Drone imagery/Lidar data
    - [ ] Meteorological data (e.g., heavy precipitation, temperature changes)
    - [ ] Historical hazard event data (e.g., landslide inventories)
    - [ ] Geological/Geotechnical data
    - [ ] Remote sensing data
    - [ ] Other (Please specify): [Short text answer]

D. Climate Change Monitoring (e.g., glacier retreat, permafrost degradation, biodiversity shifts, extreme weather trends, climate modeling refinement)

20. Are you involved in AI-related applications or research in Climate Change Monitoring?
    - [ ] Yes
    - [ ] No (If No, skip to Section 4)
22. Are you involved in EU/regional-funded AI-related projects? (Repeat for every project if any)
    - [ ] Yes:
        1. Project Name:
        2. URL:
        3. Short Description:
        4. Partners Involved:
        5. Main Oucomes expected:
    - [ ] NO
21. Please describe your primary AI-driven application(s) or research project(s) in Climate Change Monitoring: (Focus on objectives, AI methods used, and stage of development/deployment)
    - [Long text answer]
22. What types of data are you primarily using for AI in Climate Change Monitoring? (Select all that apply)
    - [ ] Satellite imagery (e.g., glacier extent, snow cover, vegetation changes)
    - [ ] Ground-based sensor networks (e.g., permafrost temperature, weather stations)

- [ ] Long-term meteorological data
- [ ] Historical climate records
- [ ] Biodiversity monitoring data
- [ ] Atmospheric data
- [ ] Proxy data (e.g., ice cores, tree rings)
- [ ] Other (Please specify): [Short text answer]

Section 4: Best Practices, Challenges and Future Needs

23. Are you aware of or involved in any initiatives within the Alpine Arc that focus on the development of digital twins and/or dataspaces? ? (Repeat for every initiative if any)
    - [ ] Yes:
        1. Project Name:
        2. URL:
        3. Short Description:
        4. Partners Involved:
        5. Main Oucomes expected:
    - [ ] NO
24. **Do you see any potential synergies between these initiative(s) and the application of Artificial Intelligence (AI) in any of the following areas (check all that apply)? (Select all that apply)**
    - [ ] Water Management
    - [ ] Tourism & Sports
    - [ ] Natural Hazards Risk Management
    - [ ] Climate Change Monitoring
    -
25. Please describe briefly how AI could be integrated or enhanced through these synergies
    - [Long text answer]
26. What would you identify as best practices in applying AI for your domain (tourism, water, hazards, climate strategies) in the Alpine area?
    - [Long text answer]
27. What are the biggest challenges you face when applying or researching AI in the context of alpine regions? (Select all that apply)
    - [ ] Data availability (lack of relevant data)
    - [ ] Data quality (inaccurate, inconsistent data)
    - [ ] Data accessibility (difficult to obtain, proprietary data)
    - [ ] Lack of sufficient computational resources
    - [ ] Technical skill gaps within the team/organization
    - [ ] Integration difficulties with existing legacy systems
    - [ ] Ethical concerns (e.g., data privacy, bias, transparency of AI models)
    - [ ] Lack of clear regulatory frameworks for AI
    - [ ] Difficulty in validating/interpreting AI model outputs
    - [ ] Funding limitations for AI projects
    - [ ] Public acceptance/trust in AI solutions
    - [ ] Other (Please specify): [Short text answer]

28. What are your organization's key future interests or needs regarding AI in alpine regions? (Select all that apply)
    - [ ] Access to new/more diverse datasets
    - [ ] Training and upskilling in AI technologies
    - [ ] Collaboration with AI experts/researchers
    - [ ] Access to high-performance computing (HPC)
    - [ ] Development of standardized AI models/tools
    - [ ] Support for piloting and scaling AI solutions
    - [ ] Funding opportunities for AI research/implementation
    - [ ] Best practices and guidelines for ethical AI
    - [ ] Building interdisciplinary teams
    - [ ] Other (Please specify): [Short text answer]
29. What are Alpine priority areas for future development of AI in your sector?
    - (e.g., predictive analytics, decision support systems, AI for climate resilience, real-time hazard monitoring)
    - [Long text answer]

Section 5: Strategic Needs

30. What strategic actions should EUSALP and the EU promote to foster AI adoption? (e.g., cross-border collaborations, standardization of data, ethical guidelines)
    - [Short text answer]
31. What kind of financial support or funding models would be most effective? (e.g., grants, living labs, pilot project co-funding, innovation vouchers)
    - [Short text answer]
32. What kind of skills development programs or educational activities are needed?
    - [Short text answer]
33. What infrastructure (digital, physical, data sharing platforms) is missing or inadequate?
    - [Short text answer]

Section 6: Ethical, Environmental, and Societal Considerations

34. Which ethical challenges must be addressed (e.g., transparency, data privacy, bias)?
    - [ ] Transparency
    - [ ] Data Privacy
    - [ ] Bias
    - [ ] Other (Please specify): [Short text answer]
35. AI's energy consumption and environmental footprint is a concern?
    - [ ] Yes:
        - [Short description]:
    - [ ] No
36. AI adoption ensure inclusive development and benefits for local communities by:
    - [ ] Community Engagement and Co-creation

- [ ] Targeted Skill Development and Training
- [ ] Equitable Access to Technology and Infrastructure
- [ ] Addressing Bias and Fairness in AI Algorithms
- [ ] Tailoring AI Solutions to Local Needs
- [ ] Transparent Communication and Explainability
- [ ] Economic Empowerment and Job Creation
- [ ] Supporting Traditional Knowledge and Practices
- [ ] Establishing Ethical Oversight and Governance
- [ ] Sharing Best Practices and Success Stories
- [ ] Other (Please specify): [Short text answer]

Section 7: Collaboration and Open-ended Feedback

37. Are you interested in collaborating with other EUSALP partners (DIHs, research institutions, industry, public authorities) on AI projects related to these thematic areas?
    - [ ] Yes
    - [ ] No
    - [ ] Maybe (Please explain): [Short text answer]
38. Do you have any further comments or suggestions regarding the application of AI in the alpine regions of EUSALP?
    - [Long text answer]

Thank You!

Thank you for taking the time to complete this questionnaire. Your valuable insights will contribute to a better understanding of the current state of AI in the EUSALP region and help identify opportunities for future cooperation and innovation.

The compiled questionnaire should be sent to christian.micheloni@uniud.it and eusalp.ag5@regione.vda.it

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