IMPETUS

Turning climate commitments into action

COAST OF CATALONIA

Innovation Package for adaptation and resilience

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Coastal 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 (RKB), an innovative approach to combine 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 demo-site level. They are composed of three blocks:

1. RKBs and their digital dimension for engaging stakeholders and boost 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. Portfolio 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 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 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 Portfolio of Solutions. Each block includes a synthesis of 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

The Catalan coast, located in the northeast of Spain, stretches for 600 km along the Mediterranean Sea. This temperate region is characterized by a rich variety of geological and biological systems that provide essential ecosystem services. At the same time, it hosts critical infrastructure - such as Barcelona's airport and harbour - alongside major industrial hubs (e.g., Barcelona's Zona Franca and Tarragona's petrochemical complex), renowned tourist destinations (e.g., Costa Brava and Costa Daurada), densely populated urban areas and highly productive agricultural zones. This unique combination creates intense competition for limited natural resources, making the region particularly vulnerable to environmental and socio-economic pressures.

Current climate trends indicate an increasing risk of various climate hazards, including rising temperatures, sea level rise, extreme marine storms and reduced precipitation. These changes are likely to exacerbate the impact on coastal flooding, coastal erosion, biodiversity loss, and water scarcity.

Sea Level Rise

Sea level rise poses a significant threat to the low-lying coastal areas of Catalonia, particularly deltas and estuaries. These areas face an increased risk of flooding, saltwater intrusion, and related impacts that affect ecosystems, infrastructures, and agriculture. With global sea levels continuing to rise, these challenges are expected to become more severe in the coming decades.

Marine Storms

The frequency and intensity of marine storms are increasing, resulting in more frequent damage to coastal infrastructure and assets. These events also disrupt coastal ecosystems and negatively impact biodiversity. Stronger and more frequent storms exacerbate erosion, reshape shorelines, and pose risks to both human activities and natural habitats.

Water Scarcity

Water scarcity is a chronic problem in Catalonia, and climate change is intensifying this issue. Growing tourism pressure and dependency on river water transfers, desalination plants, and reclaimed water make the water supply more vulnerable. Reduced water availability threatens agriculture, industry, and urban populations, creating competition between different uses.

Irregular Rainfall and Flooding

Increasingly irregular rainfall patterns are causing more frequent flash floods and associated damages. This is particularly problematic in densely populated areas where heavy rain events can coincide with marine floods, amplifying the risk. The resulting damage to infrastructure, property, and public health highlights the urgent need for improved flood management and adaptation measures.

A PLATFORM TO EXCHANGE AND BOOST KNOWLEDGE

Content

The RKB (Resilience Knowledge Booster) web platform presents and explains the regional challenges related to the management of sea level rise, water supply, extreme events and biodiversity loss and helps exploring possible solutions in the perspective of climate change. The Solutions section of the platform include solutions for Resilient Tourism, Species distribution, Water quality in bathing areas and Dune restoration.

The Adaptation Pathways section includes a conceptual model for increasing water availability and improve water quality (Impact chain) showcasing how hazard, exposure, and vulnerability elements interact to generate the risk of water scarcity. 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/coastal/.

Resilient tourism

Resilient Tourism is a decision-support tool designed to adapt tourism activities to climate change. It offers insights into the climate suitability of different outdoor activities, enabling the matching of ideal tourist experiences with weather forecasts and supporting effective tourism planning and infrastructure management.

Species distribution Visor

Species Distribution Visor is a tool designed to analyse and predict, by integrating predictive ecological models, how climate change impacts species distribution and habitat suitability in future climate scenarios. It supports managers and decision makers to appropriately prioritise conservation actions and implement efficient adaptation strategies.

Water quality in bathing areas

Quantitative Microbial Risk Assessment (QMRA) is a tool developed to predict and manage health risks from pathogens in seawater. It estimates infection risk based on pathogen concentrations and dose-response relationships, using E. coli and enterococci as indicators. The tool integrates continuous monitoring data (e.g. from AquaBio) with water quality models to forecast contamination events, issue alerts, and support preventive actions such as beach closures. The results will improve recreational water management and reduce the risk of water-borne disease under changing climate conditions.

Dune restoration

The dune restoration is focused on testing and assessing the effectiveness of this action as a nature-based solution to coastal hazards along the Catalan coast. It analyses the current status of dune systems through field and remote surveys, applies multi-scale indicators to evaluate climate change and human pressures, and monitors restoration actions at pilot sites in Calafell and Sant Pere Pescador. The goal is to identify the most efficient management techniques—such as sand fences, roped dunes, and traffic management—enhancing storm resilience, biodiversity, and public awareness. The results will support guidelines and upscaling plans for future dune restoration along the Catalan coastline.

Resilient tourism

© IUCN | Alba Serrat. Source: Las dunas y su vegetación

Species distribution Visor

Water quality in bathing areas

Cinzia Leccardi

Dune restoration

Carla García-Lozano

RKB - Exploitation potential

The exploitation potential of RKB has been evaluated with a particular focus on water quality and tourism-related tools.

STAKEHOLDERS INTEREST

score 4/5

MAIN STAKEHOLDERS INVOLVED

Industry and Economy, State government and policy

The main stakeholders belong to State government and policy (water utilities, irrigation communities, environmental institutions) as well as governmental institutions (water agencies, municipalities and regional authorities).

FEEDBACK FROM STAKEHOLDERS

Positive feedback was received from the stakeholders involved in RKB platform evaluation. During meetings and information sessions, many — especially those from public health and environmental sectors — emphasized the value of real-time risk map visualization, identifying it as one of the most promising and useful features for decision-making and timely interventions. The RKB was presented to stakeholder in a non-finalised version, not mature enough to demonstrate its full potential. This limited the capacity of stakeholders to provide a thorough evaluation. However, co-creation with stakeholders was viewed positively.

STRENGTHS

score 3/5

A WELL-DESIGNED AND INFORMATIVE TOOL THAT EFFECTIVELY VISUALIZES ADAPTATION OPTIONS AND DELIVERS ACTIONABLE KNOWLEDGE

RKB DIGITAL DIMENSION COMPONENT	SCORE
Visualisation (layout, images, graphic design)	3.5
Knowledge content (quality and type of information displayed)	3.5
Interactive functionalities (animations, customised navigation, dashboards)	3
Feedback collection tools (pools, chats)	2

OPPORTUNITIES FOR RKB USE

score 3/5

Stakeholder engagement and the co-creation process of RKB platform, highlighted clear opportunities for its application in both current planning and future initiatives within the DS Region. Stakeholders emphasized the potential to support local climate adaptation strategies and tourism planning by offering accessible, location-specific climate information. They also recognized the platform's value in informing proposals and actions aligned with Next Generation EU projects, particularly in the areas of sustainable tourism, water management, and climate resilience. The integration of co-designed indicators ensures that the tools (RKBs) directly address regional priorities, enhancing their relevance and practical applicability in upcoming decision-making processes.

RKB - Gaps & needs

CHALLENGES FOR PLANNING AND DECISION MAKING PROCESS: governance first

The main challenges are integrating the RKB into institutional workflows, improving user capacity and data interpretation, and building trust in its outputs. Sustained training, clear procedures and reliable data are essential to turn digital insights into effective and long-term decision-making.

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

WHAT TO IMPROVE

A key weakness of the current RKB, in particular for water quality and tourism tool, is the lack of real time environmental data, climate forecasts and long-term climate projections. While the existing indicators are effective for assessing historical trends and present conditions, integrating forward-looking climate data and real-time monitoring would greatly improve forecasting accuracy and operational relevance. Future developments should include uncertainty quantification and adaptive thresholds to support more balanced and context-sensitive decision-making.

RKB - Transformational potential

AN INSTRUMENT RESPONSIVE AND FLEXIBLE TO CHANGING CONDITIONS

The RKB platform demonstrates a good level of responsiveness to changing conditions, providing a flexible framework that can be adapted as new challenges emerge. Its participatory approach is well reflected, as stakeholders were involved in co-creation. The platform has been developed at a local scale and is easily scalable to other coastal sites supporting also potential scalable deployment across regions. Equity considerations were addressed, prioritising the protection of vulnerable population groups. While the platform represents a novel approach for the region, it is not expected to generate a radical transformation of the socio-ecological system.

TRANSFORMATION ELEMENT	SCORE
SCOPE: Responsive (flexible) to changing conditions	4
INCLUSIVITY: Co-developed/discussed with stakeholders	3.5
SCOPE: Developed at scale or easily scalable	3.5
SCOPE: The RKB platform includes a multi-sector approach	3.5
DEPTH OF CHANGE: Novel approach for the region	3.5
INCLUSIVITY: Consideration for the equity of measures, attention for vulnerable groups	3
TEMPORALITY: Long-term vision/expected to produce long-term and durable outcomes	2.5
DEPTH OF CHANGE: Expected to generate radical shift or large restructuring in your region	2.5

ADAPTATION PATHWAYS TO ADDRESS THE 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, different or larger measures is triggered when current adaptation measures and policies are no longer effective 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 interactions were performed in each region with formal events and informal interactions. Interactions were continuously 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.

Along the Catalan coast, the main goal of the adaptation process is to increase water availability and improve the quality of the region's inner watersheds. These watersheds cover 52% of Catalonia's territory and are home to 92% of its population. Managed by the Catalan Water Agency, they account for 40% of the region's total water consumption, with domestic use (44%) representing the largest share, followed by agriculture (36%) and industry (20%).

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 represent cause–effect chains that capture the key factors and processes leading to specific climate risks within a given context.

For the Catalan case study, the conceptual model was developed in alignment with the Catalan Strategy for Adapting to Climate Change 2021–2030 (ESCACC30, Estratègia catalana d'adaptació al canvi climàtic 2021–2030) and in close collaboration with the Catalan Office for Climate Change (OCCC), a project partner. The impact chain was intentionally simplified to focus on the most significant drivers and impacts currently influencing water scarcity in Catalonia. Within the Catalan DS, the climate risk addressed is water scarcity — a critical and highly relevant challenge in the region. This risk emerges mainly from the interaction of two closely linked climate hazards:

1. Diminished and altered precipitation patterns: changes in rainfall regimes, including reduced overall precipitation and increased variability, significantly affect water availability. This creates challenges for replenishing natural water reserves, such as aquifers, rivers, and reservoirs, and exacerbates seasonal or regional shortages.
2. Increased temperatures: rising temperatures amplify water scarcity by driving higher evaporation rates from surface water bodies and soils, intensifying drought conditions. Additionally, increased temperatures often lead to greater water demand, particularly for agriculture and energy production, further straining resources.

These factors are inherently connected, collectively contributing to the heightened vulnerability of water systems.

The objectives of the adaptation pathways are therefore:

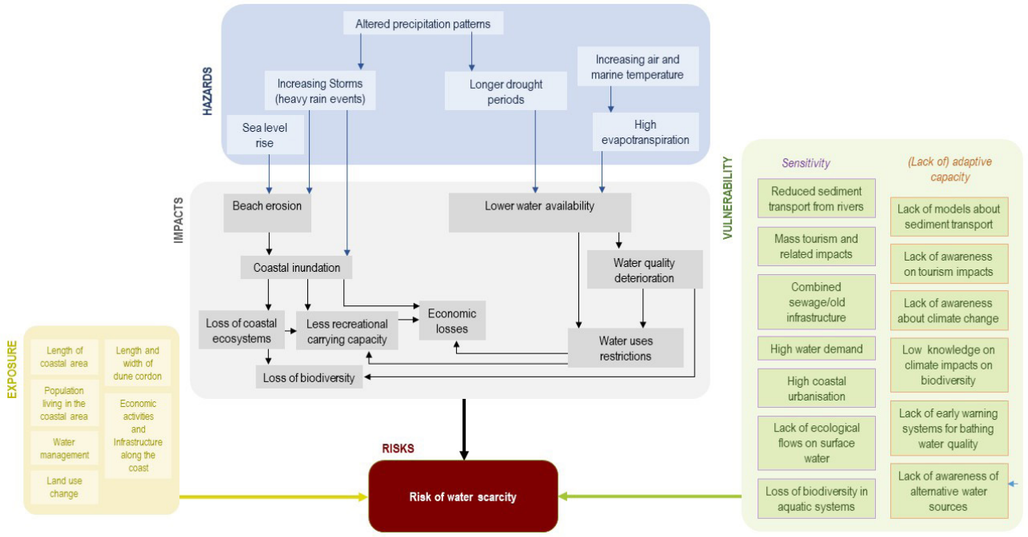
- increase water availability.
- improve its quality.

with a particular focus on water reuse and resilience of freshwater bodies.

Impacts refer mainly to lower water availability and water quality deterioration, which together increase competition in water uses and potential water uses restrictions. Reduced water availability limits the replenishment of natural reservoirs and decreases ecological flows, leading to biodiversity loss and reducing water recreational potentialities. These effects cascade into economic losses due to reduced agricultural productivity, increased costs for water treatment and supply, and limitations for industrial and domestic consumption.

Exposure elements play a crucial role in shaping the extent of these impacts. High population density in the coastal area increases water demand, while intensive economic activities and infrastructure along the coast further raise pressure on already scarce resources. Inadequate or inefficient water management can worsen these effects. Catalonia's vulnerability is further amplified by local factors such as high water demand, mass tourism, high coastal urbanisation, and insufficient ecological flows in surface waters.

Addressing water scarcity through adaptation pathways is thus crucial not only to ensure a sustainable water supply but also to support the resilience of ecosystems, agriculture, and communities that depend on this vital resource.



Content

THE PATHWAYS MAPS

The results of the activity on adaptation pathways, achieved also through engagement and co-creation with stakeholders, identified four adaptation pathways built around three key tipping points for water scarcity and quality, aligned with Catalan Government policy horizons and expert judgment. The first tipping point targets reduced urban water demand - below 150 L/day per person by 2030 and below 100 L/day by 2050. The second focuses on irrigation efficiency - 50% of demand met with reclaimed water by 2030 and 100% by 2050. The third warns of critical water scarcity by 2100, with inner watershed availability falling below 15% (100 hm^3), triggering a level 1 emergency if no action is taken.

Socio-environmental. This pathway seeks to minimize environmental impact while maximizing social benefits. It emphasizes solutions that are both ecologically sound and socially inclusive. In this pathway, all five proposed adaptation measures are included and considered viable, as they collectively address the needs of diverse stakeholders while promoting environmental sustainability. The goal is to ensure that no group is disproportionately affected and that ecological systems remain resilient.

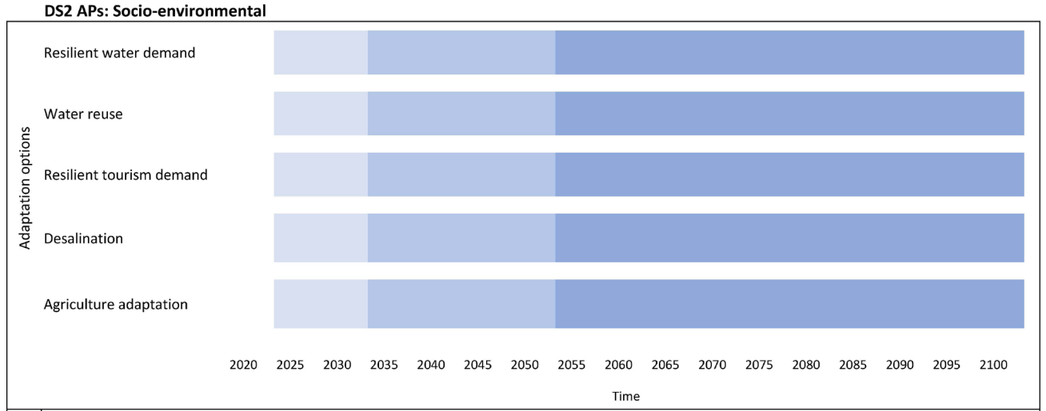
Technological. This pathway only includes desalination, which represents a technologically advanced solution to water scarcity, involving the conversion of seawater into freshwater. While it can provide a reliable water source (the water stress indicator has the highest reduction compared to the other pathways), especially in coastal areas, it comes with significant challenges-primarily high energy costs and environmental concerns that trigger social debate. Nevertheless, when properly managed, desalination can avoid pressure on valuable freshwater sources and overexploited water bodies.

Techno-environmental. This pathway highlights the potential of combining technological innovation with environmental sustainability. By integrating desalination with water reuse practices, water security can be enhanced while reducing environmental footprints. This hybrid approach balances the strengths of both systems: desalination provides supply-side resilience, while water reuse reduces waste and conserves natural resources.

Socio-political: Effective adaptation also requires strong governance, coherent policies, and shifts in social behaviour. This pathway minimize structural interventions, while focusing on improving institutional coordination, fostering transparent decision-making, and encouraging public engagement in water conservation efforts. It includes three adaptation options related to creating policies that support sustainable water use, investing in public awareness campaigns, and facilitating participatory governance to build trust and collective responsibility for managing climate-related water challenges.

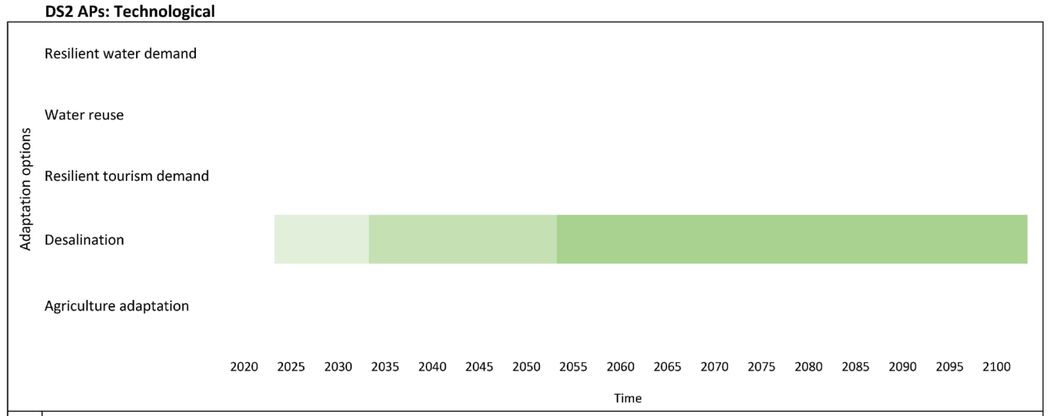
In the following graphs, the light colour of the bars represents the implementation time of measures, while the dark colour represents how long they stay in place. The two small circles representes the tipping points whose.

DS2 APs: Socio-environmental



		2025	2030	2050	2100
SSP1	WSI - no adaptation	0.55	0.59	0.59	0.65
	WSI - Socio-environmental pathway	0.49	0.47	0.39	0.36
SSP3	No adaptation	0.60	0.62	0.67	0.76
	WSI - Socio-environmental pathway	0.53	0.49	0.44	0.42
SSP5	No adaptation	0.54	0.59	0.64	0.84
	WSI - Socio-environmental pathway	0.48	0.47	0.41	0.46

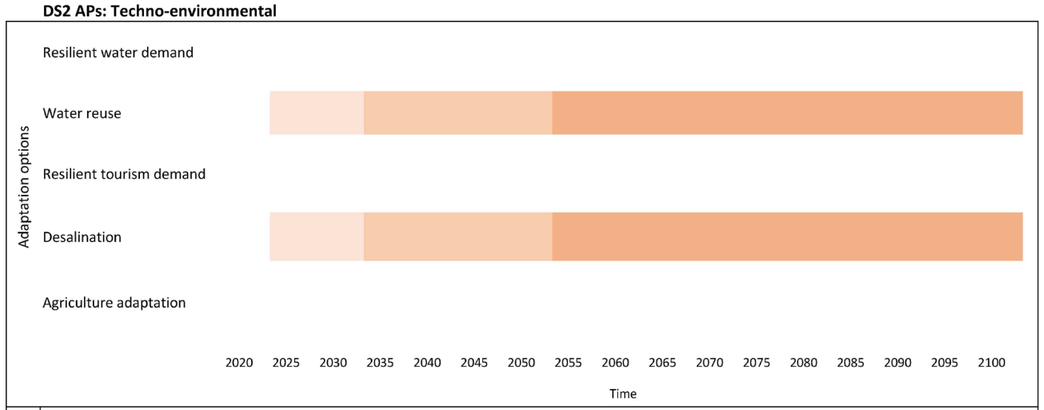
DS2 APs: Technological



		2025	2030	2050	2100
SSP1	WSI - no adaptation	0.55	0.59	0.59	0.65
	WSI - Technological pathway	0.48	0.44	0.33	0.28
SSP3	WSI - no adaptation	0.60	0.62	0.67	0.76
	WSI - Technological pathway	0.52	0.45	0.38	0.34
SSP5	WSI - no adaptation	0.54	0.59	0.64	0.84
	WSI - Technological pathway	0.47	0.44	0.36	0.38

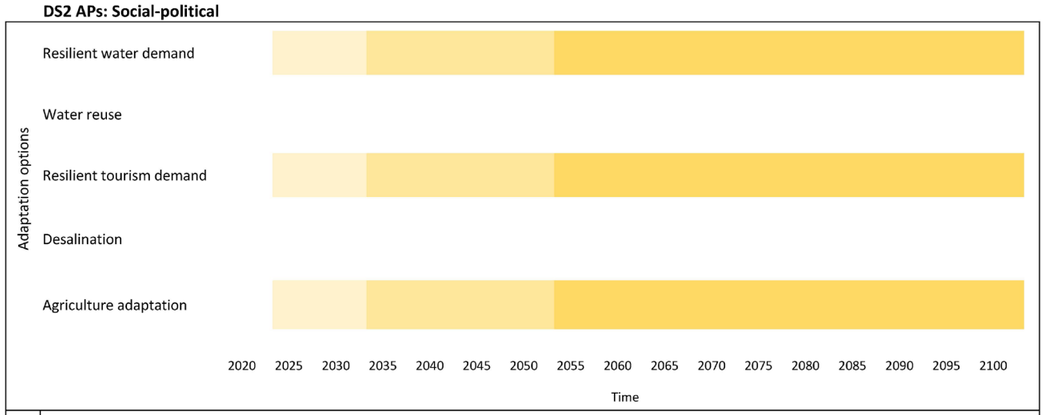
Figures: DS2 Adaptation Pathways Maps

DS2 APs: Techno-environmental



		2025	2030	2050	2100
SSP1	WSI - no adaptation	0.55	0.59	0.59	0.65
	WSI - Techno-environmental	0.49	0.43	0.44	0.49
SSP3	WSI - no adaptation	0.60	0.62	0.67	0.76
	WSI - Techno-environmental	0.54	0.51	0.49	0.51
SSP5	WSI - no adaptation	0.54	0.59	0.64	0.84
	WSI - Techno-environmental	0.49	0.49	0.47	0.56

DS2 APs: Social-political



		2025	2030	2050	2100
SSP1	WSI - no adaptation	0.55	0.59	0.59	0.65
	WSI - Socio-political	0.51	0.54	0.50	0.51
SSP3	WSI - no adaptation	0.60	0.62	0.67	0.76
	WSI - Socio-political	0.56	0.56	0.57	0.60
SSP5	WSI - no adaptation	0.54	0.59	0.64	0.84
	WSI - Socio-political	0.51	0.54	0.54	0.66

Figures: DS2 Adaptation Pathways Maps

Adaptation pathways - Exploitation potential

STAKEHOLDERS INTEREST

score 4/5

MAIN STAKEHOLDERS INVOLVED: State government and policy

Representatives from key institutions, especially at regional level, have engaged with the proposed solutions, recognising their potential to enhance climate resilience through structured, phased implementation.

FEEDBACK FROM STAKEHOLDERS

The adaptation approach pathway is generating growing interest among public sector stakeholders. This interest highlights the relevance and applicability of the pathway model in supporting long-term decision-making and integrated water management.

OPPORTUNITIES TO USE ADAPTATION PATHWAYS IN PLANNING/DECISION MAKING

score 3/5

The adaptation pathways offer strong potential as a communication tool to clearly illustrate long-term strategies and trade-offs, making complex decisions more accessible to expert stakeholders. Their phased structure helps frame policy discussions, align sectoral priorities, and support transparent, participatory decision-making. By promoting dialogue, aligning expectations, and raising awareness, this approach fosters structured debate and encourages forward-looking thinking, effectively communicating complex strategies to a wide range of actors.

Adaptation pathways - Gaps & needs

CHALLENGES - HOW TO TRANSLATE INTO PRACTICE

Governance and Knowledge challenges come first: the construction and validation of the pathways rely heavily on detailed technical data and ongoing inputs that are often only accessible to public bodies. Such institutions not only hold the most up-to-date data, but also the sector-specific expertise needed to interpret it accurately. This data is subject to frequent updates that reflect political, environmental, or regulatory changes. A challenge lies is keeping strong, continuous engagement with these public actors. Without such engagement, there is a risk that pathways become outdated or disconnected from real-world decision-making.

PRIORITY	CHALLENGES
1	Governance challenges
	Knowledge challenges (availability of information)
2	Capacity challenges (ability and motivation to use knowledge for action)
	Financial challenges

WHAT TO IMPROVE

One key area for improvement is increasing flexibility within the adaptation pathway framework. While the methodology is valuable, some steps felt redundant or overly rigid, making it difficult to capture the unique context and dynamics of the DS. A more adaptable, context-sensitive approach would help avoid the risk of oversimplifying complex realities and better support tailored, effective decision-making.

Adaptation pathways - Transformational potential

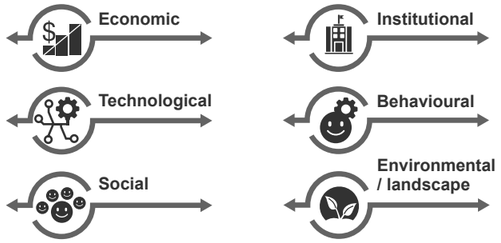
ELEMENTS OF TRANSFORMATION

The developed pathways provide valuable insights into local adaptation measures, while the approach itself is designed to be scalable and applicable across regions by repeating the process with a focus on the new scale and specific local characteristics. The adaptation pathways were co-developed with a selected group of key stakeholders, ensuring that the most relevant actors were actively engaged, even if not all stakeholders were directly involved. Although the methodology adopts a multi-sectoral approach, the role of public bodies remains predominant. The developed adaptation pathway at the DS level is novel to the region, combining multiple solutions into an integrated framework that supports informed policy dialogue and decision-making. If implemented, the adaptation pathway methodology can remain flexible and responsive to evolving climatic conditions. However, shifts in governance contexts and rapid changes in technical data may quickly turn the pathways outdated, requiring regular review and updates. At present, no long-term implementation of the adaptation pathways is foreseen in the DS. Nevertheless, they are expected to generate short-term outcomes, particularly in terms of communication and awareness-raising, which can be equally valuable for supporting future adaptation efforts. The relatively low performance on inclusivity reflects that discussions often focused heavily on technical data, sometimes diminishing crucial aspects such as equity, attention to vulnerable groups, and the broader social dimensions of adaptation. Finally, a radical shift or large restructuring is not expected, as the abundance of data held by public bodies is difficult to integrate into the pathways, which are designed as more synthetic and simplified decision-support tools.

TRANSFORMATION ELEMENT	SCORE
SCOPE: Developed at scale or easily scalable	4
SCOPE: The RKB platform includes a multi-sector approach	3
INCLUSIVITY: Co-developed/discussed with stakeholders	3
DEPTH OF CHANGE: Novel approach for the region	3
SCOPE: Responsive (flexible) to changing conditions	2
TEMPORALITY: long-term vision/expected to produce long-term and durable outcomes	1
INCLUSIVITY: Consideration for the equity of measures, attention for vulnerable groups	1
DEPTH OF CHANGE: Expected to generate radical shift or large restructuring in your region	1

IMPACT OF TRANSFORMATION

Applying the adaptation pathways to the local climate risk of water scarcity would certainly foster positive transformations at all levels in different intensity. It could make a positive change in all different societal layers depending on the chosen pathways. The pathways allow for choices between the options, but requires, environmental/landscape transformation, societal and economic transformation, and might induce social and behavioural chances. By this all, a technical transformation would be inevitable



A PORTFOLIO OF CLIMATE ADAPTATION SOLUTIONS

Content

Twelve adaptation solutions to address sea level rise, marine storms, biodiversity loss and water scarcity were assessed.

Nine of them were specifically tested in IMPETUS: multifunctional wetlands, sand dune restoration, water reclamation system, sediment transport modelling, Microbiological Risk Assessment (QMRA) tool for bathing water quality, reducing cyanotoxins in water treatment plants for drinking purposes, modelling of spatial distribution of species and tourism behavioural change.

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). The nine solutions tested in IMPETUS belong to four categories: two are green options (category D1), including multifunctional wetlands and sand dune restoration to reduce coastal erosion; two are grey options (category C1), consisting of water reclamation systems for non-potable uses and three-dimensional sediment transport modelling for improved river and irrigation management; four are technological options (category C2), including sediment transport modelling, QMRA tool for pathogen risk prediction, ultrasonic and solar disinfection for cyanotoxin removal and modelling techniques to assess species distribution under climate change; finally, one solution belongs to capacity-building option and it is focused on the development of alternative and sustainable tourism strategies.

The solutions not tested in IMPETUS are all focused on water scarcity and their category spans from E1-Information and awareness raising, to D1-Green options and C1-Grey options. They include reducing per capita water consumption through awareness campaigns, behavioural change and water-saving technologies, a desalination plant and lowering irrigation demand via crop selection, precision irrigation, and adjusted planting schedules.

OPTION	DESCRIPTION	MAIN OBJECTIVE(S)	IMPETUS CLIMATE RISK	KEY TYPE OF MEASURE	TESTED IN IMPETUS
Multifunctional wetlands	Below sea-level multifunctional wetland.	To demonstrate the feasibility of the technology in wetlands, as decentralized water treatment systems able to reduce nutrients and pollutants from agricultural fields.	Sea level rise	D1 - Green Options	Y
Sand dune restoration	Sand dune restoration and monitoring to prevent coastal erosion.	To reduce the exposure of the hinterland and thereby enhance the protection of people and infrastructure from sea level rise.	Marine Storms	D1 - Green Options	Y
Water Reclamation System (Water reuse)	Centralized and decentralized hybrid fit-for use water reclamation system.	To increase water availablity for non-drinking purposes. To prove the economic, social and environmental benefits of greywater reuse.	Water scarcity	C1 - Grey options	Y
Sediment transport modelling	Three-dimensional (3D) water flow and sediment transport model using computational fluid dynamics (CFD).	To reproduce the water flow and sediment dynamics within the Ebro river and the irrigation channels, as a tool to propose an efficient management and adaptation measures.	Marine Storms	C2 - Technological options	Y
Microbiological Risk Assessment (QMRA) tool for bathing water quality	Quantitative Microbiological Risk Assessment (QMRA) to determine the risk due to the presence of pathogens in bathing seawater.	To develop and implement tools for risk prediction, monitoring and management of water-borne disease in Barcelona demo-site,	Health diseases	C2 - Technological options	Y
Reducing cyanotoxins in water treatment plants for drinking purposes	Implementing advanced monitoring tools in water reservoirs to predict harmful algal blooms (HABs) Implementing/evaluating ultrasonic and solar disinfection techniques for cyanotoxins removal.	To increase the resilience of water plants to water-borne pathogens,	Health diseases	C1 - Grey options	Y
Avalanches EWS: Modelling of Spatial distribution of species	Modelling techniques and analytical frameworks for assessing species distribution change.	To improve the understanding of climate change impacts on species distribution; to provide information for conservation practitioners to use within the context of their planning at national and local scales.	Biodiversity Loss	C2 - Technological options	Y
Coastal monitoring system	Development of a coastal information system by collecting information about the areas most vulnerable to flood risk in the Catalan coast.	To assess the economic impacts of extreme storms in infrastructures.	Marine Storms	C2 - Technological options	Y
Tourism behavioural change	Development of alternative and sustainable tourism strategies.	To make tourism less affected by and more resilient to climate change.	Water scarcity	E2 - capacity building, empowering and lifestyle actions	Y
Sustainable and resilient water demand management	Progressive reduction in daily per capita water consumption through a combination of measures (public awareness campaigns, behavioural change strategies, water-saving technologies, and coordinated policies).	To support long-term water security under increasing climate pressure.	Water scarcity	E1 - Information and awareness raising	
Desalination	Construction of a desalination plant.	To enhance water availability by converting seawater to potable water.	Water scarcity	C1 - Grey options	
Crop/agricultural adaptation	Reducing irrigation demands through a combination of strategies, including shifting to less water-dependent crops, adopting precision irrigation technologies, and revising planting schedules to align with changing climate patterns.	To optimize water use while maintaining agricultural productivity and supporting rural livelihoods.	Water scarcity	D1 - Green Options	

Portfolio of solutions - Evaluation

Many of the solutions are quite mature since they are characterized by medium to high technological and social readiness level (TRL and SRL). Among the solutions tested in IMPETUS, the most effective are considered Water Reclamation Systems and Tourism Behavioural Change. These tested actions deliver significant environmental and social benefits. Water reclamation systems reduce pressure on traditional water sources such as rivers, lakes, and groundwater reserves, support biodiversity, improve water quality, and help ensure a more reliable water supply. Tourism behavioural change complements these benefits by promoting more sustainable tourism models, which enhance the well-being of local communities and visitors and strengthen the local economy. Together, these measures can generate increased revenues in sectors most affected by water scarcity, including agriculture and tourism. In addition, tourism behavioural change creates a positive synergy with climate mitigation by reducing emissions linked to transport, accommodation, and recreational activities. While these actions offer strong environmental and social benefits, their implementation faces some hidden risks. Gaining stakeholder acceptance for water reuse is essential to ensure successful uptake. Moreover, biological water treatment processes require strict monitoring, as their effectiveness can decline under peak seasonal loads and low temperatures, leaving surfactant and detergent residues untreated. For tourism measures, risks include the potential overexploitation of fragile habitats such as dune systems and wetlands, gentrification effects that may reduce affordability for local residents, and higher short-term operational costs before financial returns are realized.

Considering the solutions not tested, particular effectiveness is attributed to “Desalination” and “Sustainable and Resilient Water Demand Management”, both characterized by medium to high TRL and SRL, confirming their maturity for implementation. Sustainable and Resilient Water Demand Management, shows a strong positive synergy with climate mitigation, as reducing per capita water consumption also lowers the energy footprint of water abstraction, treatment, and distribution. For desalination, the main gaps and needs relate to negotiation at the socio-political level to secure stakeholder acceptance, and the challenge of high operational expenditures (OPEX), which require stable funding mechanisms and improved energy efficiency to make the process economically viable. Residual salt and other substances potentially discharged into the sea require careful attention, as they can harm marine ecosystems.

		ASSESSMENT												GAPS & NEEDS for implementation
#	Synthetic name of the option	Effectiveness for the expected objective	Lifetime	Feasibility - TRL	Feasibility - SRL	Economic costs	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	Multifunctional wetlands T4.2	+		++	+	- -	Water Quality improvement. Biodiversity. Habitat regeneration.	+++		Possible release in the environment of pollutants captured by biochar.	- -		-	Yes	Further investigation is needed to: understand the potential risks associated to the measures; estimate the lifespan of the materials used for pollution remova; find economic solutions to scale up the solution; estimate the minimum wetland surface needed to generate a positive impact on the surrounding ecosystems.
2	Water Reclamation System (Water reuse) T4.5.1	+++	++	+++	++	- -	Reduced pressure on traditional water sources like rivers, lakes, and groundwater reserves. Biodiversity. Enhanced water quality. Increased revenues from sectors affected by water scarcity (e.g.agriculture, tourism).	++	++	Effectiveness in the biological water treatment due to peak seasonal loads combined with low temperatures. Possible surfactants and detergent residues that cannot removed with biological treatment.	-	-	-	No	Stakeholder acceptance for water reuse is needed.
3	Tourism behavioural change T4.22	++	++	++	+++	- -	Reduced pressure on natural water resource. Well-being of local communities and tourists. Local economy enhancement.	++	++	Overexploitation of specific local resources or habitats, especially in sensitive areas such as dune systems or wetlands. Gentrification, with rising accommodation and food prices potentially reducing affordability for locals. Higher short-term operational costs before financial returns materialize.	- -	- -		Yes	Careful monitoring of hidden risks will be crucial to avoid maladaptation and ensure long-term sustainability.
4	Sustainable and resilient water demand management	+++	++	++	++	- -		++	++		-		-	Yes	
5	Desalination	+++	++	+++	++	+++				Residual salt and other substances are discharged in the sea and can harm ecosystem.				No	Need to be negociated at socio□political level. High OPEX demanding.

Portfolio of solutions - Transformational potential

ELEMENTS OF TRANSFORMATION

A subset of solutions was assessed in terms of their transformative potential. The set of analysed measures presents a solid potential for transformation, with an average score of 3.5 out of 5 across all criteria. Overall, the portfolio is highly responsive to climate change — particularly water reclamation systems and tourism behavioural change, both scoring the highest for climate responsiveness — and includes solutions that are scalable and capable of delivering long-term, durable outcomes. These attributes make them well-suited to address future climate pressures in a progressive manner.

However, the measures are not expected to bring a radical shift or a complete restructuring of the regional system. Instead, they are likely to drive incremental improvements, gradually embedding change into existing water and coastal management frameworks. For example, multifunctional wetlands score highly for novelty and scalability but have low transformational impact, suggesting a complementary rather than systemic role.

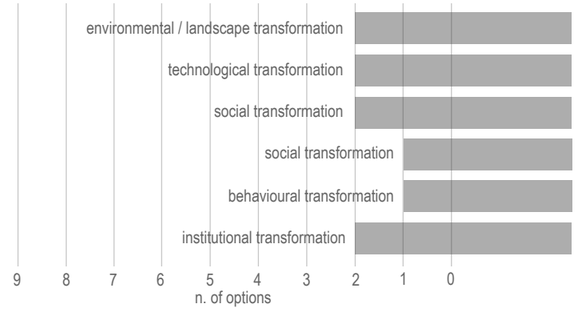
Equity considerations remain an aspect to strengthen, as most solutions show only moderate attention to vulnerable groups and marginalised communities with water reclamation systems receiving one of the lowest equity scores. While tourism behavioural change has been widely co-developed with stakeholders, its moderate score for long-term outcomes suggests the need for sustained engagement to secure lasting behavioural shifts.

Considering all scoring dimensions, Water reclamation systems show the strongest transformational potential, with top scores for adaptability to changing climatic conditions, scalability and long-term effectiveness and good performance on stakeholder engagement. Tourism behavioural change also stands out, achieving the highest scores for depth of change and co-creation with stakeholders, as well as strong adaptability and scalability.

	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	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
Multifunctional wetlands	3	1	4	5	1	3	not applicable	3
Water Reclamation System (Water reuse)	3	5	5	4	3	4	2	5
Tourism behavioural change	5	5	4	4	3	5	3	3

Portfolio of solutions - Transformational potential

Figure: Impacted sectors



IMPACT OF TRANSFORMATION

Environmental and landscape transformations are mainly driven by the creation and restoration of multifunctional wetlands and, to a broader extent, by tourism behavioural change, both of which enhance ecosystem services and the ecological quality of the territory. Water reuse through water reclamation systems supports both technological and institutional transformation by securing additional water resources and promoting innovation and efficiency in water management. At the same time, water reclamation requires a shift in societal attitudes toward water reuse, reflecting its contribution to social transformation. Economic and social transformations are less consistently addressed across the portfolio, being associated only with tourism behavioural change. This solution is also the most cross-cutting, engaging multiple sectors and combining behavioural, institutional, economic, and social dimensions, which gives it the broadest systemic impact. In general the portfolio of solutions seems to focus mainly on technical and environmental improvements.

IMPACT OF TRANSFORMATION						
Synthetic name of the option	Economic transformation	Technological Transformation	Social transformation	Institutional transformation	Behavioural transformatio	Environmental / Landscape transformation
Multifunctional wetlands						X
Water Reclamation System (Water reuse)		X	X	X		
Tourism behavioural change	X		X		X	X

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