IMPETUS

Turning climate commitments into action

VALLE DEI LAGHI

Innovation Package for adaptation and resilience

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Mountains demo-site

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ABOUT THIS DOCUMENT

The impetus project

The EU-funded IMPETUS project (2021-2025) helps accelerate Europe's climate adaptation strategy and meet the European Union's ambitions to become the world's first climate-neutral continent by 2050. The objective is to turn climate commitments into tangible, urgent actions to protect communities and the planet.

Central to the IMPETUS project are the Resilience Knowledge Boosters (RKBs), an innovative approach that combines the voice and experience of local and regional communities with the power of digital tools. In this way, policy-makers, businesses, citizens and other stakeholders can explore climate change evidence together, share information, learn, test ideas and co-create knowledge, discover which actions could constitute the best paths towards climate adaptation, and so contribute to decision-making and policies.

IMPETUS has demonstration sites in 7 European biogeographical regions. Here, multidisciplinary teams and local stakeholders work together to shape adaptation by testing diverse solutions for the local impacts of climate change and exploring alternative pathways for risk reduction and transformative change.

The innovation packages

Innovation packages are built on major IMPETUS results achieved at the demo-site level. They are composed of three blocks:

1. RKBs and their digital dimension for engaging stakeholders and boosting knowledge for developing a long-lasting territorial resilience.
2. Adaptation pathways, to explore alternative sequences of measures to address specific climate risks at the regional level.
3. Repository of climate adaptation solutions, to learn from alternative adaptation options, tested or discussed across the project, and evaluated through a common set of criteria.

The objectives are:

- To present an organised synthesis of results achieved at the demo-site level within the IMPETUS project.
- To facilitate mutual learning among demo-sites by comparing different solutions to face various climate risks.
- To facilitate replication and upscaling.
- To highlight major limiting or success factors that hinder or enable the progress toward adaptation and resilience.

Key concepts: Innovation and Transformation

The "innovation component" of innovation packages is related to:

- The incorporation of a transformational approach: adaptation that changes the fundamental attributes of a social-ecological system in anticipation of climate change and its impacts (IPCC, 2022; Cools et al., 2025).
- The inclusion of new technologies and tools.
- The inclusion of non-structural solutions (governance, finance, and knowledge) as enabling factors to implement adaptation interventions.

INNOVATION

1. Adopting a transformational approach to adaptation.
2. Working with data-driven and digital technologies.
3. Proper consideration to enabling conditions for adaptation.

TRANSFORMATION

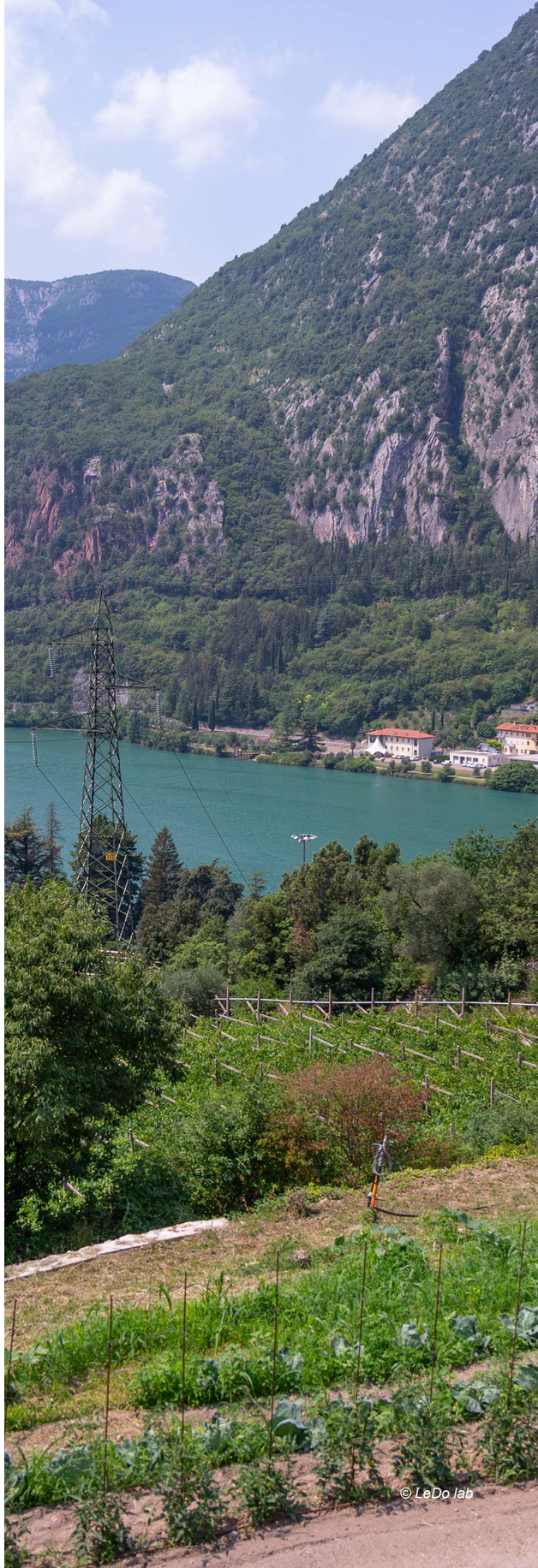
1. Scope of change (e.g. holistic, cross-sector, systemic)
2. Impact of change (e.g. governance, behaviour, socio-ecologic systems)
3. Depth of change (e.g. path shifting, path restructuring, innovative)
4. Temporality of change (e.g. future looking, long lasting)
5. Inclusivity (e.g. participatory, equity)

Reader's guide

This document provides an overview of the climate risks in the region and a synthesis of the knowledge, tools and solutions produced, tested or analysed in the framework of the IMPETUS project. After the section presenting the climate risks, the document is organized following the three building blocks of the Innovation package: RKBs, Adaptation Pathways, and Repository of Solutions. Each block includes a synthesis of the main results achieved during the project, followed by a 3-angle evaluation proposed by demo-site leaders after extensive consultation with stakeholders:

- Exploitation potential for further boosting knowledge and adaptation in the region.
- Major gaps and needs to translate ideas into concrete commitments.
- Potential for fostering transformational adaptation.

Expert judgment was used to score the evaluation elements using a 1 to 5 scale.



THE CLIMATE RISKS OF THE REGION

Valle dei Laghi is located in the south-west part of the Province of Trento (north-eastern Italy). The natural boundaries of the valley are the mountains of the Brenta Group (Paganella) to the north-west and Mount Bondone to the east. The valley stretches from Lake Terlago to Lake Garda following a north-south orientation. It exhibits a unique climate gradient, transitioning from an Alpine to a Mediterranean climate. The valley is governed by two Valley Communities, an intermediate level of governance between the Province and the municipality. Agriculture (mainly vineyards and apple orchards), hydropower generation, forestry and tourism are the major economic activities in the area.

Climate related challenges in land use and water use

Despite its name (Valle dei Laghi means lakes valley) and the natural abundance of water in the landscape, climate change is posing new water scarcity conditions in this site. Increasing air temperature, resulting in higher water needs, together with altered precipitation patterns with possible exceptional dry summers may generate unease among the concurrent uses of the water resource especially between agriculture, hydropower generation and potable use.

Moreover, due to increasing temperature, the altitudinal shift of areas compatible with vineyard cultivation generates conflicts between land uses, such as agriculture, woodland and pasture. Shifting from woodland to cultivated surfaces will lead to increased hydro-geomorphological risks, in a territory already naturally prone to natural hazards.

Finally, extreme weather events (storms) are increasing in magnitude and frequency: further land use conflicts are already in place, e.g. those between agricultural land and flood retention areas. Climate change will lead in the future to the exacerbation of the already existing conflicts in water and land use. Innovative policies are urgently required to manage such conflicts. New adaptation solutions, defined through participatory approaches engaging local population and stakeholders, must be implemented to ensure a rapid transition towards a sustainable and integrated approach to the management of the water resource under the WEFE (water-energy-food-ecosystems) nexus framework, as well as to pursue ecosystems balance for biodiversity conservation and disaster risk prevention and reduction.

A PLATFORM TO EXCHANGE AND BOOST KNOWLEDGE

Content

The RKB (Resilience Knowledge Booster) web platform presents and explains the regional challenges of land use and water use conflicts and helps exploring possible solutions in the perspective of climate change. The *Solutions* section of the platform includes four sections to explore: Tangible cultural heritage; Intangible cultural heritage; Impact Chains; and the Decision Support for Water Management

The *Adaptation Pathways* section includes a conceptual model for water scarcity (Impact chain) showcasing how hazard, exposure, and vulnerability elements interact to generate the risk for social tensions and conflicts among multiple water uses. Navigable maps with alternative Adaptation Pathways able to mitigate this risk are then proposed. In the section *Insights* it is possible to download the Innovation Packages report including the present document.

The platform is available at https://impetus.mantisims.gr/knowledge-boosters/mountains/

TANGIBLE CULTURAL HERITAGE

Users can explore the results of hygrothermal simulations done for two 18th-century residential buildings located in the hamlet of Calavino. The effects of different adaptation strategies (ventilation and shading, envelope insulation, mechanical ventilation) are compared to enable informed decisions.

IMPACT CHAINS

Impact chains are conceptual models that map the cause-effect relationship between climate hazards, vulnerabilities and exposures, helping to visualize and understand risk pathways. Users can learn from impact chains on built environment and agriculture, prepared through two participatory workshops with local stakeholders, complemented by desk-research and insights from interviews. The RKB allows users to navigate impact chains, by panning and zooming, and clicking on each of the elements and their connections

INTANGIBLE CULTURAL HERITAGE

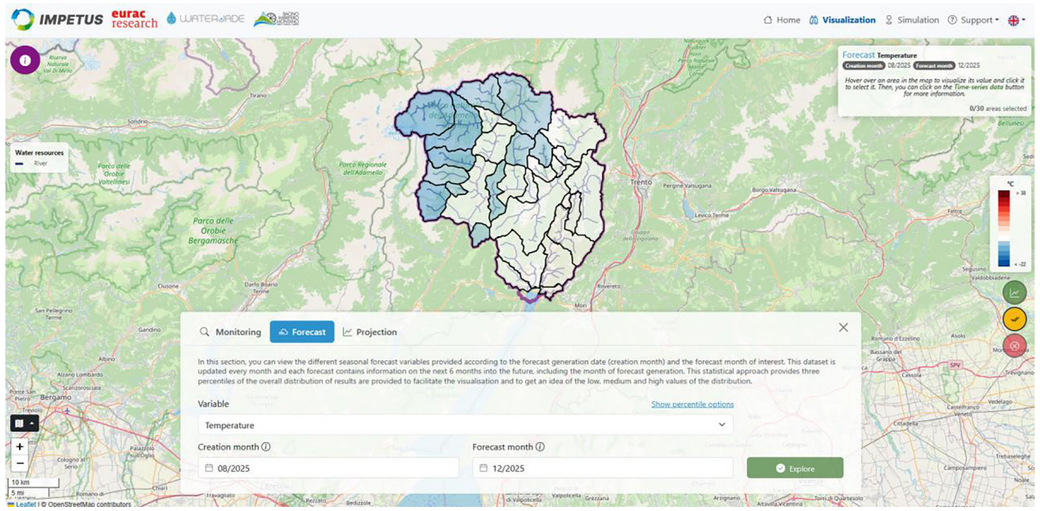
Users can discover the potential of traditional knowledge and practices for adaptation to climate change. The research focused on agriculture and on the winemaking sector. While rooted in traditions, the identified solutions are open to innovation and scientific development.

DECISION SUPPORT SYSTEM (DSS) FOR WATER MANAGEMENT

The DSS integrates multiple information to support the sustainable management of regional water resources in different climate change scenarios. The RKB provides access to the DSS, designed to assist in the development of medium and long-term water management strategies. The back end of the DSS is built around a Digital Twin of the Sarca river basin, (...) developed by the project partner Waterjade.

RKB section on tangible cultural heritage (Source: Eurac Research).

DSS for water management (Source: Eurac Research).



RKB - Exploitation potential

STAKEHOLDERS INTEREST

score 4/5

MAIN STAKEHOLDERS INVOLVED

Academia, Industry and economy and local government

The RKB was developed with the involvement of research centres (FEM) and universities (University of Trento), economic actors (Hydro Dolomiti Energia-HDE, farmers), and local authorities (Municipalities, Valley Communities, Provincial offices/agencies, Irrigation consortia).

FEEDBACK FROM STAKEHOLDERS

Feedback was captured when the RKB platform was not fully complete. However, all adaptation solutions presented in the RKB received interest from the relevant SHs. Specific interest for the water management DSS was manifested from irrigation consortia, while the Province of Trento's energy manager expressed high interest in the solutions for tangible cultural heritage.

STRENGTHS

A POWERFUL TOOL TO VISUALIZE ADAPTATION OPTIONS AND PROVIDE ACTIONABLE KNOWLEDGE

RKB DIGITAL DIMENSION COMPONENT	SCORE
Visualisation (layout, images, graphic design)	4
Knowledge content (quality and type of information displayed)	4
Interactive functionalities (animations, customised navigation, dashboards)	3
Feedback collection tools (pools, chats)	3

OPPORTUNITIES FOR RKB USE

score 3/5

The RKB helps municipalities to make better-informed decisions on climate risks.

The RKB has a potential role in helping different actors to collaborate and coordinate their efforts in addressing the impacts of climate change (primarily water scarcity). Further opportunities for using the RKB are offered from the Province of Trento's ongoing Strategy for Mitigation and Adaptation. Possible political changes can affect the potential of RKB.

RKB - Gaps & needs

CHALLENGES FOR PLANNING AND DECISION MAKING PROCESS: Ensuring effective communication and motivation for using RKB in the future

The main challenge lies in communicating to stakeholders the added value of RKB compared to other tools already available for decision making at different governance levels (provincial, valley and municipal). Furthermore, ensuring long-term technical support to potential RKB users is decisive: without continuous stakeholder involvement, the future use of the RKB may be limited.

PRIORITY	CHALLENGE
1	Capacity challenges (ability and motivation to use knowledge for action)
2	Governance challenges
3	Knowledge (availability of information)
4	Finance challenges

WHAT TO IMPROVE

The RKB should be managed by experts that keep it alive and running in the future, also addressing possible integration with other tools already developed and used in the region still avoiding overlaps.

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RKB - Transformational potential

A MULTI-SECTOR APPROACH CO-DEVELOPED WITH STAKEHOLDERS

Climate change poses new challenges in land use and water use in the Valle dei Laghi. The RKB platform supports informed decisions for integrated multi-sector management of resources, supporting water management, agriculture, hydropower production and environmental protection.
It can boost a participatory approach to adaptation due to the extensive interactions with stakeholders organised for co-create the RKB. It brings innovation to the community by offering novel tools and ways to understand the system holistically.
More consideration for specific needs of vulnerable groups could help a real transformational approach to adaptation.

TRANSFORMATION ELEMENT	SCORE
SCOPE: The RKB platform includes a multi-sector approach	5
INCLUSIVITY: Co-developed/discussed with stakeholders	4
DEPTH OF CHANGE: Novel approach for the region	4
DEPTH OF CHANGE: Expected to generate radical shift or large restructuring in your region	3
SCOPE: Responsive (flexible) to changing conditions	3
TEMPORALITY: long-term vision/expected to produce long-term and durable outcomes	3
SCOPE: Developed at scale or easily scalable	3
INCLUSIVITY: Consideration for the equity of measures, attention for vulnerable groups	2

ADAPTATION PATHWAYS TO ADDRESS WATER SCARCITY

Content

INTRODUCTION

Adaptation pathways are sequences of adaptation measures that are planned to be progressively implemented to cope with the increasing or evolving risks posed by climate change. The implementation of additional, alternative or larger measures is triggered when current adaptation measures and policies are no longer capable to withstand climate change (tipping points), marking the need to shift to different and more effective solutions. The IMPETUS methodology for developing adaptation pathways (AP methodology) was applied in the seven project demo-sites.

Stakeholder engagement was performed in each region with formal events and informal interactions. The interplay among all actors was ensured from the beginning and across all the process of pathway development, also considering that key stakeholders include public administrations and utilities. Stakeholders were specifically consulted for discussing adaptation options and adaptation pathways, and their feedback was used to refine or even change the final outcomes.

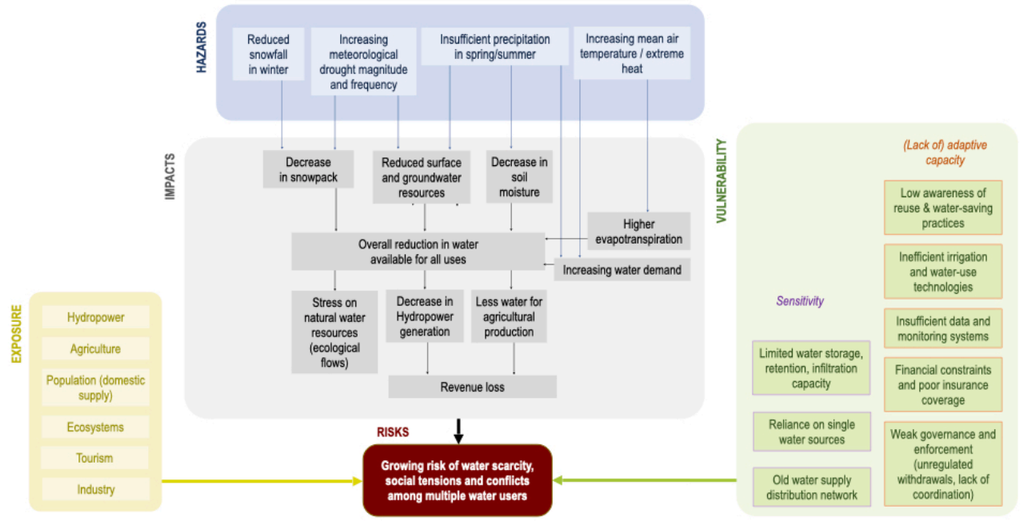
The **main objective** of adaptation pathways developed for Valle dei Laghi is to **enhance the efficiency of water usage and storage**, in order to reduce the risk of water-related controversial emergence under concurrent uses, especially between agriculture, hydropower generation and potable use. The geographical area covered by the adaptation pathway the area administered by the Valley Community of Valle dei Laghi (140 km2), including three municipalities. This approach can be scaled up to encompass the wider geographic territory of the valley.

THE IMPACT CHAIN

Impact chains (GIZ and EURAC, 2017; Zebisch et al., 2022, 2023) are useful tools to delineate conceptual models for climate change risk assessment. They are cause-effect chains that include all major factors and processes leading to specific climate risks in a specific context.

The impact chain for water scarcity in Valle dei Laghi highlights that reduced snowfall, longer and more intense droughts, and higher air temperatures all converge to lower surface and groundwater resources, which in turn undermine the region's overall water availability. This drop in supply simultaneously affects ecological flows -threatening freshwater habitats- and leads to decreased hydropower generation, reflecting a direct link between climate drivers and energy production, also involving a reduction in economic revenues for local administrations. Other economic losses are expected for the agricultural sector that suffers from water deficits for irrigation, leading to reduced yields and higher operational costs. The model underscores that vulnerabilities such as outdated water infrastructure, reliance on single sources and inefficient irrigation systems compound the stress on the system. The lack of specific regulations that envisage the possibility of re-using wastewater for agricultural uses represents an additional issue to overcome water stress in the valley. Financial constraints are also important for the valley, as well as poor accessibility of certain types of data and information and lack of monitoring systems.

The impact chain reveals that each stakeholder group-ranging from local communities relying on domestic supply, to tourism and industries, represented in the Exposure box of the model-faces heightened risks of competition and conflict when water becomes scarce, driving home the urgency of adaptation and risk management strategies.



THE PATHWAYS MAPS

Three alternative adaptation pathways are proposed to address the growing risk of seasonal water scarcity in the Valle dei Laghi. The different pathways reflect different approaches to managing water resources and their interaction with the hydropower system, as it strongly affects the natural water flow regime:

1. **Urban & Agricultural Efficiency Pathway**
   This pathway concentrates on measures that do not affect hydropower in any direct way. Measures included in the pathways are nature-based solutions aimed at restoring ecosystem functions, improved irrigation efficiency in agriculture or the introduction of new water-saving technologies in urban areas. These interventions are assumed to reach their full potential by 2050, yielding an overall reduction of about one percentage point in the water stress index. While the magnitude of this improvement is modest, it illustrates the positive impact that can be achieved by focusing on measures outside the hydropower sector alone.
2. **Hydropower Reconfiguration Pathway**
   This pathway includes only those actions that directly target hydropower. In practice, these measures involve sediment dredging to maintain reservoir capacity, repurposing reservoir use for multiple sectors or adjusting hydropower concessions to allow for better water sharing. By restructuring how hydropower infrastructure is managed, this pathway also produces an approximate one-point decrease in the water stress index, effectively matching the improvement observed in the Urban & Agricultural Efficiency Pathway. The similarity of the results indicates that action exclusively within the hydropower sector can yield outcomes on a par with a strategy that focuses on non-hydropower measures.
3. **Comprehensive Water Integration Pathway**
   This pathway involves a broader set of actions that include all measures from both the Urban & Agricultural Efficiency and the Hydropower Reconfiguration pathways. By taking a comprehensive view of water resource management-encompassing hydropower-specific interventions alongside nature-based solutions, efficient irrigation systems and other cross-sectoral strategies-this pathway generates a noticeably larger reduction in the water stress index. The synergy arising from targeting multiple sectors simultaneously leads to a more substantial impact than relying on a single set of interventions. Consequently, the Comprehensive Water Integration Pathway highlights the added value of integrating efforts across the board, suggesting that long-term water security and resilience are most effectively achieved when hydropower is addressed alongside other critical sectors.

Four additional measures were considered functional to the implementation of the above pathways:

- Integration of adaptation measures into spatial planning.
- Enhancing synergies among stakeholders involved in the water management.
- Using monitoring devices for water resources.
- Training and knowledge transfer of good practices.

A more detailed analysis of the measures included in the adaptation pathways is reported in the section “Portfolio of Solutions”.

A water scarcity index (ADAPT-WSI) was designed to evaluate the effectiveness of various pathways at the the sub-basin level:

$$\text{ADAPT-WSI (\%)} = \frac{WW}{AW - EFR}$$

Where:

WW = Water Withdrawal (m^3)

AW = Water Availability (m^3)

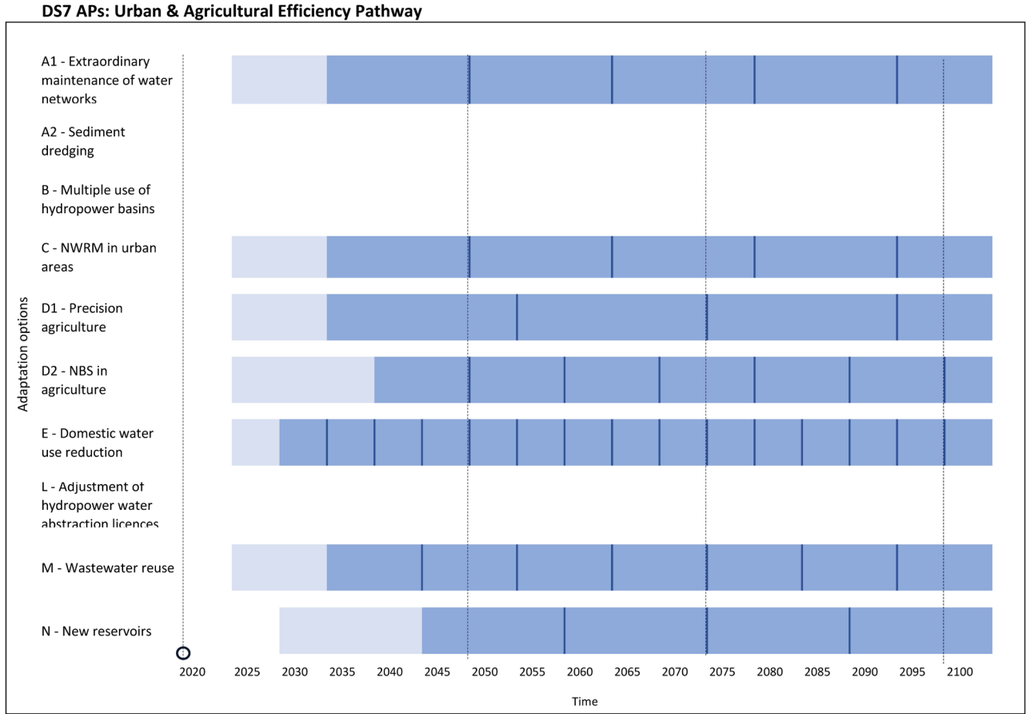
EFR = Ecological Flow Requirements (m^3)

Two climate scenarios (**SSP3-4.5** - middle-of-the-road and **SSP5-8.5** - high-emission) were considered to explore different future conditions in water availability (WA) in a business as usual scenario (BAU) and with the implementation of alternative pathways.

figures: DS1 Adaptation Pathways Maps

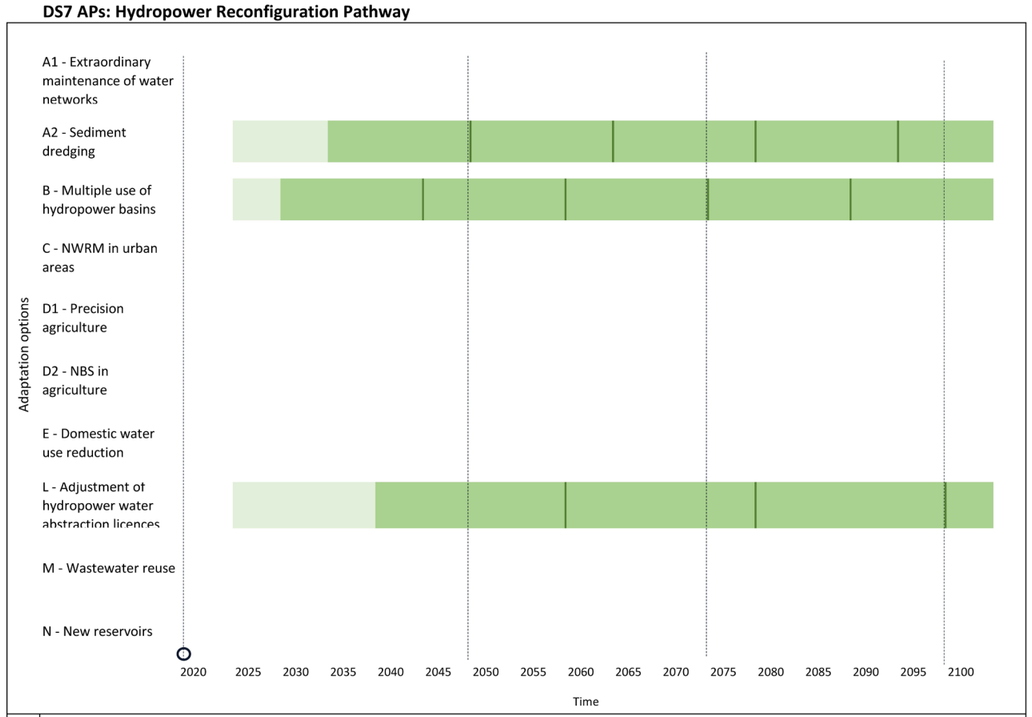
In the following graphs, the light colour of the bars represents the implementation time of measures, while the dark colour represents how long they stay in place. The expected frequency of maintenance is represented by vertical lines in the bars

DS7 APs: Urban & Agricultural Efficiency Pathway



SSP5 -8.5	WA variation (Mm3) - BAU		+25	-54	-126
	WA variation (%) - BAU		3.84	-8.22	-19.15
	Hydropower production (% variation) -BAU		4.39	-9.36	-22.52
	Hydropower production- economic losses (Meuro) - BAU		+5.5	-11.8	-28.5
	WSI -BAU	0.84	0.85	0.84	0.82
	WSI after the implementation of the pathway		0.83	0.82	0.81
SSP3 -4.5	WA variation (Mm3) - BAU		+3	+4	-17
	WA variation (%) - BAU		0.46	0.61	-2.58
	Hydropower production (% variation) -BAU		1.04	1.05	-2.5
	Hydropower production- economic losses (Meuro) - BAU		+1.3	+1.3	-3.2
	WSI -BAU	0.84	0.85	0.85	0.85
	WSI after the implementation of the pathway		0.84	0.83	0.83

DS7 APs: Hydropower Reconfiguration Pathway



SSP5 -8.5	WA variation (Mm3) - BAU		+25	-54	-126
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	Hydropower production- economic losses (Meuro) - BAU		+5.5	-11.8	-28.5
	WSI -BAU	0.84	0.85	0.84	0.82
	WSI after the implementation of the pathway		0.83	0.82	0.8
SSP3 -4.5	WA variation (Mm3) - BAU		+3	+4	-17
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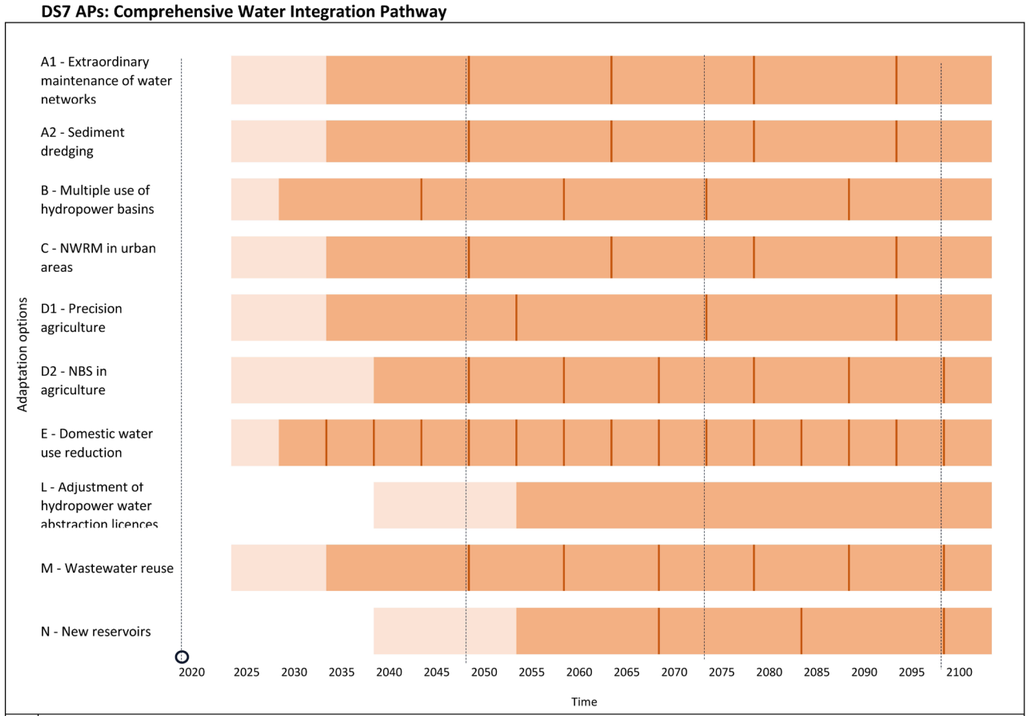
	WSI -BAU	0.84	0.85	0.85	0.85
	WSI after the implementation of the pathway		0.83	0.83	0.83

DS7 APs: Comprehensive Water Integration Pathway



SSP5 -8.5	WA variation (Mm3) - BAU		+25	-54	-126
	WA variation (%) - BAU		3.84	-8.22	-19.15
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	Hydropower production- economic losses (Meuro) - BAU		+5.5	-11.8	-28.5
	WSI -BAU	0.84	0.85	0.84	0.82
	WSI after the implementation of the pathway		0.82	0.8	0.78
SSP3 -4.5	WA variation (Mm3) - BAU		+3	+4	-17
	WA variation (%) - BAU		0.46	0.61	-2.58
	Hydropower production (% variation) -BAU		1.04	1.05	-2.5
	Hydropower production- economic losses (Meuro) - BAU		+1.3	+1.3	-3.2
	WSI -BAU	0.84	0.85	0.85	0.85
	WSI after the implementation of the pathway		0.82	0.82	0.81

Adaptation pathways - Exploitation potential

STAKEHOLDER INTEREST

score 5/5

MAIN STAKEHOLDERS INVOLVED
State, government and policy

Adaptation pathways were elaborated with the support of the Provincial Agency for environmental protection, the Provincial Agency for water and energy resources, the Valley Community of Valle dei Laghi, and the Consortium of municipalities of the Sarca mountain catchment basin.

FEEDBACK FROM STAKEHOLDERS
Stakeholders showed interest in the adaptation pathways for the following reasons:

- The overall approach was found methodologically sound and consistent with European (e.g. Climate-ADAPT) and provincial frameworks.
- The method, integrating science-based climate projections and local impact assessments, can foster informed and resilient decision-making processes at different levels.
- The approach is considered relevant and innovative as it demonstrates the impact of adaptation pathways on future water availability, quantified by water volumes, and it providesan nitial evaluation of the costs associated with the proposed measures.
- The approach also indirectly addresses water quality degradation due to reduced environmental flows, pollutant concentration, and increased pressure during summer months. Water quality, often secondary to quantity, is acknowledged as critical in the adaptation pathways development.

OPPORTUNITIES TO USE ADAPTATION PATHWAYS IN PLANNING/DECISION MAKING

score 3/5

For Valle dei Laghi, the developed adaptation pathways offer a useful basis for local integrated water management and strategic planning. Moreover, the final pathways are considered useful to set up a discussion on future actions to be taken by the different local stakeholders (e.g. municipalities, Valley Community, BIM, etc.).
For the whole Trento Province: it is a useful example that can contribute to the ongoing development of the Mitigation and Adaptation Strategy on climate change of the Province of Trento.

Adaptation pathways - Gaps & needs

CHALLENGES - HOW TO TRANSLATE INTO PRACTICE

Several stakeholders expressed concerns over potential reductions in hydropower production or modifications to the existing infrastructure, given the socio-economic importance of the sector. Therefore, the options that affect existing hydropower infrastructure tend to be less socially acceptable but, at the same time, they seem to be the most effective solutions (in terms of available water volumes for multiple uses) on the long-term.
There is a challenging need to balance immediate interests (e.g. pumping energy costs for irrigation) with the pursuit of durable, resilient strategies for water management (long-term sustainability).
Moreover, continuous collaborative processes among local administrations, irrigation consortia and hydropower operators is needed to shape effective adaptation pathways.

PRIORITY	CHALLENGE
1	Governance challenges
2	Finance challenges
3	Knowledge challenges (availability of information)
4	Capacity challenges (ability and motivation to use knowledge for action)

WHAT TO IMPROVE

The adaptation pathways could be improved in terms of robustness and reliability if more data were available (e.g. concerning hydropower water use, real water consumption/withdrawals, etc.), as well as more modelling capacity, more time and resources for the index calculation and the quantitative assessment of options and pathways.

Adaptation pathways - Transformational potential

ELEMENTS OF TRANSFORMATION

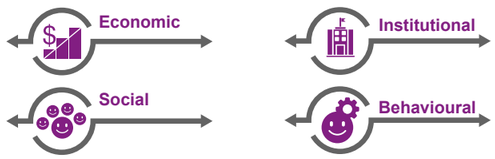
A novel multi-sector approach co-developed with stakeholders

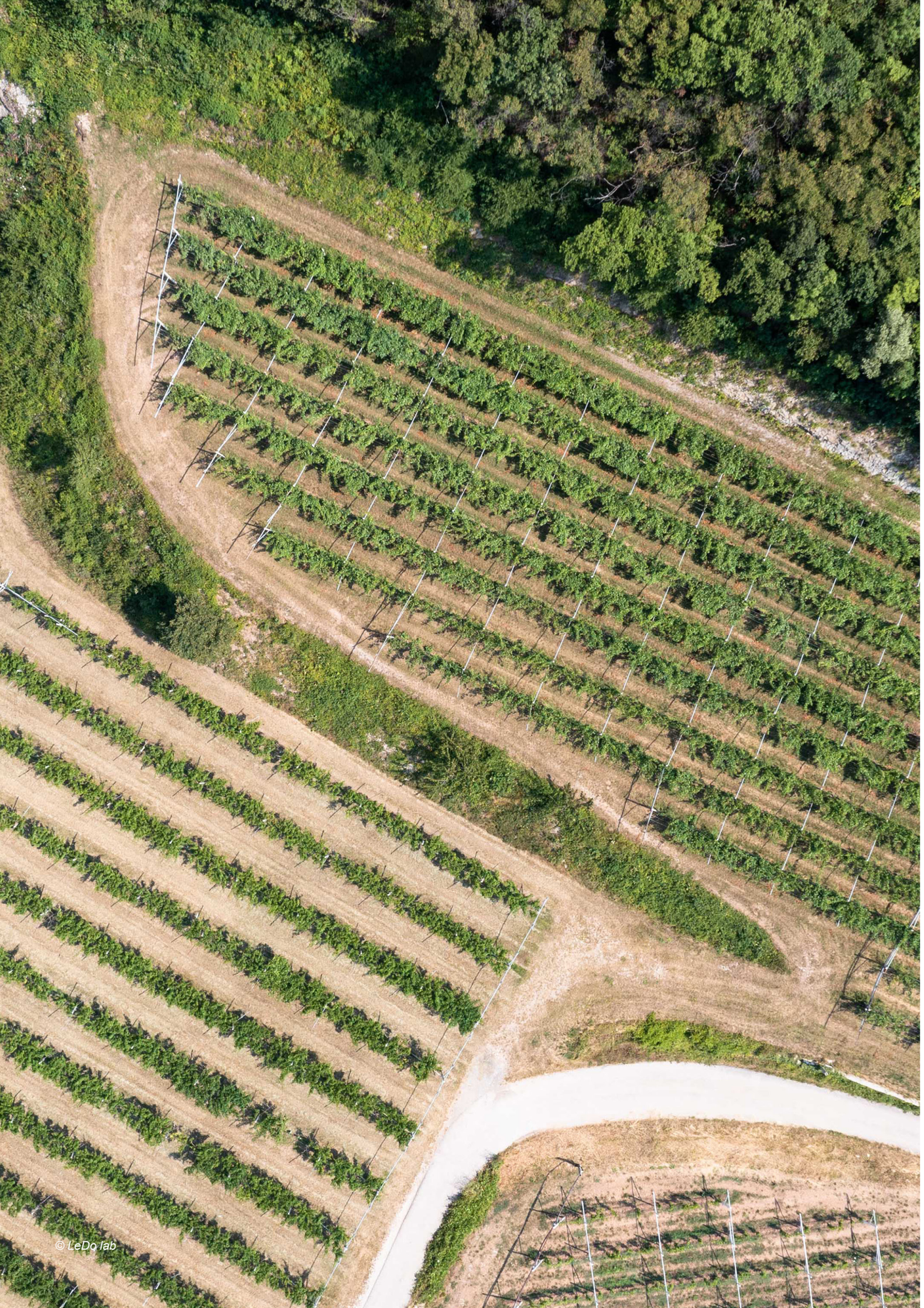
The APs embrace a **multi-sector approach**, considering agriculture, hydropower production, drinking water management, and suggesting a comprehensive water integration pathway to maximize the impacts on water resources. The pathway approach was not used before in the Province of Trento to address climate change adaptation, thus boosting **innovation** in long-term planning. It is easily **scalable** from demo-site to water catchment basin level. Further scaling or replication is possible in similar regional contexts, with hydroelectric exploitation predominance. The adaptation options were early discussed and co-identified with **stakeholders**, while pathways have been discussed in a final step of the process for validation purposes. Although a pronounced gender imbalance was observed in stakeholders involved in water governance and decision-making, no specific measures to change this condition and enhance **inclusivity** were incorporated. Built on different scenarios, the selected pathways are quite **adaptable to changing conditions**. Moreover, they offer win-win strategies since they address water scarcity while also considering extreme storms. They have been designed with a **long-term vision**, considering solutions that can be effective also in quite extreme water scarcity conditions expected in the future under high emission scenarios. If incorporated in the provincial strategy for mitigation and adaptation, they may have durable legacy. While the adaptation pathway has strong potential to drive major transformation in the water management, their implementation is not expected in the short term, so large immediate restructuring of the system is not expected.

TRANSFORMATION ELEMENT	SCORE
SCOPE: The AP elaboration process includes a multi-sector approach	5
DEPTH OF CHANGE: Novel approach for the region	5
SCOPE: Developed at scale or easily scalable	3
INCLUSIVITY: Co-developed/discussed with stakeholders	3
SCOPE: Responsive (flexible) to changing conditions	3
TEMPORALITY: long-term vision/expected to produce long-term and durable outcomes	3
DEPTH OF CHANGE: Expected to generate radical shift or large restructuring in your region	2
INCLUSIVITY: Consideration for the equity of measures, attention for vulnerable groups	2

IMPACT OF TRANSFORMATION

IThe implementation of adaptation pathways would entail large economic, social, institutional and behavioural transformation. More integrated water governance but also behavioural changes with more aware water consumption are especially expected.





A PORTFOLIO OF CLIMATE ADAPTATION SOLUTIONS

Content

Nineteen adaptation solutions were assessed to address climate change in the Valle dei Laghi and the related challenges for conflicting land use and water use. Ten solutions were also tested in IMPETUS.

In order to facilitate comparison among the high variety of adaptation options considered across all DSs, adaptation options were categorised according to the Key-Type-of-Measure (KTM) system, defined at the European level (Leitner et al., 2021) as voluntary mechanism to report climate adaptation actions in the EEA member countries, as part of the EU Regulation on Governance of the Energy Union and Climate Action Energy Union Governance Regulation (2018/1999).

Solutions belong to all the four main typologies: Governance and institutional, Economic and Finance, Physical and technological, Nature-based solutions and ecosystem-based approaches, and Knowledge and behavioural change.

Evaluation

All solutions are quite mature since they are characterized by medium to high technological and social readiness level (TRL and SRL).

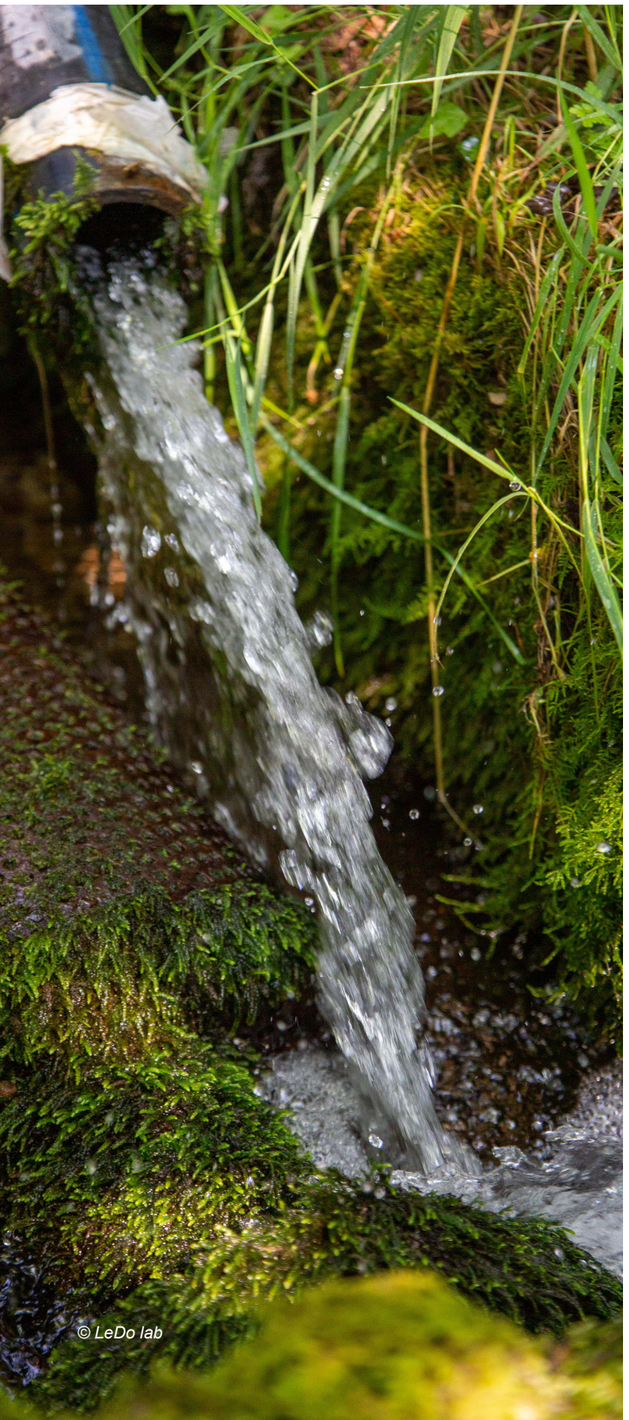
They are expected to bring a wide range of benefits, but their tailored implementation in the territory of Valle dei Laghi would especially require more robust data, dedicated financial resources and policy support.

New social tensions might also be expected, especially from the implementation of the most transformational measures that would touch large economic interests (e.g. hydropower water abstraction licences) displace existing land uses (e.g. creation of new flood reservoirs), or change priorities in land use development (integration of adaptation measures into spatial planning).

OPTION	DESCRIPTION	MAIN OBJECTIVE(S)	IMPETUS CLIMATE RISK	KEY TYPE OF MEASURE	TESTED IN IMPETUS	NOTES
Water Management Decision Support System (DSS)	**Decision Support System integrating multiple information layers for the sustainable and integrated management of regional water resource.**	**To develop management strategies concerning smart irrigation, flood risk alert, operation of water levels in hydropower reservoirs for energy production in small and large plants, flood control and ecosystem protection.**	**Water scarcity**	**E1 - Information and awareness raising**	**Y**	
Innovative insurance products for agriculture, forestry, hydropower energy production	**Parametric or index-based insurance products (offering pre-specified pay-outs on the basis of triggering events) as passive protection measures or sustainable financing instruments to invest in active protections (hail nets, drip or top crown irrigation).**	**To protect agricultural crop yields, forest stands, hydropower energy plants (especially small systems) against climate-related economic losses.**	**Water scarcity**	**E1 - Information and awareness raising**	**Y**	
Evaluation of the effects of the altitudinal shift of crops on vineyards	**Organic agriculture practices, alternative varieties cultivation and engagement of socio-economic stakeholders & local community.**	**To adddress challenges posed by the altitudinal shift of crops due to raising temperatures in mountains. To co-design multifunctional farming plans to manage in a sustainable and integrated way the future conflicts in water and land use.**	**Temperature increase**	**E2 - Capacity building, empowering and lifestyle actions**	**Y**	
Activated cultural heritage to enhance climate resilience	**Identification of relevant cultural practices and traditions (intangible heritage) and renovation measures for historical buildings (tangible heritage), for further development and upscaling/transferability.**	**To identify triggers of behavioural change and develop innovative climate change adaptation pathways. To Develop tools (such as risks maps or performance coefficients) to foster societal awareness and facilitate win-win solutions for adaptation & implementation of low-carbon measures for historic buildings (tangible heritage).**	**Non-specific risk**	**E2 - Capacity building, empowering and lifestyle actions**	**Y**	
Improvement of risk management practices through the application of participatory approaches (Impact Chains and Rapid Risk management Appraisal)	**Combination of Innovative participatory approaches like Impact Chains (IC).**	**To improve risk management capacities and increase resilience to climate change. To bridge the gap between disaster risk reduction (DRR) and climate change adaptation.**	**Non-specific risk**	**E2 - Capacity building, empowering and lifestyle actions**	**Y**	
Extraordinary maintenance of water networks	Extraordinary maintenance, digitalization, and monitoring of water networks; integrates hydraulic modelling, real-time data collection, and targeted infrastructure update.	To enhance reliability of water supply networks and reduce leakage.	Water scarcity	C2 - Technological options		
Sediment dredging of existing water retention basins	Removal of deposits that reduce the basin capacity.	To restore or increase storage capacity.	Water scarcity	C1 - Grey options		
Multiple use of hydropower basins	Development of multiple-use water retention basins designed to integrate hydroelectric power generation, agricultural irrigation, and tourism-related activities. Extension of model in use in the Sarca catchment area.	To store excess rainwater, reduce stormwater run-off, and support diverse water demands.	Water scarcity	A3 - Coordination, cooperation and networks		Though the option was not tested in IMPETUS, it was discussed in bilateral meetings with stakeholders (i.e. hydropower basins for irrigation water use).
Natural Water Retention Measures in urban areas	Multi-functional interventions designed to sustainably manage excess water in urban areas; they include green roofs, permeable pavements, rain gardens, and rainwater harvesting systems..	To restore natural hydrological processes, manage water resources, and improve water quality.	Extreme storms	D2 - Blue Options		Though the option was not tested in IMPETUS, it was discussed in workshop sessions.
Precision agriculture	**Advanced technology in agriculture, including the use of weather forecasting, hydrological monitoring, remote sensing technologies, and ICT-based agro-advisory services.**	**To optimize water use, decrease fertilizer consumption, and lower environmental impacts.**	**Water scarcity**	**C2 - Technological options**	**Y**	**Partially tested (Alto Garda-Albola pilot case).**
NbS in agriculture	Various NbS practices including crop rotation, low-till methods, and green covers.	To improve soil water infiltration and retention, reduce run-off.	Water scarcity	D1 - Green Options		
Domestic water use reduction	Initiatives to raise public awareness on climate impacts on water consumption.	To raise public awareness on climate impacts and ecourage behavioural change.	Water scarcity	E1 - Information and awareness raising		Though the option was not tested in IMPETUS, it was included in dissemination activities, i.e. Solar cinema.
Integration of adaptation measures into spatial planning	**Definition of adaptation solutions/priorities that should be included in planning documents.**	**To make informed decisions future-proof development decisions against climate impacts.**	**Water scarcity**	**A2 - Management and planning**	**Y**	**Partially tested in IMPETUS as part of the DSS.**
Enhance synergies among stakeholders involved in water management	**Engaging local administrations, hydroelectric companies, irrigation consortia, and agricultural cooperatives, for collaboration, knowledge sharing, and consensus-building.**	**To strengthen synergies among stakeholders involved in water management through participatory processes that facilitate the co-design and implementation of adaptation solutions.**	**Water scarcity**	**A3 - Coordination, cooperation and networks**	**Y**	**Tested in IMPETUS through stakeholder engagement activities (i.e. workshops, bilateral meetings).**
Use of monitoring devices for water sources	**Deployment of monitoring devices to track water availability and usage in real-time, improving decision-making.**	**To enable decision-making for potable and non-potable uses.**	**Water scarcity**	**C2 - Technological options**	**Y**	**Partially tested in IMPETUS (Integrated groundwater monitoring system).**
Training and knowledge transfer of good practices	**Organization of training courses on diverse water-related topics addressing different target groups.**	**To enhance practical knowledge, promote the adoption of innovative solutions, and facilitate broad collaboration among stakeholders, including local authorities, farmers, industries, and community groups.**	**Water scarcity**	**E2 - Capacity building, empowering and lifestyle actions**	**Y**	**Partially tested in IMPETUS as part of stakeholder engagement and dissemination activities, with a main focus on topics related to the options: Natural Water Retention Measures in urban areas and Precision Agriculture.**
Adjustment of hydropower water abstraction license	Adjustment of water abstraction during emergency state based on actual water availability to ensure essential uses.	To ensure that essential water uses are prioritized when water resources are critically scarce (essential uses are, e.g., drinking water, agricultural irrigation and ecosystem maintenance).	Water scarcity	A2 - Management and planning		
Wastewater reuse	Waste-water collection, treatment and re-use for non-potable purposes, e.g. agricultural and industrial.	To reduce use of potable sources of water.	Water scarcity	C1 - Grey options		
New water reservoirs	Artificial water storage basins designed to ensure stable water supply.	To provide water in areas that face water shortage.	Water scarcity	C1 - Grey options		

		ASSESSMENT												GAPS & NEEDS for implementation
#	Synthetic name of the option	Effectiveness for the expected objective	Lifetime	Feasibility - TRL	Feasibility - SRL	Economic costs	(co)-Benefits	Evaluate Environmental benefits	Evaluate Social benefits	Negative unintended effects/hidden risks	Evaluate Environmental negative unintended effects/ hidden risks	Evaluate Social unintended effects/hidden risks	Implementation time	Synergy with mitigation	
1	Water Management Decision Support System (DSS)	++	++	++	++	-	Longer-term management strategies concerning smart irrigation, flood risk alert, operation of water levels in hydropower reservoirs for energy production in small and large plants, flood control and ecosystem protection.	++	++	Lack of integration of socio-environmental dynamics and of ecosystem services economic assessment may drive to prioritizing short-term goals over long term resilience / Overreliance on technology.	-	-	--	No	Data needed: observed meteorological data, seasonal forecast, climate projections, hydropower, water demand/supply, land cover, DTM.
2	Innovative insurance products for agriculture, forestry, hydropower energy production	+	++	+	++	- -	Protection of agricultural crop yields, forest stands, hydropower energy plants against climate-related economic losses. Economic evaluations based on the assessment of future return periods for adverse climate events.	+	++	Due to the increasing consequences of anthropogenic climate change, which will lead to an increase in insurance claims over time, this can raise premiums in the medium and long term, compromising the affordability and availability of these products. Insurers must promote innovative insurance products that incentivise climate adaptation measures, such as offering lower premiums to insurance-holders who implement adaptation measures. This is important to avoid relying solely on risk transfer mechanisms.	-	-	- - -	Yes	Data needed: economic assessment metrics, future return periods for adverse climate events, current insurance products for different sectors, impact data (loss and damage).
3	Evaluation of the effects of the altitudinal shift of crops on vineyards	++	++	++	++	-	Recovery of abandoned/afforested mountain agricultural areas; preservation of viticulture in traditional regions and related economic benefits.	++	+	Although the altitudinal shift is considered an adaptation option to rising temperatures, vineyard expansion could threaten biodiversity and soil stability / Lack of consideration for other climate risks, such as extreme rainfall, which can trigger erosion phenomena in mountainous areas / land use conflicts.	-	-	- -	Yes	Data needed: micro-climate conditions, vine productivity, grape quality parameters and vulnerability to pests, climate projections, land-use trends, historical data from farmers, info on other crops, ecological indicators. Increase community awareness on the need to act.
4	Activated cultural heritage to enhance climate resilience	++	++	+++	++	- -	Quality of life and living comfort are greatly improved. The buildings in the city centers of the villages are not abandoned and come back to life. Less land consumption for the construction of new buildings. Less energy consumption for heating and cooling buildings, thus mitigating climate change.	+++	+++	The renovations of historic buildings involves risks of mould if not planned correctly. Mould can be a health problem for the people who live there and can also increase the deterioration of buildings.	- -	-	- - -	Yes	Data needed: building stock information, Digital Surface Model (DSM) and Digital Terrain Model (DTM), traditional construction crafts, historic maps, cultural practices, values and traditions, local perceptions of climate change and coping strategies, local environmental knowledge, climate data.
5	Improvement of risk management practices through the application of participatory approaches (Impact Chains and Rapid Risk management Appraisal)	++	++	++	++	-	Co-creation of an improved and integrated risk management strategy bridging the gap between disaster risk reduction and climate change adaptation, encompassing flexible preparedness, recovery, and response measures. Opportunity for different stakeholders to sit at the same table. Awareness increase.	++	+++	The selection of invited stakeholders can introduce bias in the identification of risk factors e.g. overlooking of vulnerability factors.	-	-	-	No	Data needed: exposure, vulnerability, climate hazard factors, direct and indirect impacts, historical data on extreme climate events and impacts, climate projections.
6	Extraordinary maintenance of water networks	+++	++	+++	+++	- -	Reduction of the water withdrawl from water supply system. Preserve ecosystem servicese.	+	+	Corruption in public procurement. Habitat disruption due to maintenance and construction. Operational inefficiencies.	- -	- -	- - -	No	Financial resources.
7	Sediment dredging of existing water retention basins	+++	++	+++	++	- -	Restoration of ecological functions by preventing flooding and erosion. Improve wildlife habitats. Reduce damage to infrastructure and turbines. Enhance water quality by removing pollutants. Increase reservoir capacity. Support economic activities.	+	+	Impact on water quality and ecological health. Increased turbidity. Treatment of dredged material if contaminated is costly. Corruption in public procurement.	- -	- -	- - -	No	Financial resources.
8	Multiple use of hydropower basins	+++	+++	+++	++	- - -	Support to hydroelectric power, irrigation and tourism. Groundwater recharge. Reduction of reliance on groundwater. Improvementrs in water quality, biodiversity and recreational opportunities. Improvements in water quality, biodiversity and recreational opportunities.	++	++	Land-use conflicts among hydroelectric, agriculture and tourism uses. Impact ecosystems and landscape aesthetics.	- -	- -	- -	Yes	Financial resources. Hidden risks, such as conflicts over land and water use, may emerge and need careful management.
9	Natural Water Retention Measures in urban areas	+++	+++	+++	++	- - -	Biodiversity enhancement. Well-being improvement. Aesthetic and recreational values. Allow rainwater reuse. Generate avoided costs and lower maintenance expensesfor drainage infrastructure. Reduce flood risk. Enhance groundwater recharge.	++	++	Alter ecosystems and affect landscape aesthetics. Shifts in local water dynamics. Unexpected maintenance challenges.	-	-	-	No	Land-use planning.
10	Precision agriculture	+++	++	++	++	- -	Reduce energy use. Reduce use of fertilizer decreasing costs, eutrophication and pollution. Enable implementing a compensation scheme.	++	++	Sensor use has carbon footprint. Smart irrigation system may require more frequent maintenance, increasing costs. Initial investment may be prohibitive for small-scale farmers.	-	-	-	Yes	Financial resources.
11	NbS in agriculture	+++	++	+++	++	-	Boost soil fertility. Enhance biodiversity. Reduce erosion. Increase farm productivity. Improve ecosystem services. Reduce chemical input.	+++	+++	Pest control.	-	-	- -	Yes	Policy support, training and participatory planning.
12	Domestic water use reduction	+++	+++	+++	++	-	Foster a culture of sustainability and social engagement. Create positive economic spillover, e.g. reduce water treatment costs.	+	+	Overemphasis on behavioural changes may divert attention from other necessary interventions.	-	-	- -	Yes	Political support and public awareness.
13	Integration of adaptation measures into spatial planning	++	+++	++	++	-	Better coordination among stakeholders. Climate-proofing of development decisions. Awareness increase.	+	+	Conflicts among stakeholders with different social, environmental and economic priorities.	-	-	- -	Yes	Revision of and integration in the current regulatory planning instruments.
14	Enhance synergies among stakeholders involved in water management	++	+++	+++	+++	-	Systemic approach to climate change. Strengthen stakeholder networks. Raise awareness. Reduce long-term operational costs.	+++	+++	Tension among economic, environmental and social interest.	-	-	- -	Yes	Limited data availability. Legal constraints, e.g. water and land-use rights.
15	Use of monitoring devices for water sources	++	++	+++	++	-	Monitoring and data sharing can reduce stakeholder conflicts. Improve forecasting models. Optimize water allocation. Srengthen synergy in water management.	+++	+++	Conflicts among stakeholders with different social, environmental and economic priorities.	-	-	-	No	Limited awareness of benefits. Funding.
16	Training and knowledge transfer of good practices	++	+++	+++	+++	-	Increase awareness of climate impacts. Strengthen capacity building. Foster collaboration among stakeholders. Promote cross-sector cooperation.	++	++	Lack of quality trainers and of experts.	-	-	-	Yes	Lack of quality trainers and of experts.
17	Adjustment of hydropower water abstraction license	+++	+++	+++	++	- - -	Improve river flow. Enhance ecosystem conservation. Maintain biodiversity and water quality. Protect publich health and food production.	++	++	Conflicts among stakeholders with different social, environmental and economic priorities. Economic pressure on local authorities.	- -	- -	- - -	Yes	Careful planning and stakeholder engagement.
18	Wastewater reuse	+++	+++	+++	++	- - -	Reduce stress on freshwater bodies. Improve river flow conditions. Enhance biodiversity. Ensure stable non-potable water supply for agriculture and industries.	++	++	Inadequate treatment may lead to soil contamination and health concerns. High upfront costs.	- -	- -	- -	Yes	Initial costs and social acceptance are challenges that need to be addressed.
19	New water reservoirs	+++	+++	+++	+++	- - -	Support agriculture. Benefit tourism. Contribute to local economies.	+	++	Disrupt local ecosystems. Alter river flow regimes. Displace existing land-uses. Habitat loss. Changes in sediment transport. Social conflicts.	- - -	- - -	- - -	Yes	Financial resources.

Portfolio of solutions - Transformational potential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ELEMENTS OF TRANSFORMATION

The portfolio of measures outlines a moderate potential for transformation, as the average scoring of all solutions is 2.8 (on a scale of 5). In particular, almost all measures are deemed scalable and quite responsive to climate change conditions. They are also largely discussed with stakeholders, boosting an inclusive approach to adaptation. However, more efforts are needed to address inclusivity, to avoid disproportions among social groups. Among the most transformational measures, the multiple use of hydropower basin and the use of nature-based solutions in agriculture and in the urban environment are novel solutions for Valle dei Laghi, and would produce large restructuring in how decisions are made, in stakeholder behaviour and attitude to sustainable water consumption.

	SCOPE			DEPTH OF CHANGE		INCLUSIVITY		TEMPORALITY
Synthetic name of the option	Include a multi-sector approach	Responsive to changing climatic conditions	Developed at scale or easily scalable	Novel for the region	Expected to generate radical shift or large restructuring in your region?	Co-developed/ discussed with stakeholders	Consideration for the equity of the measure with specific attention to vulnerable groups, marginalised communities and gender balance	Expected to produce long-term and durable outcomes
Water Management Decision Support System (DSS)	**4**	**4**	**3**	**4**	**3**	**4**	**2**	**3**
Innovative insurance products for agriculture, forestry, hydropower energy production	**1**	**1**	**2**	**3**	**2**	**2**	**1**	**1**
Evaluation of the effects of the altitudinal shift of crops on vineyards	**1**	**3**	**3**	**1**	**2**	**2**	**1**	**1**
Activated cultural heritage to enhance climate resilience	**3**	**3**	**4**	**3**	**2**	**2**	**NA**	**4**
Improvement of risk management practices through the application of participatory approaches (Impact Chains and Rapid Risk management Appraisal)	**4**	**3**	**4**	**3**	**2**	**4**	**2**	**3**
Extraordinary maintenance of water networks	1	2	4	1	3	1	NA	3
Sediment dredging of existing water retention basins	3	3	2	2	2	1	NA	3
Multiple use of hydropower basins	4	4	4	3	4	3	NA	4
Natural Water Retention Measures in urban areas	3	4	4	4	3	4	NA	4
Precision agriculture	**1**	**4**	**4**	**3**	**3**	**4**	**NA**	**4**
NbS in agriculture	2	4	4	4	3	4	NA	4
Domestic water use reduction	1	1	1	2	2	2	NA	2
Integration of adaptation measures into spatial planning	**3**	**3**	**3**	**4**	**3**	**4**	**NA**	**3**
Enhance synergies among stakeholders involved in water management	**4**	**NA**	**4**	**2**	**3**	**NA**	**1**	**3**
Use of monitoring devices for water sources	**1**	**2**	**4**	**2**	**3**	**4**	**NA**	**3**
Training and knowledge transfer of good practices	**1**	**1**	**3**	**2**	**2**	**3**	**1**	**2**
Adjustment of hydropower water abstraction license	4	4	2	3	3	1	NA	3
Wastewater reuse	2	4	4	4	3	3	NA	3
New water reservoirs	2	4	2	1	2	3	NA	2

Portfolio of solutions - Transformational potential

IMPACT OF TRANSFORMATION

The majority of solutions, if implemented in the Valle dei laghi, would especially bring institutional transformation, requiring deep changes in the water and land use governance. This is followed by changes in the environment and landscape, related to the implementation of nature-based solutions in agriculture and in the urban environment as well as to the altitudinal shift in crops. Technological transformation is expected from scaling up currently limited experiences of precision agriculture, the activation of new measures for preserving cultural heritage, and from integrating adaptation measures into spatial planning through decision-support tools. Social transformation is mainly related to changes in people attitude to water reuse and in the involvement of stakeholders from different sectors for co-managing water resources. This is also related to behavioural changes (e.g. more awareness in water consumption), that are crucial for the long-term sustainability of water management. Finally, the implementation of insurance products would entail economic transformation.


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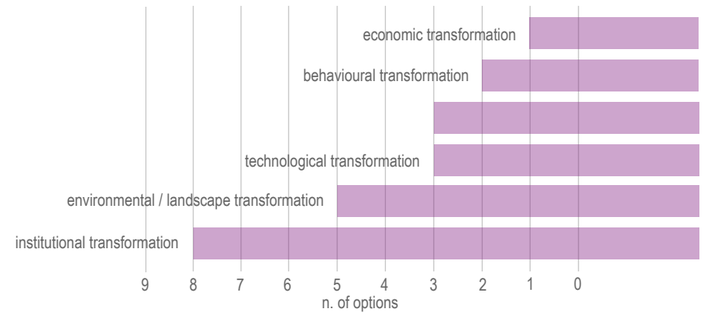
Figure: Impacted sectors



IMPACT OF TRANSFORMATION						
Synthetic name of the option	Economic transformation	Technological transformation	Social transformation	Institutional transformation	Behavioural transformation	Environmental/ landscape transformation
Water Management Decision Support System (DSS)				**X**		
Innovative insurance products for agriculture, forestry, hydropower energy production	**X**					
Evaluation of the effects of the altitudinal shift of crops on vineyards						**X**
Activated cultural heritage to enhance climate resilience	**X**					
Improvement of risk management practices through the application of participatory approaches (Impact Chains and Rapid Risk management Appraisal)				**X**		
Extraordinary maintenance of water networks				X		
Sediment dredging of existing water retention basins						X
Multiple use of hydropower basins				X		
Natural Water Retention Measures in urban areas				X		X
Precision agriculture	**X**					
NbS in agriculture						X
Domestic water use reduction					X	
Integration of adaptation measures into spatial planning	**X**			**X**		
Enhance synergies among stakeholders involved in water management		**X**		**X**		
Use of monitoring devices for water sources				**X**		
Training and knowledge transfer of good practices					**X**	
Adjustment of hydropower water abstraction license		X				
Wastewater reuse		X				

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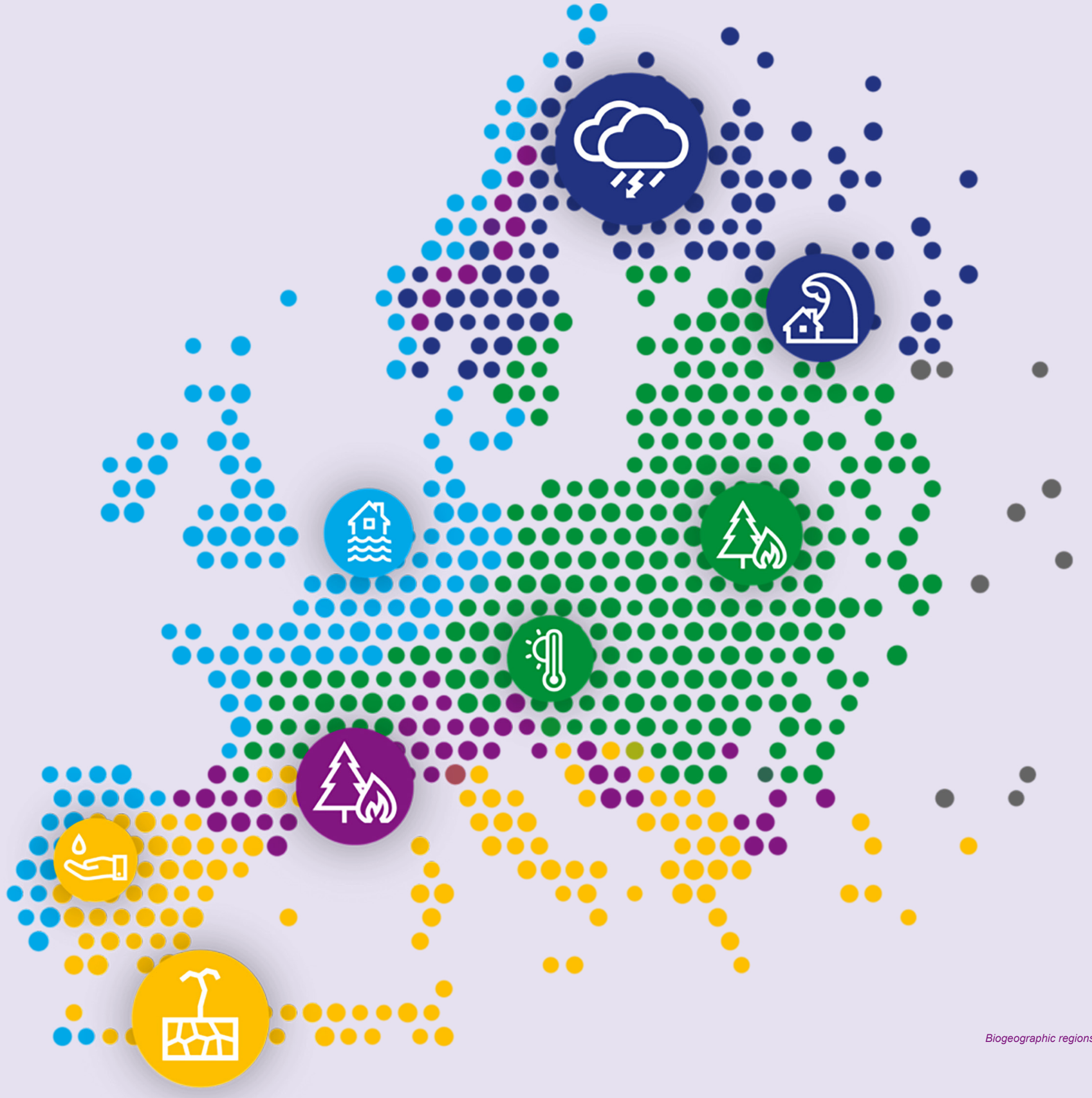

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