I-CISK

HUMAN CENTRED CLIMATE SERVICES

Deliverable D2.6
User-centred validation of the integration of climate action information

June 2024

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I-CISK

Innovating Climate services through Integrating Scientific and local Knowledge

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Table of Contents

List of Figures

List of Tables

Acronyms

ARPAE	Regional Environmental Agency of the Emilia Romagna
CAP	Common Agricultural Policy
CCA	Climate change adaptation
CS	Climate services
DMA	Disaster management agency
EAP	Early action protocol
ECMWF	European Centre for Medium-Range Weather Forecasts
EU	European Union
EWS	Early warning system
LRCS	Lesotho Red Cross Society
LL	Living labs
MAP	Multi actor platform
NCCC	National climate change committee
OAK	Organization for the Development of Crete
PER	Preparedness for effective response
SMHI	Swedish Meteorological and Hydrological Institute
UHI	Urban heat islands
WFP	World Food Programme

1. Introduction

Climate services (CS) are critical elements to support decisions for adaptation to climate-related risks and climate change impacts. To be effective, CS need to be tailored to the knowledge, experience and needs of the users and the contexts in which decisions are being made (Hewitt et al., 2021). I-CISK recognizes that, in order to achieve behavioural change, the active use of climate information for adaptation and mitigation action requires CS users to be at the centre of the design, implementation and evaluation of CS.

An important starting point, which is the goal of Task (T2.3), which is documented in this deliverable, is to identify current and potential climate-related adaptation measures that can be informed and supported by existing and new CS. Multiple sources of information are used when making adaptation decisions. Not only climate-related information is used, but also past experience, policies, norms, perceived risks, sense of urgency, knowledge, capacities and barriers, and the expected consequences of implementing adaptation measures. Here, we explore how local actors combine and use different sources of knowledge in the adaptation decision-making process in the different living labs (LL) that make up the I-CISK project (Masih & Van Cauwenbergh, 2022). The specific goals of this task are to:

- Identify relevant existing and potential climate risk-management measures that can be informed and supported by CS at different temporal scales (short, medium, and long).
- Explore how different types of knowledge are combined and used in the adaptation decision-making space.
- Identify barriers (such as capacity, existing power distributions or legal-political obligations) that obstruct the consideration of certain adaptation measures in this space.

In a first phase (April 2022 - April 2023), we conducted a preliminary mapping of the adaptation decision-making space in the different I-CISK LL, that is, the decisions actors take to manage climate-related risks, the information used, and the identified barriers and enabling conditions (levers). The results of this work, reflected in *D2.3: Preliminary report on user-centred validation of the integration of climate action information* (Hernández-Mora et al., 2023) pointed to the limited use of existing climate information when making adaptation decisions. Actors implement a wide range of climate-risk adaptation measures, but they primarily rely on experience when making decisions on what measures to enact. Major barriers identified for implementing measures included financial considerations and the institutional and regulatory frameworks. Despite this, they also saw opportunities for improved decision making when given enhanced CS adapted to their needs – e.g. downscaled climate predictions and projections offered with sufficient lead times and in a seasonal and sub seasonal (1-3-6 and 12 months) time scale.

In this second phase (April 2023-April 2024), we have continued to better characterize the adaptation decision-making space, considering the social, temporal, and spatial dimensions of adaptation decisions, to understand the nature of adaptation pathways undertaken by different actors, sectors or regions. Specifically, in collaboration with other work packages (particularly WP3 and WP5) we have worked to:

- Validate and characterize the adaptation options identified in the first phase and explore adaptation options not previously considered.
- Identify barriers, windows of opportunity and enabling conditions to implement enhanced adaptation options.
- Continue to characterize & develop the necessary climate services for enhanced adaptation decisions.

- Understand the nature of adaptation strategies in terms of their long-term effectiveness and resilience in the face of climate risks.

This Deliverable, *User-centred validation of the integration of climate action information* (D2.6), further develops the (preliminary) results presented in D2.3 and includes the results of the second phase of T2.3. The report is structured in six chapters. After this Introduction, Chapter 2 presents the conceptual framework that guided the work of T2.3. Chapter 3 explains how this Task fits within the co-creation framework developed in I-CISK and how it relates with other tasks within the project. Chapters 4 to 10 describe, for each LL, the methodological approaches followed, the characterization of the current adaptation decision space, and the potential new additional adaptation measures that have been identified and could be implemented. Chapter 11 summarizes and discusses the results obtained in the different I-CISK LL. Chapter12 and presents concluding remarks.

2. Evolution of the conceptual framework: From adaptation decision space to adaptation pathways

Adaptation to climate change and its impacts may require a fundamental transformation to rebalance the relationship between humans and nature. In this sense, CS can facilitate decisions that contribute to increase the resilience of human and natural systems to climate-related risks. To ensure that CS are useful and used by different types of stakeholders, it is necessary to focus on user engagement, relationship building and the context of decision making (IPCC, 2023).

2.1. The adaptation decision space: concept and approaches

The adaptation decision space encompasses the entire context of the decision-making process: assets, knowledge, as well as the socioeconomic, biophysical and institutional environment. It corresponds to the ensemble of the adaptation options implemented; not implemented; and discarded, as well as the barriers and levers (enabling conditions) to their implementation. This view of the decision-making process facilitates the identification and mapping of the most influential factors acting on a given system.

The results of a preliminary characterization of such space were presented in Deliverable 2.3, *Preliminary report on user-centred validation of the integration of climate action information* (Hernández-Mora et al., 2023). That report identified the adaptation options currently implemented in the different I-CISK LL, the range of available options and possible barriers and enablers, including existing CS used for decision making, and the user-adapted CS needed to inform adaptation measures (Figure 1).

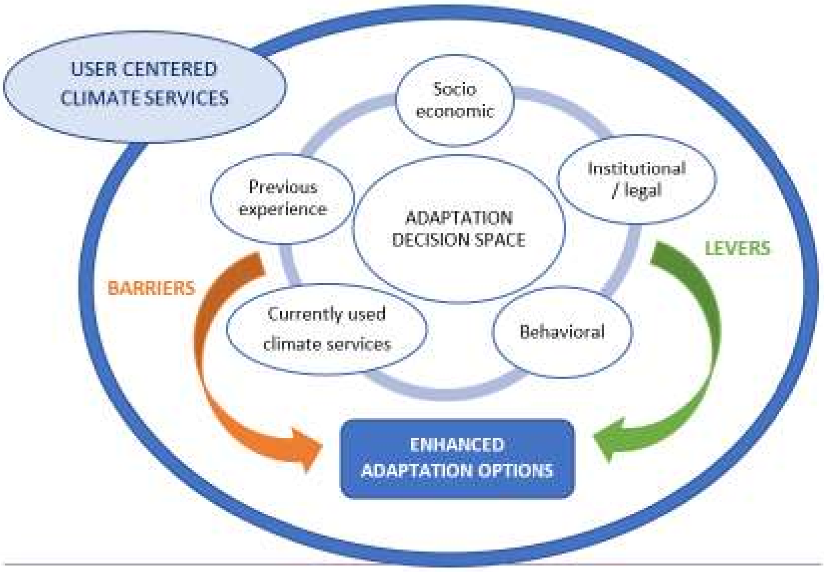

Figure 1. Conceptual framework for the investigation and mapping of the adaptation decision space. Source: Hernandez-Mora et al. (2023).

The methodological approach introduced in D2.3 identified the information used and needed for decision-making in each LL and the factors influencing each adaptation decision space. It also acknowledged the iterative nature of decision-making processes.

2.2. Integrating current and enhanced adaptation decision space into adaptation pathways

Vulnerability to climate change evolves over time due to the inherent characteristics of exposure and sensitivity that define it. Changes in natural hazards and the characteristics of the natural systems result in changes in exposure. Similarly, the sensitivity of ecosystems and society are not fixed and respond to local environmental dynamics, generating spatiotemporal heterogeneity (Magnan et al., 2016). Consequently, the process of adjusting to new environmental and climatic conditions with the objective of reducing this vulnerability is constantly evolving from a social, spatial, and temporal point of view.

The work reported in this deliverable aims to take this spatial and temporal evolution into consideration when investigating how individuals and institutions make decisions to manage present and future climate risks by introducing the concept of adaptation pathways. Adaptation pathways can be understood as sequences of decisions and actions that steer a social-ecological system towards a vision in response to biophysical and socio-economic drivers of change (Bruley et al., 2021).

Framing the decision-making process as an evolving pathway that responds to changing ecological, social, and spatiotemporal context facilitates overcoming the dilemma of having to place risk-management decisions in a dichotomy of either incremental versus transformational or short versus long term actions. Rather, it supports understanding risk management as an evolving process and the adoption of flexible and anticipatory management strategies (Magnan et al., 2020). The adaptation pathways approach may be a valuable tool to support this shift in framing adaptation. Adaptation pathways are process-oriented sets of decisions made in response to biophysical and/or economic change (Bruley et al., 2021) (Figure 2). This approach incorporates flexibility into decision-making processes that seek solutions tailored to different (and evolving) socio-economic, cultural and ecological contexts and avoid potential maladaptation (Möller et al., 2023; Wise et al., 2014).

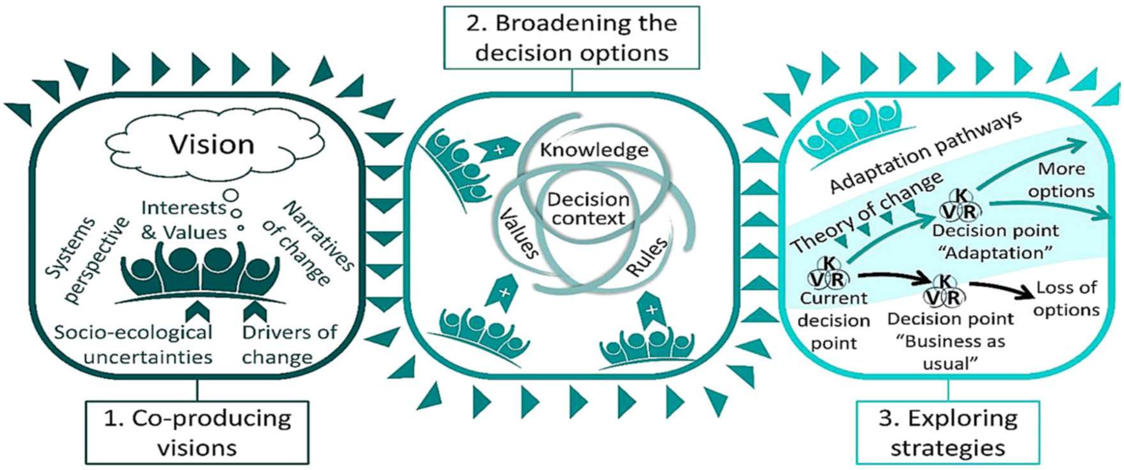

Figure 2. Adapting transformation and transforming adaptation to climate change using a pathways approach
Source: Colloff et al., 2020.

Often a pathway is represented by decision cycle points connected to each other by paths. These pathways may lead to the next decision cycle point, which will be located either in the adaptive or in the maladaptive space, that is, in the space that reduces or increases vulnerability to climate risks and conditions the availability of future adaptation options (Wise et al., 2014) (Figure 3). Understanding the adaptation decision space at each decision point and its associated adaptation options can facilitate the understanding of the factors that constrain/facilitate the decision process and the possible synergies between different actors in a territory.

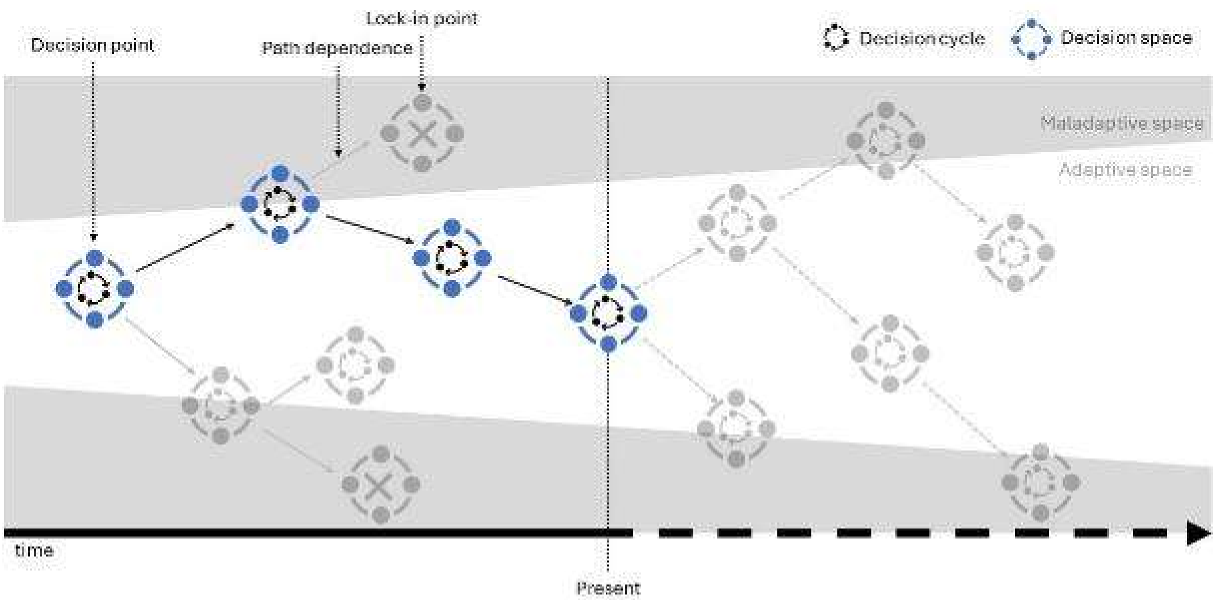

Figure 3. Simplified representation of the adaptation pathways within the temporal scale.
Source: elaboration based on Fazey et al. (2016) and Wise et al. (2014).

In addition to the temporal dimension, the adaptation pathway approach also reveals that adaptation responses operate at different spatial or social scales (Fazey et al., 2016). Although adaptation involves changes that enable a system to live with changing environmental conditions, adaptive capacity can differ between social groups or socio-ecological systems within the same region in the medium to long term. Therefore, it is necessary to recognise that the limits and potential of adaptation strategies differ between communities or group of actors, even within the same case study (Birkmann, 2011). The identification of adaptation options within each I-CISK LL can be assessed at different scales: regional, community, organisation or social group (e.g. cooperatives, watershed authorities) and individuals (e.g. farmers, tourists, citizens, etc.).

The following box includes the definition of some of the key terms used in this document.

- **Adaptation**: in human systems, is understood as the process of adjustment to expected climate and its effects, in order to mitigate harm, exploit beneficial opportunities or improve future suitability to the environment (Fischer, 2019; Möller et al., 2023).
- **Adaptation decision space** encompasses the entire context of the decision-making process: assets, knowledge, socioeconomic, biophysical, and administrative environment. It corresponds to the global vision of the adaptation options implemented, not implemented, and discarded, as well as the barriers or levers to their implementation.
- **Adaptation options** refer to measures that are available to individuals, communities, or regions. Available measures will differ depending on the social, economic, or physical context where they will be implemented, as well as the knowledge and resources available. They can be categorized as structural, institutional, ecological, or behavioural (Möller et al., 2023).
- **Adaptation pathways** can be understood as sequences of decisions and actions made in response to biophysical and/or economic drivers of change and that steer a social-ecological system towards a vision (Bruley et al., 2021; Möller et al., 2023). They involve trade-offs between short and long-term goals and values. They can reduce or increase vulnerability to climate risks, that is, steer the system toward adaptive or in the maladaptive space and condition the availability of future adaptation options (Wise et al., 2014). For the purpose of this deliverable, we consider adaptation time scale are related with the time scales in which

decisions are being made, and for which CS projections are developed, and that range from the seasonal-sub seasonal through to decadal/climate time scales.

- **Adaptation strategy:** encompasses routine actions or selected adaptation options (practices) that pursue the same goal (Fischer, 2019).
- **Coping**: short term responses that use available skills, resources, and opportunities to address, manage and overcome adverse conditions, with the aim of regaining stability in the short-term (one season or year, for instance) (Fischer, 2019; Möller et al., 2023).
- **Lock-in**: a situation in which the future development of a system is determined or constrained by historical developments (Möller et al., 2023) and/or past decisions.
- **Maladaptation**: actions that may lead to increased risk of adverse climate-related outcomes, increased, or shifted vulnerability to climate change of oneself and others, less equitable outcomes, or diminished welfare in the future. Most often, maladaptation is an unintended consequence (Fischer, 2019; Möller et al., 2023).
- **Path dependence**: situation where decisions, events or outcomes constrain adaptation, mitigation or other actions or options at a later point in time (Möller et al., 2023).

2.3. Characterizing the adaptation decision space in the adaptation pathways

In this Deliverable, we aim to characterize the climate risk management options implemented or considered by actors in the different LL and place them within the coping (short-term) to adaptation (long term) continuum. This as a first step towards understanding the adaptation pathways undertaken in the different LL. We also attempt to further characterize the adaptation pathways and place the decision-making space along the temporal dimension and considering multiple spatial scales of action, although this has not been possible in many LLs.

We build on the characterization framework proposed by Fischer (2019) and Magnan et al. (2020). This was done by:

- Understanding the goals of each of the adaptation options identified
- Characterizing the temporal and spatial dimension of adaptation options (looking at timing, scope, etc.)
- Understanding the nature of adaptation strategies in terms of their effectiveness and long-term durability.
- Understanding how barriers and levers (institutional, economic, technical, knowledge, etc.) prevent or favour the adoption of adaptation options that reduce long-term vulnerability.

These steps were carried out to different degrees in each of the seven living labs, depending on their specific contexts and setting, as well as the constitution of the multi-actor platforms (MAP). The data based on which the finding in this deliverable is compiled, were provided by the different LL leads by filling out a draft outline of this deliverable and responding to specific questions that were outlined by the main authors. Given the different characteristics of each LL, the information gathered has different degrees of detail and specificity.

3. Links to other tasks and work packages

The development of CS has traditionally emphasised the supply side of climate services, that is, they have often not taken user needs, preferences or capabilities into consideration when generating forecasts and projections (Vincent et al., 2020). As Carr and Ozere (2018) point out, different actors have different vulnerabilities to climate risks, which may depend on several factors such as type of activity, belief, gender, age, education, or experience. They may therefore have different CS needs and requirements. These factors need to be investigated and understood so that climate information is "tailored to the contexts of the decision-making and perception of the users", who will combine "information from models with other relevant information to enable the integration of climate risks into their decision-making processes" (Hewitt et al., 2021).

I-CISK recognizes that the active use of climate information for climate adaptation and mitigation action requires CS users to be at the centre of the design, creation, implementation and evaluation of CS. Furthermore, I-CISK acknowledges that users construct the climate information they consult to inform adaptation decisions from multiple sources of knowledge, and act within their (socioeconomic, behavioural and institutional) context, which may include incentives as well as barriers to the uptake of that information. These sources of knowledge include present and past experiences, knowledge of the local weather system and of adaptation options and their effectiveness, as well as data from climate and citizen-science (Van den Homberg et al., 2023).

In order to generate user-centred CS and ensure these are adequate for end user's needs and context, thus supporting society's transition toward a more resilient and sustainable future (Hewitt et al., 2021), the I-CISK Framework for co-creating CS (I-CISK, 2022) defines a sequence of iterative steps illustrated in Figure 4.

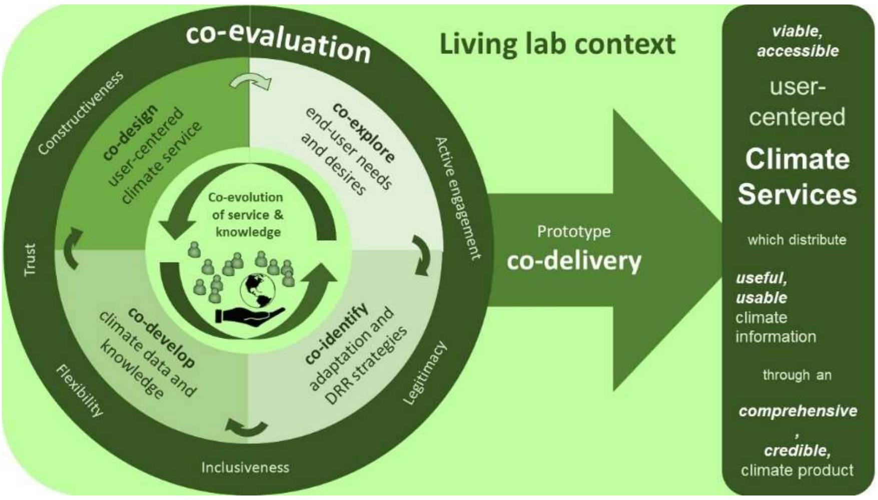

Figure 4. Co-creation of user-centred climate services: building blocks of the process that take place in a LL context.
Source: I-CISK, 2022.

The process starts by co-exploring user needs and co-identifying relevant local knowledge, perceptions and concerns. This is critical to understand the context within which CS will be used and inform how to adapt these accordingly. This work is part of T2.1 *Co-exploring climate information and adaptation information needs and obligations* and of T2.2 *Co-identifying local knowledge on climate & its impacts* (see Figure 5) and is reflected in the corresponding deliverables (Moschini & Emerton, 2022; van den Homberg et al. 2023).

LL participants contribute to the process of identifying the climate parameters and thresholds, and the spatial and temporal scales of climate information that match with the envisioned climate adaptation actions that CS will support. The co-identification of existing and potential climate adaptation actions supported by existing as well as new CS (such as I-CISK developed user-driven climate services), is the focus of Task 2.3. Task 2.3 implements phase C of the co-creation framework on the co-identification of adaptation pathways and disaster risk reduction strategies to be supported by the CS. The results of the methodologies used to co-identify the strategies within each LL support the development of Task 2.5 Guidelines for co-design of Climate Services. The work undertaken in Task 2.3 also complements the objectives of several other tasks within the I-CISK project (Figure 5). The interdependency and links with other project tasks are described below.

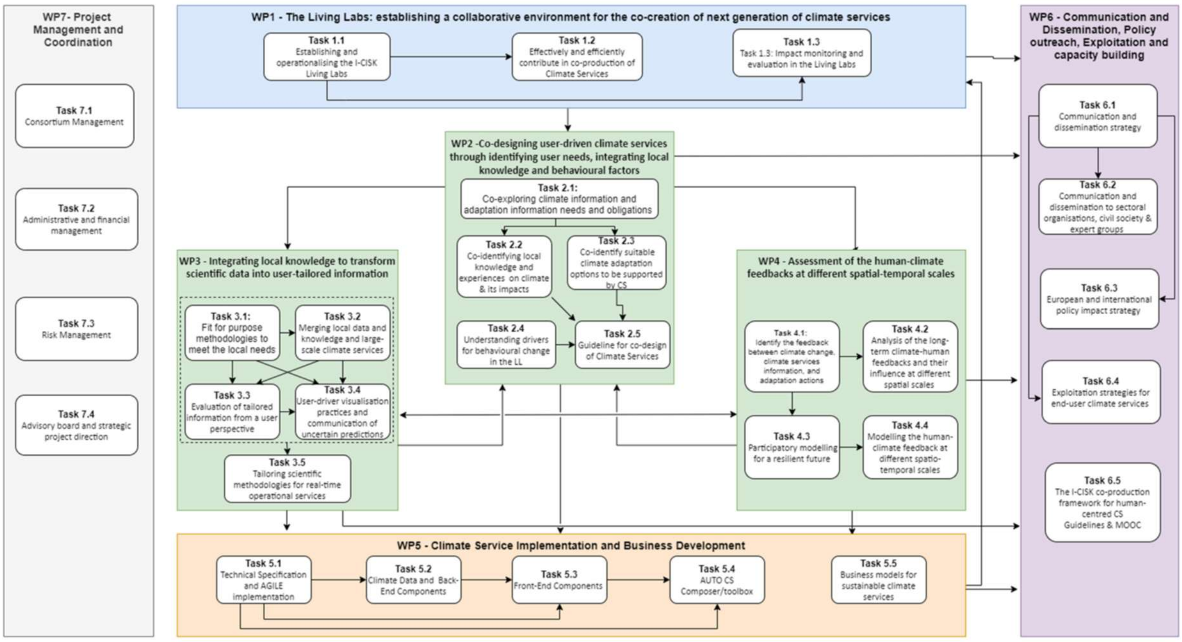

Figure 5. PERTT Diagram showing the I-CISK project structure.

Task 2.3 contributes to Task 2.2 *Co-identifying local knowledge on climate and its impacts,* which reflects on the crucial role of local knowledge within the decision-making process, identifying local knowledge as a driver that can change the adaptation decision space.

By considering the temporal dimension of the adaptation decision space, that is, how climate information is integrated into the decision-making process over time, this Task contributes also to Task 3.3 *Evaluation of tailored information from a user perspective,* which focuses on the type of climate information used, and on when and how it is used to make decisions to address climate risks.

Furthermore, by incorporating the spatiotemporal dimension of the decision-making space to understand adaptation pathways, Task 2.3 contributes to Task 4.4 *Modelling the human-climate feedback at different spatiotemporal scales* helping understand how decisions in one point in time and space interact with each other to make certain adaptation options viable.

4. Alazani-Iori River Basin LL

4.1. Methodological approach used to understand the adaptation decision space

The multi-actor platform (MAP) in Georgia includes a diverse group of stakeholders ranging from climate service providers (National Environmental Agency) to service purveyors (civil society organisations) and end users (individual farmers). These actors represent agriculture, water management and environment sectors (Masih et al., 2022). Previous and recent interactions with the MAP underscored the need for climate information pertaining to water availability and drought to inform water allocation and agricultural planning processes.

Insights from the data collection process conducted in August 2023 and March 2024 are presented below. This data collection was conducted to understand local perceptions of drought, its impact on livelihood processes as well as coping and adaptation strategies employed by farmers in the basin. Stakeholders consulted included those belonging to the MAP as well as other members of the local community. A focus group discussion was organized with members of the MAP where several qualitative tools such as problem trees, seasonal calendars, historical timelines, and surveys (see Table 1) were used to elicit responses and engage members in a discussion around the issues of water scarcity, droughts, and other climate hazards that participants considered as important stressors to their livelihoods. Agriculture was identified as the main source of livelihood by most stakeholders consulted. Additional data was collected through semi-structured individual interviews (Table 1).

Table 1. Overview of the qualitative tools used during the data collection process in Alazani-Lori LL

Qualitative tool	Purpose	Stakeholder involvement
Problem Tree	Understand local narratives around the problem of water scarcity, its causes and consequences.	Constructed by the MAP Validated through interviews with local community members
Decision Timelines	Develop a more in-depth discussion around climate change perception, daily livelihood activities, coping or adaptation strategies, and information used for decision making.	Constructed by the MAP and by members of the local community
Historical timeline	Understand long term climate changes as well as impacts on farming activities.	Constructed by the MAP Validated through interviews with local community members
Survey	Follow-up survey to understand livelihood assets possessed and information use of the participants.	Filled by the MAP and by members of the local community
Semi-structured interviews	Validate information obtained from the MAP and obtain complementary information.	Local community members

4.2. Characterizing the current adaptation decision space

Climate change models predict a steady increase in temperature between 1.2 ^{0}C – 2.3 ^{0}C by 2050 in the Alazani-Lori River basin (Ahouissoussi et al., 2014). Though there is more uncertainty than for the projected trend in temperature, climate projections suggest that precipitation is expected to decline in the low lying and southern parts of the basin. This decline is expected to be most pronounced between May – October. This coincides not only with periods of low flows in the Alazani River, but also with periods of peak irrigation water demand because of high evaporative demand, thereby leading to water shortage situations. The consultations carried out with local communities confirm this lack of water during the irrigation season. Additionally, farming communities in the region also suffer from droughts, hail, and sudden onset high intensity precipitation events. Response strategies adopted by farmers broadly fell under two categories: short-term and long-term adaptation.

4.2.1 Short-term adaptation and coping strategies

Many of the response strategies identified by the farmers in the Alazani-Lori River basin were primarily associated with adapting at a seasonal or shorter-term timescale. This included changing planting schedules or changing harvesting dates. Most farmers also practised multi-cropping to maintain steady income and minimize losses. It is important to note that these strategies were seldom driven by climate-related stressors alone. Non-climate related factors such as prices offered on the local market, or availability of resources such as labour or storage space for harvested crops also informed adaptation strategies adopted by farmers. A minority of farmers also mentioned their willingness to adapt by growing crops (particularly wheat) with shorter vegetation periods to avoid climate risks.

For farmers with access to irrigation channels, paying for irrigation in case of precipitation deficit during the growing season was also a way to cope with water shortages. Some farmers also reported adapting their tilling strategies to maintain soil moisture in case of drought. Cleaning irrigation canals to maintain water flowing was another measure to mitigate the impacts of droughts and flash floods. Beyond these, many farmers also mentioned ‘doing nothing and accepting losses’ as a response to climate related stressors.

4.2.2 Long-term adaptation strategies

Long-term adaptation strategies reported by farmers included investing in infrastructural measures such as drip irrigation or digging wells to compensate for the lack of water. Farmers with sufficient financial resources also transitioned to greenhouse farming to cope with lack of water. Farmers also mentioned installing windbreaks to reduce effects of wind erosion during droughts. Many farmers also practised livelihood diversification in the form of agritourism (particularly in the case of winemakers), renting out their farmland to other farmers or transitioning to other professions (such as investing in livestock or emigrating to urban areas).

In terms of information use, some of the farmers interviewed relied on scientifically generated weather forecasts, social media, or websites (for example, https://yr.no provided by Norwegian Meteorological Institute and Norwegian Broadcasting Corporation) to guide their decision making. Most farmers, however, mentioned that they relied on their past experience to guide their decision making as well as learning from other farmers in their community, especially when it came to on-farm management strategies such as sowing and planting dates, sharing information on mildew appearance etc.

4.3. Additional adaptation measures and required context-adapted climate services

Current water management practices, infrastructure and pollution challenges have already put pressure on the water resources in the Kakheti region, which is the region of Georgia within which the Alazani basin is found. Research has shown that even if there were no constraints to water availability through irrigation, agriculture in Georgia will be negatively impacted by temperature and precipitation changes, while under a declining water supply scenario the consequent yield decline is much more substantial (Ahouissoussi et al. 2014). This is further complicated by the competing need to supply water for hydropower generation.

Interaction with local communities already confirms impacts resulting from unreliable water supply, for e.g., lack of water during irrigation periods, acute water losses due to improper infrastructure, loss of harvest because of sudden hail events or intense precipitation. As mentioned above, most of the current strategies adopted by local communities focus on coping at shorter timescales. This is primarily due to lack of information on seasonal water availability and related farming advice. Effective adaptation in the region therefore requires better information on the seasonal and sub seasonal availability of water to guide on-farm operations for both rainfed and irrigated farmlands, as well as to support water management and planning to meet the competing demands for water in the region (agriculture and hydropower).

The main CS developed under I-CISK includes the streamflow prediction system that forms the basis for hydrological drought monitoring and forecasting. Understanding streamflow in the basin is critical for reliable and robust water resources planning and management. It is vital for hydropower operation, agricultural planning, and flood control. This streamflow system along with information on other essential climate variables (precipitation, temperature) and drought indicators to help identify drought conditions, will be used to enrich currently provided agrometeorological bulletins to farmers, thereby informing strategies such as crop choice, need for irrigation and timing etc.

5. Budapest LL

5.1. Methodological approach used to understand the adaptation decision space

The MAP in the Budapest LL is made up of the municipalities of Erzsébetváros and Budapest; the National Public Health Institute (OKI), responsible for monitoring the health consequences of heatwaves and instrumental in the operation of the national heat alarm system; the Department of Meteorology of Eötvös Loránd University; and civil society organizations such as the Clean Air Action Group.

The LL team followed different methodological approaches to develop a common vision of the urban heat island challenge and understand and enhance the adaptation decision space.

5.1.1 Map out common knowledge and shape a shared vision for a desirable future:

- **Discussions** with municipal employees and experts working in the field of climate change who had joined the MAP meetings.
- **Online questionnaire**, followed by multiple stakeholder events to map out common knowledge and shape a shared vision for a desirable future. The questionnaire was targeted to residents of the municipalities of Erzsébetváros and Budapest.
- **Facebook campaign** on urban heat issues carried out with the local Színes Erzsébetváros NGO, which helped participants to consider the systems perspective, interests, and values

5.1.2 Broadening the decision options of residents

- Multiple rounds of **meetings and discussions** were held with MAP members to develop a shared understanding and interpretation of the information provided by the urban heat maps generated in I-CISK, based on drone measurement data and published on a publicly accessible web platform.
- **Workshops** with MAP members to collectively understand the context of urban heat islands (UHI). Together, we interpret the heat data and explore a range of technologies and green infrastructure designs, assessing their feasibility, and understanding the regulations or policies that may facilitate or hinder their implementation.

5.1.3 Exploring strategies.

In the project's final stage, the Budapest LL will aim to identify potential adaptation pathways and discuss them with MAP members based on the finalized climate service developed in the project. Adaptation options to be considered and discussed will include both long-term changes that make the urban environment more suitable and resilient to heat, as well as short-term coping mechanisms for heatwaves. Discussions will focus on how the developed climate service can enhance the following strategies:

- Public Health and Safety Measures
- Promoting Technological Solutions
- Promoting Nature-based and Blue Solutions
- Education and Outreach
- Adaptive Governance/Long-term Adaptation Planning

5.2. Characterizing the current adaptation decision space

In the context of the Budapest Living Lab, the current climate change adaptation strategy is characterised by a comprehensive yet fragmented approach. Resilience efforts have traditionally been driven by individuals rather than a unified community effort, indicating a limited use of shared resources to collectively address climate risks. While there are instances of adaptation initiatives, these are primarily manifested through individual efforts. Systematic adaptation at a larger scale, such as comprehensive urban planning or the integration of building-specific resilience measures, remains uncommon.

Historically, the response to climatic threats in Budapest has tended to be immediate and reactive. For example, the use of heat alert systems was designed to quickly alert residents to impending risks, to trigger short-term risk management responses. The Hungarian heat alert system, introduced in 2005, aims to mitigate these risks by alerting health and social care systems, local authorities, and the public. The National Public Health Center oversees heat alerts by monitoring temperature trends, weather forecasts, and mortality rates. It communicates these alerts through various channels to reach different target groups. However, the system does not consider the unique characteristics and disparities within urban areas, including the additional heat retained by urban heat islands. The alert levels currently considered are:

- **Level 2:** When the daily mean temperature reaches or exceeds 25°C for at least three consecutive days.
- **Level 3:** When the daily mean temperature reaches or exceeds 27°C for at least three consecutive days.

Urban design interventions have also been modest, with small reductions in car parking suggesting an incremental approach to adapting the urban fabric. Financial incentives have been provided to encourage green infrastructure improvements at an individual level, but examples such as subsidies for green roofs or heat reflective materials are not as widespread as may be required to have a significant impact.

The decision-making process behind these policies has typically favoured empirical wisdom from direct experience over more sophisticated climate modelling or data-driven insights. Reliance on historical patterns rather than predictive, climate-based information has shaped adaptation strategies, which may limit the ability to effectively anticipate and prepare for future climate events. This preferential reliance on local, experiential knowledge over detailed climate projections or geospatial data could potentially affect the long-term success and scalability of adaptation efforts in Budapest's evolving urban landscape.

The strategies implemented to different degrees for Budapest can be summarised as:

a) public health and safety measures;
b) promotion of technological solutions;
c) promotion of nature-based and blue solutions;
d) education and outreach; and
e) e) adaptive governance/long-term adaptation planning.

They are implemented in practice through several activities designed at different scales: building level, individual level, city level and community-led initiatives (

Table 2).

Table 2. Heat wave risk management actions implemented to different degrees in Budapest Living Lab

Building level practices	Individual level practices
-Vertical gardens on buildings -White roofing challenge -Advanced reflective pavements and roofs -Shading of the buildings -Insulation of the buildings/blocks -Night ventilation -Natural ventilation -Green walls -Updating building codes of buildings	-Reflective roofs -Shading of the flats -Insulation of the flats -Night ventilation -Natural ventilation -Green walls -Rainwater harvesting for cooling -Vertical gardens on terraces

City level adaptation	Community lead adaptation
-Awareness programs -Urban farming programs -Establishing walking streets with shading -Traffic reduction -Identifying and mitigating heat sources at streets -Lakes, streams, and ponds -Heat health action plans and Public warning systems -Providing Access to cooling centers -Heat Risk Mapping -Coordinate UHI mitigation efforts -Implementing cool zones -Energy-efficient public lighting -Reducing the number of car parking places	-Opening gates of apartment blocks for air circulation -Greening of inner courtyards of apartment blocks -Water-retentive pavements and green ground cover -Investing in research and development of new materials and technologies -Planting additional trees -Monitoring: Keeps track of adaptation efforts and their impacts -Keep the focus on vulnerable people -Amateur networks and citizen science in tracking and addressing UHI -Shading of the buildings

5.3. Additional adaptation measures and required context-adapted climate services

In the context of Budapest LL, the heat mapping service is a key tool for understanding and mitigating the UHI effect (see Figure 6). This innovative approach in LL Budapest, however, is not without its challenges.

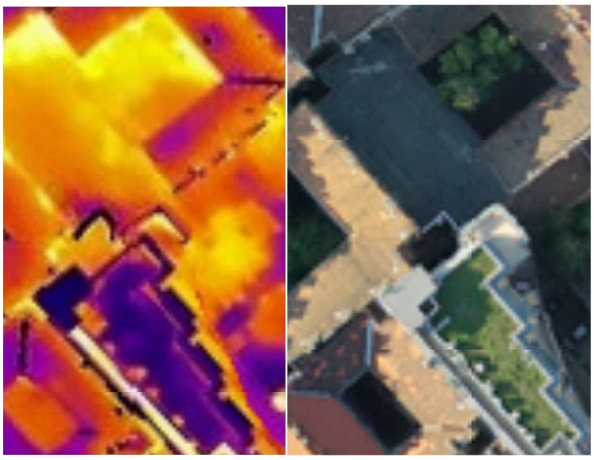

Figure 6. Heat emissions of a green roof and of a traditional roof in Terézváros, Budapest (August 2023).

The image on the left is a thermal camera capture where darker, purplish shades indicate cooler surfaces, while yellowish shades indicate warmer surfaces.

The two study districts face uncertainties ranging from climatic unpredictability and scarce financial resources to implement socio-economic changes, which pose significant barriers to urban heat risk management.

The service facilitates effective decision-making in an urban context at the individual/building blocks and district level by identifying hotspots at the street and block level, thus adaptation measures can be implemented where they are most needed.

Heat mapping raises public awareness and encourages support for adaptation initiatives such as urban agriculture and shading, greening, providing natural ventilation and eliminating hot spots. This service also provides a basis for technological interventions, such as the need to use reflective materials in construction where appropriate.

Table 3. Barriers and enabling conditions for the implementation of enhanced adaptation measures in two districts of Budapest

Adaptation Measure	Description	Barriers and enabling conditions for the implementation of enhanced adaptation measures
Technological Interventions	Leveraging technology to directly mitigate heat or warn citizens about heat hazards, e.g., public warning systems, advanced reflective pavements, energy-efficient lighting.	National Heat Warning system in place, but it does not consider local specificities and heat island anomalies.
Green Infrastructure	Using natural elements like additional trees, green walls, and water bodies to cool the environment and enhance urban biodiversity.	The districts are overcrowded with limited space for greening. The number of green walls and green roofs is low.
Urban Planning and Design	Updating building codes, maximizing airflow through urban design, and establishing shaded walking streets to make urban spaces more heat resilient.	Long-term adaptation solutions are present, but they are generally expensive.
Community and Health Measures	Focus on protecting public health and enhancing community resilience with heat health action plans, access to cooling centres, and community engagement initiatives.	The heat alert system works. On very hot days, some public spaces are opened, but there is no information available about their capacity. The municipalities in the Budapest LL area do not have heat health action plans. There are examples of misting stations and free water distribution, but these actions are very limited in number. Amateur networks and citizen science initiatives related to heat are still lacking, although there are a few initiatives regarding air quality.
Innovative Practices	Encouraging new solutions and community participation in UHI mitigation through investment in research, amateur networks, and urban farming programs.	Some amateur networks exist but with few nodes. Urban farming programs are not characteristic. NGOs in the area are addressing the issue of UHI.

The Budapest LL ‘s service also provides an efficient way to monitor and evaluate UHI mitigation measures, allowing for continuous refinement of strategies. Once these measures have been implemented, heat mapping can be used to assess their effectiveness over time.

6. Emilia Romagna LL

6.1. Methodological approach used to understand the LL adaptation decision space

The Emilia-Romagna Living Lab is composed of a diverse range of stakeholders from sectors such as agriculture, industry, water allocation, energy, utilities, and environmental management in a small, but diversified, motivated and balanced group that constitutes the MAP for the Laboratory. This reflects both the complexity of managing water resources in the face of climate change and the need of a collective effort in the Emilia-Romagna region to address these challenges, through innovative adaptation strategies and improved governance mechanisms.

The LL used tools such as workshops/online meetings, in person meetings, virtual interactive Miro boards and dedicated thematic sessions to co-develop a climate service linked to local climate data and knowledge and supporting local adaptation pathways. An iterative approach has been followed, where the co-created climate service is evaluated and refined based on stakeholder feedback.

6.1.1 Identifying climate information needs & climate services desires

The initial phase of the Emilia-Romagna LL began with an online meeting on February 14, 2022, gathering diverse stakeholders to discuss the possible development of a locally tailored climate service, focusing on the upper Secchia River catchment. Emphasizing co-creation, discussions identified essential variables and time frames for the climate service to support decision-making and tackle water scarcity. Various engagement methods and tools were used, including online meetings and digital platforms (such as Miro boards), to collect stakeholder input.

During the extreme drought of summer 2022, a workshop (July 29th, 2022) was held to discuss the management of drought, water scarcity, and the impacts of climate change, aiming to develop the innovative climate service. At that time, the MAP members clearly pointed to drought and water scarcity, with a particular emphasis on the extreme drought conditions of that season, as the primary problem to be addressed with the support of the CS.

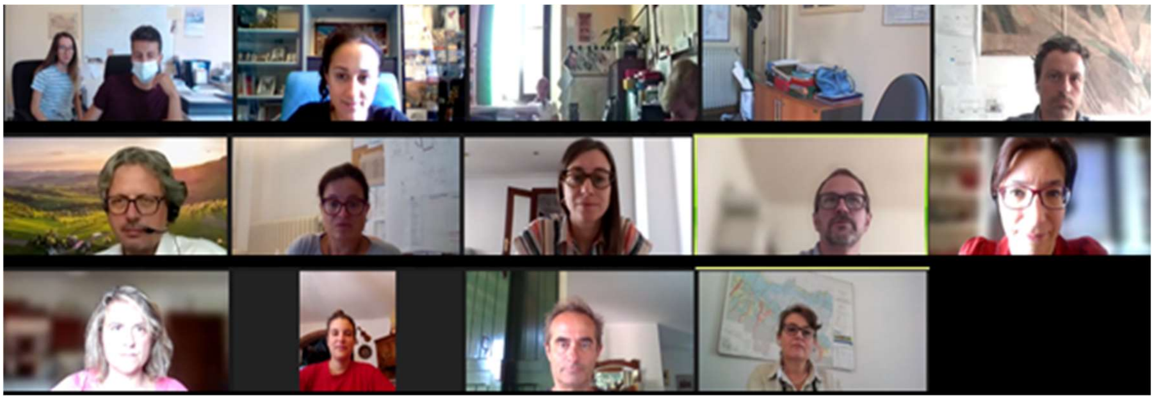

Figure 7. Online workshop (upper) held on July 2022 with MAP representatives

During the workshop, stakeholders from the MAP collaboratively reflected on the critical water management challenges faced by the region. The discussions and information sharing took place both on a regional (policy, planning and withdrawal rules) and local scales. The local scale referred to practical management at the hydraulic node of the Castellarano weir along the Secchia River where most of the water diversions for irrigation take place (see Figure *8*), and in similar contexts across the region,).

Figure 8. Hydraulic node of the Castellarano Weir

6.1.2 Towards adaptation pathways and integrating knowledge for climate service development

A second workshop was held on March 29th, 2023, and involved online discussions with MAP stakeholders on climate adaptation, emphasizing the integration of local knowledge and local data mainly provided by ARPAE (Regional Environmental Agency). It aimed to identify a first set of possible adaptation measures and assess environmental and economic impacts of droughts in a very preliminary manner. Prior to and after the workshop, stakeholders used interactive tools (e.g. online boards like the one in Figure 10) to provide initial feedback on the desired CS characteristics and adaptation measures. On July 27th, 2023, a field visit to the Castellarano weir facilitated discussions on water management challenges and the development of a predictive water resource CS prototype (Figure 9).

Figure 9. Field visit to the Castellarano weir and water diversion infrastructures in July 2023

6.1.3 Co-designing user-centred climate services

Several activities were implemented at this stage:

- **Online meeting** with representatives of the MAP on January 18th, 2024, to showcase Graphical User Interface mock-ups for the river flow forecasting prototype. The online session aimed to fine-tune predictive modelling requirements and possible integration of forecasts into water management, tailored to the Emilia-Romagna region's needs and linked as much as possible to decisions taken on adaptation and coping.

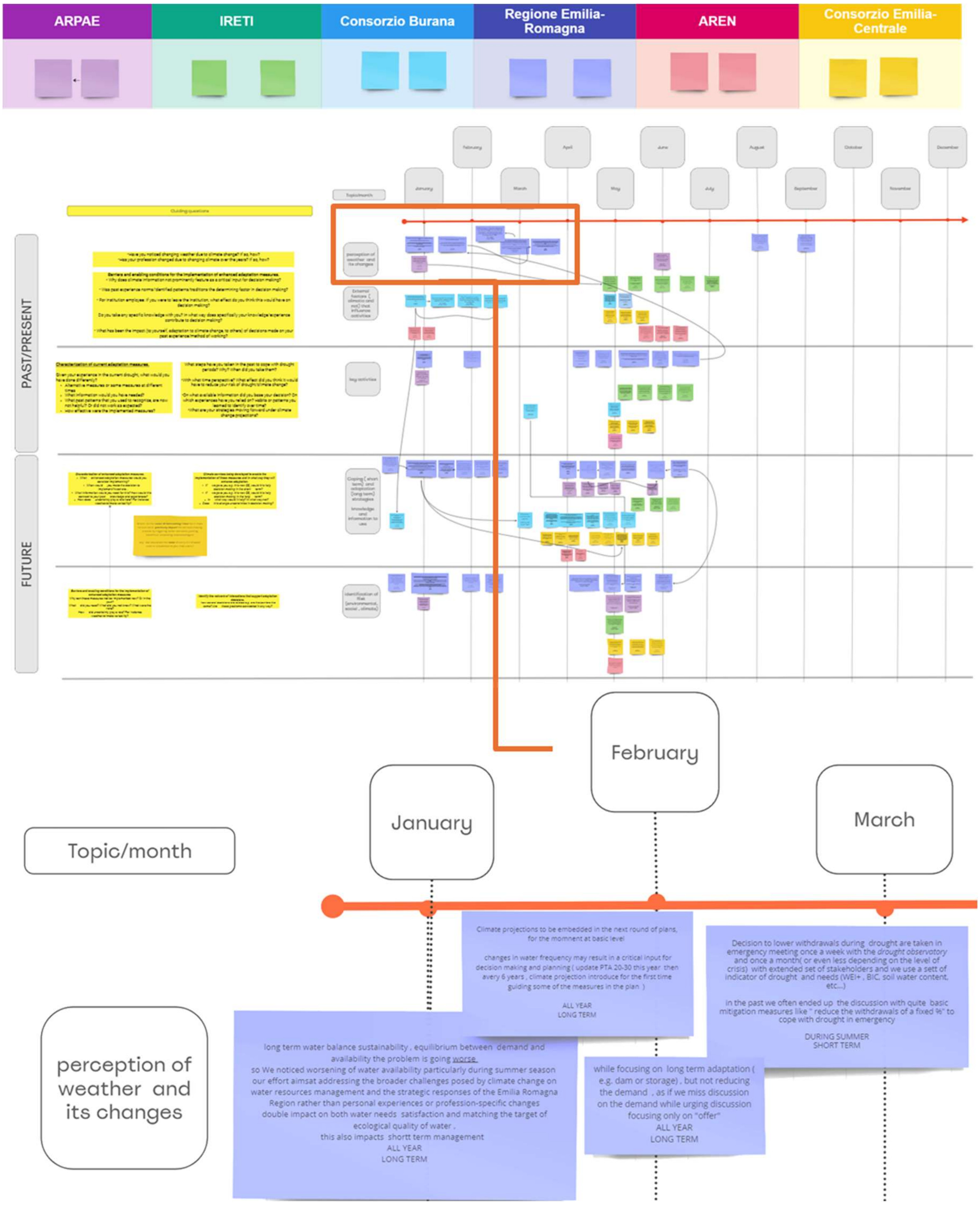

Figure 10. Timeline adopted for linking service development to practical decision making both for short term and long-term adaptation/coping, with an example of the provided answers.

- **Online shared digital platforms – Miro Board.** Feedback from stakeholder interactions informed also new Miro board to outline decision-making processes and adaptation strategies, shared in mid-February 2024 for stakeholder validation (Figure 10). This Miro board served also to incorporate and summarize the results of all previous interactions with stakeholders, including:
  - Past adaptation measures to drought, reliance on historical patterns, and effectiveness of implemented strategies.
  - Potential enhanced adaptation measures, the role of uncertainty, and the specific needs for climate service information to support decision-making.

  The synthesis aims to capture insights on adapting to climate variability, with the co-creation approach emphasizing the importance of direct experiences, historical knowledge, and the anticipation of future challenges in climate adaptation pathways.

- **Workshop** held in-person on March 2024 as side event of Climateurope2 FESTIVAL.

prototyping, and participation in co-design workshops.

6.2. Characterizing the current adaptation decision space

Iterative discussions among the members of the MAP led to the refinement of the LL understanding of the adaptation pathways and decision-making processes in place. Decisions within the stakeholder network are predominantly guided by historical experience and established emergency protocols. The reliance on local insights and past drought episodes overshadows, in general, the use of direct climate predictions or forecasts in shaping responses.

Currently, coping mechanisms informed primarily by data from monitoring networks dominate, for instance, using river flow data coupled with predefined thresholds “green, yellow, red” to trigger emergency responses ranging from progressive reduction of withdrawals to stopping water diversions. Efforts to establish a "drought observatory" for collaborative decision-making between water authorities and users often culminate in either halting or reducing withdrawals or, alternatively, granting exceptions. In practice, this means that during droughts the main choice is between prioritizing user needs at the expenses of environmental flows or, alternatively, reducing or stopping water uses in favour of environmental conservation.

For long-term adaptation, certain users (notably, irrigation consortia) implement strategies like infrastructural modifications in distribution networks and storage solutions, often supported by public funding and supplemented by insights from research and development projects, demonstrating an openness to innovative practices.

The Emilia Romagna Regional Authority, which sets water withdrawal guidelines and conservation protocols, is also tasked with maintaining the water balance on the long-term. In this context, climate projections are beginning to inform the periodic revision of water master plans, signalling a shift towards incorporating these insights into strategic planning.

Despite these policy-driven approaches, the broader application of forecasts on resource availability for both short- and long-term considerations remains limited, in favour of a more straightforward approach based on real-time monitored values and historical patterns. This consolidated practice has been recently challenged by the unprecedented drought of 2022, which created unforeseen technical issues for the first time. An exception within this context is the limited use by irrigation consortia of ARPAE-supported water demand forecasts (rather than water availability) to proactively inform farmers about impending critical conditions.

The transition towards practices informed by comprehensive climate knowledge is gradual, hindered by the conflicting demands of reducing discharges to meet environmental quality goals and the economic imperative to sustain water use for agriculture and other purposes. This delicate balance between environmental sustainability and economic viability underscores the complex dynamics at play in adapting to climate variability and managing water resources effectively.

Currently in the Emilia Romagna LL there are both adaptation and coping measures in place:

- Water Balance Masterplan Revision (adaptation). Conducted by the Regional Government every six years, incorporating climate scenario discharge models for main rivers to inform long-term water resource planning.
- Traffic light system for water withdrawals (coping). Implements thresholds for reducing or halting water withdrawals, with potential exemptions granted by the Region, based on real-time data from the RP AE network.
- On demand internal usage of regional hydrological projections (coping). Request to ARPAE on demand river discharge projections during emergencies, to support the Drought Observatory's decision-making.
- Seasonal water demand forecasting (coping). Employs water demand forecasts to prepare farmers for upcoming dry conditions.
- Hydropower plant maintenance planning (coping). Leverages weather forecasts and monitoring real time data to schedule maintenance during no-production periods.
- Pre-emptive channel storage (coping). Anticipates storage in channels before reaching critical conditions to ensure water availability, subject to regional authorization.
- Emergency protocols activation (coping). Triggered by yellow and red alerts, involves withdrawal reductions, and communicates urgency to end-users with minimal lead time.
- Water provision suspension alerts (coping). Notifies users of imminent water stoppage, offering a brief preparation window based on the traffic light system's updates.

6.3. Additional adaptation measures and required context-adapted climate services

A key part of stakeholder interaction is the transition from discussing established adaptation and coping measures to envisioning potential changes in these strategies, facilitated by the development of CS. It focuses on the application of weekly to monthly river discharge forecasts upstream of the Castellarano weir, exploring how these insights could inform decision-making and enhance strategies for adapting to and coping with climate variability. Emphasizing a descriptive approach, this section outlines the integration of climate forecasts into operational planning and infrastructure modernization, highlighting the shift towards a more resilient water management system.

Utilizing the predictive insights provided by the CS being developed in ICISK, we aim to enhance current strategies. The Regional government is championing the implementation of Resilience Plans, mandating significant water users, such as irrigation consortia, to formulate and secure approval for these plans from the Region. These strategies are to incorporate the forthcoming forecast services into water resource management plans on the user’s side, enabling them to take and promote pre-emptive actions, such as storing water ahead of droughts, independently and without the delay that results from requiring additional authorizations as is the case today. Access to (sufficiently accurate) short to medium-term discharge forecasts could potentially also change withdrawal regulations, allowing for a more nuanced and responsive approach to water management under the Resilience Plans endorsed by the Region (a measure between adaptation and coping).

This approach facilitates a shift towards a more proactive stance in managing water resources. This could take place when the emergency is still not in place e.g. when the monitoring network certifies a state of diminishing water flows (the so called "yellow" alert level on the periodic monitoring bulletin ARPAE releases). This also makes the new strategies supported by CS to be in synergy, and not conflict, with the current ones based on *traffic light style* thresholds triggered by real time monitored values.

The provision of forecasts opens avenues for early alerts to stakeholders (a coping strategy), marrying the need for precision with the imperative to minimize the occurrence of premature warnings. Enhanced communication strategies, particularly leveraging seasonal forecasts (a time scale in between coping and adaptation), are intended to play a pivotal role in informing higher level stakeholders (like farmer associations) about upcoming shifts in water availability and demand, thus enabling more strategic action for water utilization.

For irrigation consortia (representing interests of associated farmers they provide water to), forecasts are thus instrumental in both the short to mid-term management of water distribution and the long-term strategic planning, including the anticipation of and preparation for drought conditions, including communication to associated farmers. Seasonal forecasts could also facilitate a strategic diversification of water sources in anticipation of shortages, with new protocols that include forecast-driven (instead of current monitoring-driven) management of storage systems, bolstering the system's resilience against incoming challenges.

In the realm of hydropower production, the ability to forecast drought conditions well in advance, even outside traditional periods, enhances the capacity for maintenance scheduling to mitigate production losses (still a coping strategy).

Furthermore, long-term climate projections, though they are not yet implemented in the CS, have been discussed for their potential value for revising water withdrawal permissions and updating ecological flow thresholds, supporting the adaptation of water storage and demand reallocation strategies to meet the challenges posed by climate change, thereby ensuring the resilience of the water system. Irrigation consortia with a long-term vision and planned investments in modernizing their irrigation infrastructure, could find value also in a multi-year climate forecast, which informs preventive infrastructure planning, facilitating resilience in the face of evolving climate conditions.

7. Rijnland LL

7.1. Methodological approach used to understand the adaptation decision space

The Rijnland LL MAP involves water managers - the Rijnland Water Board -, research and academia - the ICISK consortium members -, representatives of civil society organizations, and individuals from water use sectors affected by droughts: recreational navigation (water tourism) and agriculture.

A mixed approach has been followed in the LL to gather information, develop common understanding of perceptions, and discuss and validate preliminary results, as part of the overall co-creation process:

- In person and online **group meetings** with representatives of each sector have been held to explore **drought challenges**.
- **Workshops** to identify:
  - **User information needs**: first by sector and then with the whole MAP, to validate drought challenges, identify current and potential drought impact mitigating actions, under current and future climate change conditions, information currently used, and information needs. Information needs were detailed for variables, time and spatial scale and resolution.
  - **Climate service user stories**: workshop with the full MAP to validate preliminary results and develop as detailed as possible user stories. This resulted in an "if-we-could-have-it-all wish list" with potential information products in the climate service to be co-developed (see Figure 11).

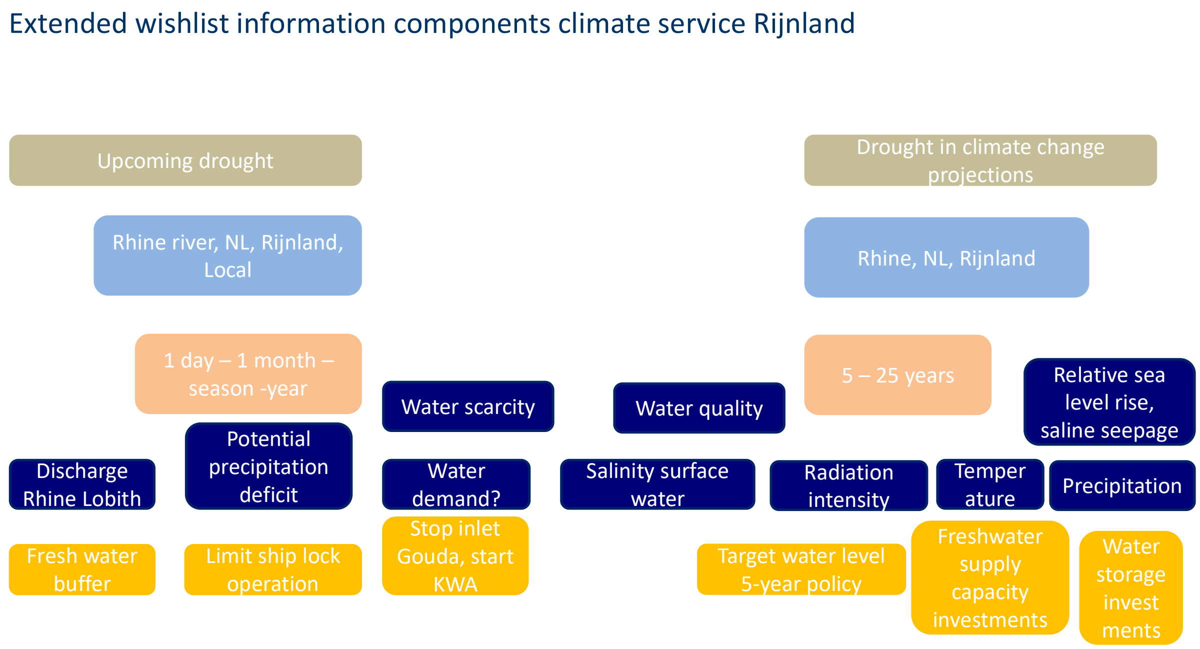

Figure 11. Extended user information wish list, including spatial and temporal coverage, variables, and measures, as resulting from the MAP LL Rijnland co-creation workshops.

- **Individual meetings** with MAP members (December-March 2024) to:
  - Present and validate a prioritized list of options from the wish list and discuss proposed mock-ups for different possible designs of the climate services. The meetings allowed

MAP members to provide feedback and express their preferences regarding the proposed services.

- **Decision timelines** (annual decision calendars and strategic investment planning) were discussed and further refined.

Figure 12. Multiple LL Rijnland meetings and workshops at key sites of the MAP sectors.

7.2. Characterizing the current adaptation decision space

Measures taken in the past in LL Rijnland to manage drought risks, include both operational drought event management (coping), and, to a limited extent, long-term strategic drought risk management (adaptation). The MAP of LL Rijnland includes water tourism, agricultural, and water management sectors. Operationally, concerning an imminent or ongoing drought, the water management authority and the agricultural sector have taken impact mitigation measures. The water tourists seem not to have taken mitigation actions in previous droughts. For the long-term strategic drought risk management to enhance climate change adaptation, the water authority has so far invested in increasing its adaptive capacity for droughts. The current coping and adaptation measures as mentioned in workshops by the LL MAP members, are listed below, followed by the climate information used by MAP members when deciding on these measures.

Type of measure:

- Short term damage mitigation (coping): dike inspections, limiting ship-lock operation, limiting surface water intake and switching to alternative intake locations, adjusting irrigation schedules, optimize use of local freshwater storage for irrigation.
- Short term communication for increased preparedness (coping) did not happen during the 2018 drought but was prepared and successfully implemented during the 2022 drought.
- Long term investment in water system infrastructure: increasing capacity and robustness of alternative surface freshwater intake during drought.

Information /knowledge used for measure design and implementation:

- The water authority intensively uses monitored and predicted hydroclimatic information with up to two-week prediction lead time for the short-term operational drought event management measures (coping) and have used climate scenario information for investment decisions on long-term drought risk management (adaptation).
- Agricultural sectors intensively use monitored and short-term predictions up to a week lead time, and strongly rely on experience, local knowledge, expert judgement for operation, also during droughts (coping). For long-term investment planning, climate change information use seems to have been limited or has not been used.
- The water tourism sector has until now been mostly interested in being informed on the short-term operational drought mitigation measures the water authority is taking, particularly those that adversely affect their recreational space. Part of the reason seems to be a lack of awareness of the predictive hydroclimatic information that is being used by the water authority. Long term drought risk information with climate projections has not yet been considered.

The effectiveness and impact of the measures is well known by the water authority and agricultural representatives for their own sector. The agricultural sector also has a good grasp of the impacts on local water resources of management measures taken by the water authority. The impact of the water management measures on recreational shipping was less well known, and not in advance, by the water tourism stakeholder. During the 2018 drought, there was a lack of communication between the water authority and recreational boating that was addressed by the water authority by organising an information meeting. The meeting served to inform about water management measures, their justification, and their impact on boating, and was positively received by the water tourism stakeholders. In subsequent drought years the Rijnland water authority has pro-actively organised such meetings with the water tourism and agricultural stakeholders.

7.3. Additional adaptation measures and required context-adapted climate services

In the MAP workshops, following the identified drought challenges and discussion of mitigation measures taken (or lack of) so far, participants were challenged to identify additional coping and adaptation measures they would like to take in the future. This resulted in the following potential measures (organised by sector):

Water tourism:

- Adjust timing of holiday: *coping*
- Adjust location and sailing route of holiday: *coping*
- Investment planning for harbour re-design: *adaptation*

Agricultural sector:

- Optimise operation of local freshwater storage: *coping*
- Invest in storage for more drought-resilient crops: *adaptation*

Water management sector:

- Increase preparedness by earlier planning, joint preparation, and communication of drought mitigation measures: *coping*

- Invest in local freshwater storage: *adaptation*

Characterization of enhanced adaptation measures, network of interactions

As can be seen from the list above, multiple additional coping and adaptation options have been developed by each MAP sectoral group. There is an interdependence between the measures taken by water managers and impacts to water tourism and agriculture. In times of drought, the Rijnland water authority takes operational measures with control structures such as pumping stations, inlets, and ship-locks, to maintain a sufficient supply of fresh surface water in the water system to meet existing demand, and to keep surface water salinity in the system below damage thresholds. The better the water authority manages water flows in the canals, the smaller the negative drought impacts on agricultural production. The more the water authority limits daily operation of the ship-locks to reduce salt-water intrusion, the more recreational shipping is hampered. This also means that if in the future the water authority manages to reduce salinity of Rijnland's boundary water systems and/or increase freshwater supply and storage for flushing inside the system, the impact of droughts on recreational shipping will decrease. The above dependence structure of measures implies that coping measures from the water authority may reduce/postpone the need perceived by other sectors to invest in adaptation measures.

Barriers and enabling conditions and role of uncertainty

The main barriers to the implementation of the identified adaptation options may be threefold: (a) limited confidence in and skill of the predictions and uncertainty in climate change scenarios; (b) significant negative impact if projected drought does not occur and adaptation or coping measures have already been taken; and (c) lack of awareness regarding (predicted or projected) drought risks (unsuccessful communication, potentially due to ineffectiveness of the co-developed climate services).

On the other hand, key enabling factors would be high confidence and skill of predictions and projections, design and implementation of no-regret adaptation measures, and effective communication of drought predictions, projections, and their associated confidence and skill.

Climate services being developed

Two key hydrometeorological variables that co-determine whether, when, and to what extent the Rijnland water authority decides to take operational drought mitigation measures are the discharge of the Rhine River at the gauging station at Lobith (on the German/Dutch border), and cumulative potential precipitation deficit in the Rijnland area and the Netherlands as a whole (generic drought indicator). For these two variables I-CISK is co-developing with the MAP climate services consisting of monthly predictions up to seven months ahead, and visualization of 25-year climate change projections. Weekly predictions will be added up to 1-month, and 1- and 5-year and 10-year outlooks will be explored.

A third key component that is being developed is the status of operational drought management measures implemented and projected by the Rijnland water authority, with lead times up to a month. Further lead times up to 3 months and 6 months will be explored as the MAP members have indicated interest in information at these lead times (seasonal planning of holidays and activities by water tourism, and irrigation planning and storage optimization for agriculture).

8. Crete LL

8.1. Methodological approach used to understand the adaptation decision space

The Crete LL (Greece) focuses on the tourism sector. Water availability can impact tourism as an economic activity since it is directly associated with the guest experience. Further, energy demand, especially for cooling needs during the hot summer days and nights, is an important consideration for the tourism industry. Extreme weather events (e.g. heavy precipitation events, high winds) and flood impacts (coastal and river) are primarily related to transportation infrastructure (mainly ports and roads), which supports the economic activity as well as tourism-related infrastructure. Crete is among the most vulnerable Greek regions to climate change, presenting high vulnerability of the tourism and transportation sectors, followed by health, agriculture and water resources. The MAP actors include public sector water managers (Organization for the Development of Crete or OAK) and road managers; tourist resort manager; port managers including policy makers and engineers; and public administration civil servants of the Greek National Tourism Organisation, with a broader engagement in the LL area.

Different members of the MAP, coming from different sectors and backgrounds, have different views and understandings of the challenges posed by climate change. This acknowledgement shaped the choice of methodological approach within the Crete LL. Interactions have consisted of **interviews and meetings with individual stakeholders** to support co-creation within the MAP, by means of e-meetings (Skype, Webex), telephone calls, as well as physical meetings. These individual meetings have been complemented with full MAP **workshops**.

Prior to the initiation of the one-on-one targeted meetings, a literature review was undertaken to evaluate the availability of climate change impact and adaptation studies on the LL area and on adaptation options and existing adaptation planning in the LL.

Between March and May 2022 interviews and meetings with MAP members aimed to co-explore climate information gaps and needs and desired climate services. Initial stakeholder engagement showed that different members of the MAP had various levels of awareness about existing CS, understanding of what a CS can offer and readiness to specifically express their CS needs. A continuous effort was made to address this disparity through the interactions with the MAP.

A second round of one-on-one interactions (in late 2022 and early 2023) with MAP members aimed to support the co-identification of adaptation pathways (Figure 13).

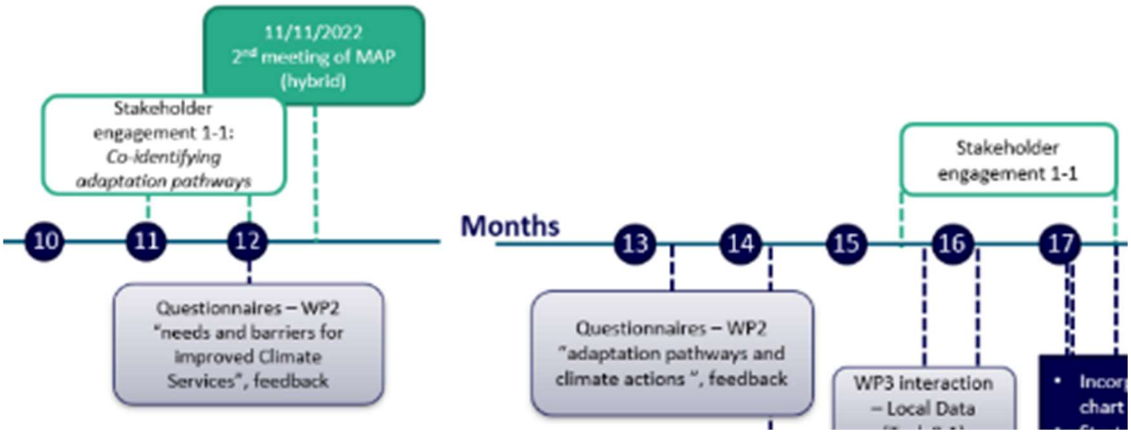

Figure 13. Part of the annual calendar of Crete LL meetings and actions towards the co-creation of CSs, focusing on co-identification of adaptation pathways.

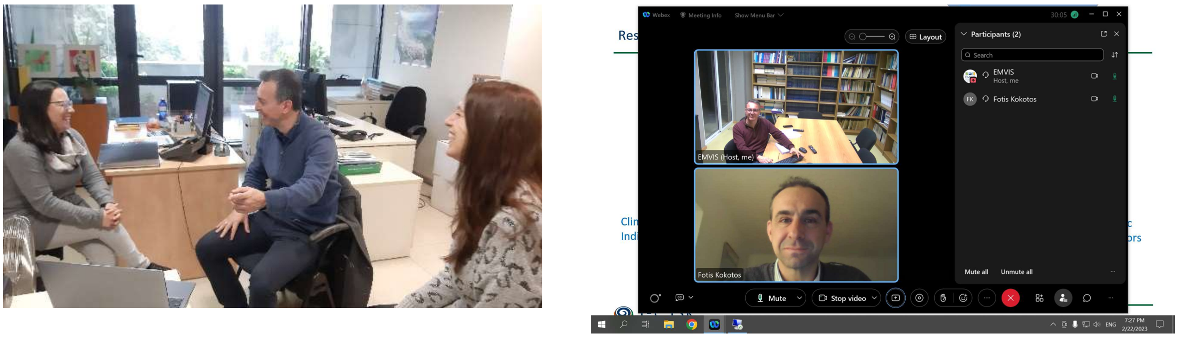

Figure 14 Individual stakeholder engagement activities

Individual meetings followed a structured interview approach addressing specific topics: critical climate threats and potential impact, opportunities, decision making, preparedness, climate service use, and climate service needs. Figure 15 shows an example of the information sheets filled in after the meetings.

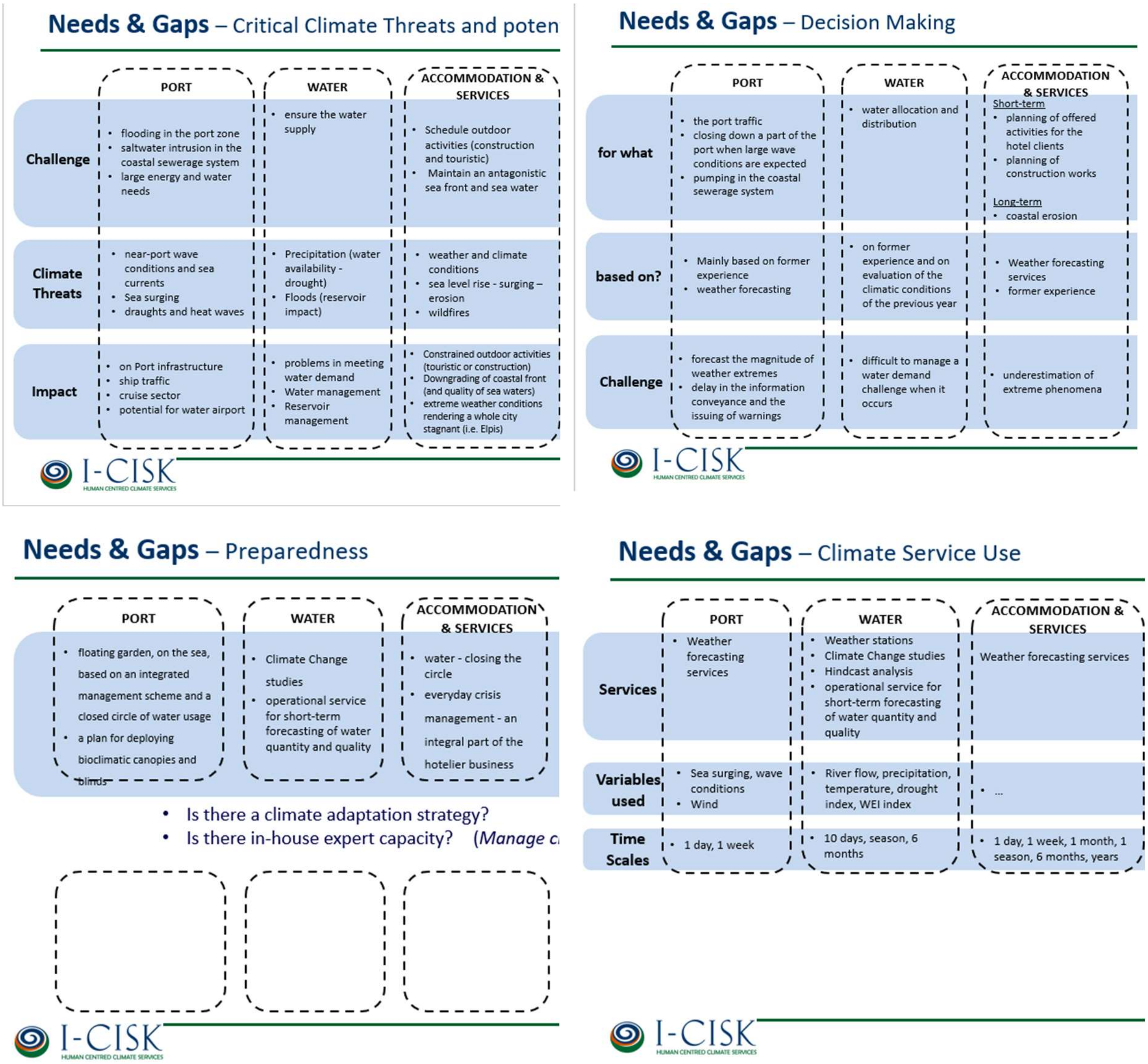

Figure 15. Example of info sheets filled in after the meetings

Initial interactions with individual MAP members (in 2022) were followed by a **workshop** with all MAP members at the end of 2022 (Figure 16). During this meeting information sheets (see Figure 15) grouping all available data collected during the interviews were discussed again under the broader concept of a cross-sectoral CS. The meeting was also an opportunity for broader discussions as well as a chance for MAP actors to create a common understanding of the co-creation process and goals, such as identification of needs and gaps and, of possible adaptation pathways.

Figure 16 Crete LL hybrid MAP meeting

Additionally, **decision timeline exercises** were developed with the MAP actors to identify information gaps and adaptation needs. Interviews were structured following an interview matrix which is shown in Table 4 as an example of the kind of information gathered during the exercise with one of the MAP members. Information was gathered in draft format and then used for the co-creation process. The climate risks addressed during the exercise included: drought and water scarcity, heavy precipitation, floods, heatwaves, sea surges and sea level rise, and specific wind patterns.

Table 4. Interview matrix used in individual meetings for identifying information gaps and adaptation needs - Example from the meeting with the Water Management MAP member.

What decisions needs to be taken	When	What worries you when making these decisions	Which variables/CS do you use	What is missing	Other
Water allocation and distribution to public clients (municipal utilities) (Water allocation *decision in April – for public users: how much and when*)	1. Once per year, usually early spring (March) or April (before the period with increased demands) 2. In September there is need for a decision on whether extra water will be allocated or withheld in the reservoirs to ensure	Will there be enough water to cover summer needs? Will it be a prolonged summer period (including a hot autumn)? Will there be a drought next year (meaning next wet period: November to February)? (*Municipalities (public users) may compete for the same resource (water)*	Maybe some monthly predictions of precipitation and temperature, assessments of expected needs, previous experience (Statistics of meteorologica l forecasting regarding precipitation amount) Question: are	Drought forecasting (seasonal, 6-month, 1 year), water availability forecasting – river flows (seasonal, 6-month, 1 year even a few years – two or three), What would be important: a forecast in September about the coming wet period (mainly Nov-Feb)	Reservoirs and surface water systems where water demands are lower than available resources are less vulnerable to drought risks and there is less risk of overallocation)

What decisions needs to be taken	When	What worries you when making these decisions	Which variables/CS do you use	What is missing	Other
	availability.	*at the end of summer and put political pressure to the water manager*)	there any specific thresholds which are used?		
Investments in new reservoirs, changes in water planning, access to other water sources, etc. Cost estimation – decide if they should invest on new reservoirs. If costs are too high and the need for extra water is not that high, then maybe other projects and works should be prioritized.	Long term (water manager *Organization for the Development of Crete uses projections up to 2080*)	Uncertainty	1. Surface water availability and general water availability 2. Are there any new needs? And where? 3. Usually consider three scenarios, good, average, bad	1. Conditions relate to possible future rivalling uses (e.g. agriculture, tourism demand etc.) 2. How often can the reservoirs replenish their full capacity?	

8.2. Characterizing the current adaptation decision space

In the Crete LL, MAP members are generally characterised by high educational background, significant awareness of climate challenges and good ability to understand the goals of the I-CISK project. However, not all MAP members started from a similar level of understanding of existing CS and of their potential. Therefore, their ability to engage productively in the CS co-creation process varied considerably. Some LL members have advanced tools and/or climate studies at their disposal, specifically developed to address their climate information needs, while others rely primarily on publicly available weather services and past experience.

The water management organization (OAK) is a high-capacity organisation that can use new tools such as advanced early warning systems, has identified climate change as a significant challenge, takes the climate change under consideration for long term decisions and incorporates adaptation actions into development planning. The main climate-related risks they have identified are drought, water scarcity and floods (see

Table 5). They address these risks through the implementation of a range of options with various associated costs and time horizons. Short-term challenges are addressed using on a combination of: (a) historical climate and hydrologic data; (b) management experience used to improve water distribution and water use monitoring; and (c) state-of-the-art operational forecasting tools. Long term challenges are addressed through significant investments in hydraulic infrastructures or the development of operational forecasting tools, supported by case-specific studies which take into consideration climate change projections and climate change impacts. Flood hazard is also mainly addressed on a short-term basis, based on weather forecasting, past experience and/or specific flood impact studies.

Tourist resorts are also high-capacity actors that address climate challenges on a more operational basis, utilising mainly weather forecasting and past experience (mainly quick actions and coping rather than adapting) to address extreme weather events. However, planned adaptation actions (e.g. against drought and water scarcity, see Table 5) are also taken under broader aspects of combining economic viability with an environmental-friendly culture. An example is the implementation of a closed water-cycle based on extensive water reuse that the tourist resort has already implemented.

Table 5. Characterization of the current LL adaptation decision space

	Problem addressed	Type of measure	Information /knowledge used	Adaptation scale
Water managers	Drought and water scarcity	Invest in new reservoirs	This is based on well-constructed studies which include analysis of historical climate data as well as estimations on future availability (climate projections) and needs	Adaptation
	Drought and water scarcity	Improve water distribution and water use monitoring	Based on historical data and management experience. A decision-making system based on hydrologic similarities to past years and current water availability and expert judgment.	In the middle of coping and adaptation
	Drought and water scarcity	Improve information on future possible risks	Studies which analyse climate projections and climatic trends	Towards adaptation
	Drought and water scarcity	Invest on operational service tools	State-of-the-art, operational forecasting tools which make use of short-term meteorological models and impact modelling	Adaptation
Water and tourist resort managers	Floods	Incorporate improved meteorological forecasting information into decision making,	Meteorological forecasting information	Coping
	Floods	Undertaking flood impact studies	Mainly historical climate data	In the middle of coping and adaptation
Tourist resort manager	Drought and water scarcity	Closing the water-cycle (reuse) in large tourist resorts/establishments	Past experience and historical data on water use and future estimations	Adaptation
Port managers	Heatwaves	Installation of renewable energy sources systems to cover energy needs	Mainly historical climate data	Adaptation
	Sea surges and sea level rise	Studies and projects for port protection – construction of a new breakwater	Mainly historical climate data	In the middle of coping and adaptation

Port managers identify heat waves, winds and sea surges as climate risks they need to cope with and take actions to adapt to (

Table 5). Measures implemented include studies to support the design and construction of port protective infrastructures, but renewable energy sources systems are also utilised to adapt to increased energy needs. Their actions are mainly based on historical climate data knowledge. Operational planning is based on weather forecasting.

8.3. Additional adaptation measures and required context-adapted climate services

Discussions between the LL lead team and the MAP members in Crete LL quickly revealed two things: although there is a shared understanding of climate change and the need to adapt, there is a significant variation in the understanding of the potential of CS to support adaptation strategies. An effort was made to address this limitation and improve the ability of stakeholders to define specific needs (CS related, co-exploration activities, see example of Table 4) or identifying opportunities for new CS development. Table 6 summarizes the results of these discussions with information on additional measures (considered or already planned) in the Crete LL, existing barriers and enabling conditions and CS needed for their development and/or implementation.

Table 6. Characterization of additional measures to be implemented in the Crete LL

Problem addressed	Type of measure	Characterization	Barriers	Enabling conditions	Climate services being developed
Drought and water scarcity: improve water storage and allocation decisions.	Early warning systems	Proactive measure that will increase resilience (adaptation)	Lack of trust on seasonal forecasting and climate information	Increased awareness on available tools	Seasonal forecasting of water availability
Extreme events (heavy precipitation and flooding) – effective resource (financial and personnel) planning allocation for expected repairs and maintenance -	Operational planning, informed planning and not reaction	Proactive measure to increase resilience	Difficult to predict – large uncertainties		Seasonal forecasting of landslide – due to heavy precipitation – prone areas
Floods	Establish better communication with Civil Protection	A proactive, long term-horizon measure aiming at adaptation. An institutional measure that helps adapt to future risk.	Administration barriers – low experience of Civil Protection on flood related risks	Increased awareness on climatic threats	Improved use of existing and new CS by Civil Protection
Floods	Early warning systems	Proactive measure that will increase resilience (adaptation)	Lack of maturity on climate adaptation and therefore lack of willingness to act, lack of in-house technical skills	Development of Flood Risk Management Plans	Early warning systems
Heatwaves	shading solutions (bioclimatic canopies and blinds)	An adaptation effort based on more environmental – friendly solutions	Financial limitations	Increased awareness of climate risks	Infrastructure and other shading solutions (not a CS)
Sea surges and sea level rise	Better information on surges and sea level rise	Proactive measure that will increase resilience (adaptation)	Financial limitations / in house technical skills	Awareness of the need to adapt to climate hazards	Seasonal forecasting on surges, with regional targeting
Specific direction winds and frequency of appearance	Early warning systems	Proactive measure that will increase resilience	Lack of trust on seasonal forecasting	Increased awareness of available tools (early warning	Seasonal forecasting on an operational level

Problem addressed	Type of measure	Characterization	Barriers	Enabling conditions	Climate services being developed
		(adaptation)		systems, case-specific and user-friendly) and uncertainty related information	
Heavy precipitation, strong winds, heatwaves	Early warning systems	Proactive measure that will increase resilience (adaptation)	Lack of trust on seasonal forecasting	Awareness of the need to adapt to climatic hazards	Seasonal forecasting on an operational level

Water managers identify the need for better informed decisions on water storage and water allocation, a more efficient annual management of the water reserves, especially if climate stress is expected to increase in the following decades. This can be translated into the need for early warning systems of expected droughts. A clear need for seasonal water availability forecasting is identified as a CS need, which is hindered by lack of trust on climate information.

The road-network manager identifies the functionality of the transport network as important for the tourist industry and the local population. Improved resource planning of infrastructure maintenance and repairs based on a well-designed operational system for decision-making based on improved climate predictions would support the manager towards this direction. Taking into consideration the possible intensification and increase in frequency of extreme events (e.g. heavy rainfalls) which pose a threat for road networks, an opportunity rises for an operational CS to provide information on landslide potential, a significant factor for road damages often related to heavy rainfalls. Under the same concept, flood early warning systems could supplement the set of tools needed.

The greater port areas provide spaces for leisure walks and activities. However, heatwaves hinder this type of use and port managers are seeking solutions. Shading solutions can be used for providing protection as an adaptation measure. The port of Rethymno plans to deploy bioclimatic canopies and blinds in the wider terrestrial zone of the port, to reduce energy consumption and protect the public against extreme heat. This type of measures are adaptation options but are not directly related to a CS opportunity.

Ports also face challenges with ship traffic management against wind and wave conditions. Weather forecasting provides some support but in view of a changing climate and increased frequency of such events, a well-structured operational management on a seasonal level, which would be based on seasonal forecasting of relevant meteorological variables, could better support port planning and help maintain income from ship traffic as well as better serve transportation, since the ports are important gateways to the island. An opportunity and a need for a CS is identified there to provide on operational basis and a seasonal time horizon information on specific wind directions, magnitudes and frequency of possible events. Uncertainty of information still poses a significant risk and a barrier towards endorsing such CS. Sea surges also pose a threat to the uses of the greater port area as well as to the sewerage systems. Again, the need for an operational seasonal forecast of sea-surges and frequency of events could support better planning on the port uses and management of resources for maintenance.

Tourist resort managers were able to express two very specific climatic challenges related to the management of their facilities. One is related to the annual needs on extensive maintenance works. These take place during the low season which is mainly during the late autumn and winter period and coincide in time with periods of events of heavy precipitation and/or wind. If extended works are planned and have to be cancelled due to unfavourable conditions, this has additional costs and poses a management burden for re-planning. The second one is related to seasonal planning needs on outdoor activities offered to the customers. Extreme weather events such as heatwaves or summer heavy precipitation and/or floods hinder outdoor activities. Up to now, such challenges are dealt by re-action to events and previous experience (e.g. which periods usually have favourable weather). However, under a changing climate a more robust planning system, on an operational basis would be needed. This is where there is opportunity of a CS with operational information, targeted to the above needs to support better planning. False predictions could also mean added costs and the burden of re-planning; therefore uncertainty of seasonal information plays an important role here.

9. Lesotho LL

9.1. Methodological approach used to understand the adaptation decision space

This Lesotho LL focuses on the Senqu Valley in southern Lesotho, where vulnerable communities rely on rain-fed agriculture and small-scale livestock farming. The LL focuses on CS to support anticipatory actions to drought and cold waves and enable national and district level stakeholders to work closely in empowering communities to decide how to adapt to climate change and mitigate the impact of extreme drought events and cold waves. The primary sectors considered are Humanitarian Aid and Disaster Risk Reduction, but climate information needs to support adaptation strategies for agriculture are also addressed.

Interactions with the LL MAP to co-create the CS gave insights into the wider adaptation decision space. A clear methodology was used to define the scope of the anticipatory action CS for drought and cold waves (Red Cross Red Crescent, 2024). The steps are:

- Decide for which hazard to develop the CS. The Lesotho Red Cross Society (LRCS) with the support of 510[1], made a ranking of the humanitarian impact of several hazards. Drought and cold waves ranked very high and were therefore selected for the preparation of adaptation measures.
- As part of a scoping study on drought (National University of Lesotho, 2022), the LRCS and the National University of Lesotho conducted an overview of existing drought forecasting sources, drought impacts on different sectors (health, water, and agriculture), and corresponding early actions to reduce impacts.
- Subsequently, a Preparedness for Effective Response (PER) assessment[2] of LRCS was conducted. A PER systematically assesses, measures, and analyses the strengths and weaknesses of the response system of a National Society to take remedial actions. This PER allowed LRCS to decide on their priorities for drought and cold wave adaptation.

The Lesotho LL conducted field-based local knowledge research. The research protocol consists of household **interviews**, community leader interviews, and **focus group** discussions. The household interviews were conducted using the smartphone Kobo Toolbox[3] for registering informed consent and collection of the GPS position of the household, demographic questions, pictures, and recordings. After this digital part of the survey, printed A3 sheets were used to conduct a **decision timeline** exercise with interviewees. The template for the decision timeline exercise is depicted in Figure 17. A decision timeline integrated into the questionnaire was used to understand decisions made by farmers in Qacha's nek district throughout the year to address drought and cold wave climate risks, and the information used to make these decisions.

The research protocol focuses primarily on the possible integration of local and scientific knowledge but also explored adaptation options. Questions around understanding the perceptions of (in particular) communities on adaptation options and developing solutions in line with adaptation behaviours were included. The decision timeline exercise covers the timescale that describes the livelihood activities and cues that are important for the participants. The timescale is mostly at the seasonal and annual scales. Participants are also asked to recall past experiences with extreme events

[1] 510 is the Netherlands Red Cross' data and digital initiative, the ICISK partner responsible for the Lesotho LL.

[2] https://go.ifrc.org/preparedness/global-summary

[3] https://www.kobotoolbox.org/

and explain what they see as long-term changes in weather and climate conditions, their livelihood practices, and risks in general. We ask also about changes in the adaptive or coping capacities of the households.

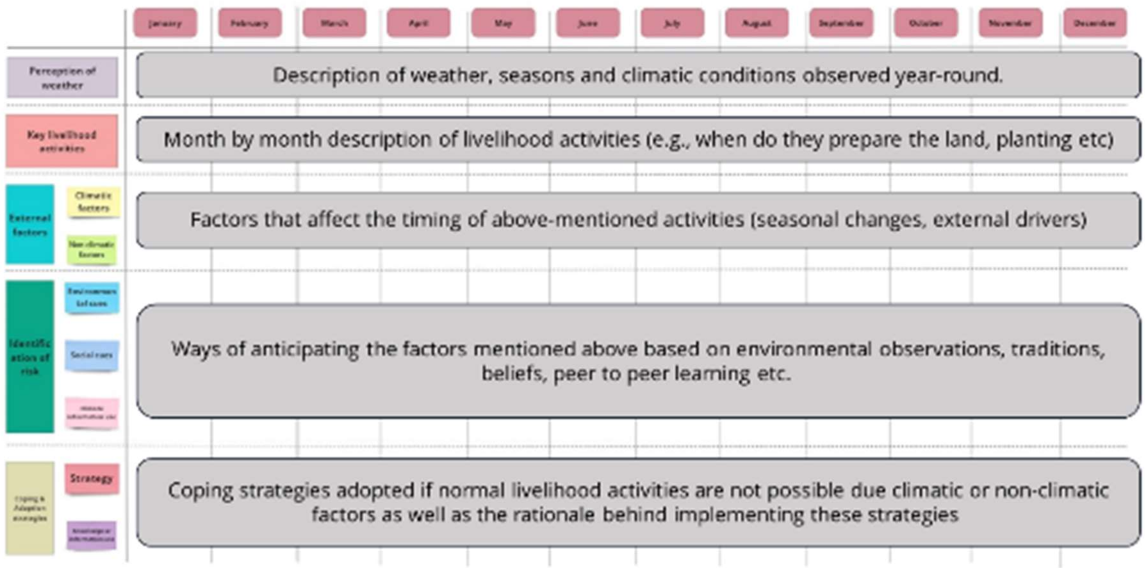

Figure 17. Decision timeline template.

9.2. Characterizing the current adaptation decision space

The key actor in the MAP of the Lesotho LL is the LRCS, a humanitarian organization whose focus is on emergency response and (early) preparedness. Strictly, speaking "normal" emergency response is not climate change adaptation but, rather, a coping response. LRCS responds regularly after a drought or food event has occurred. International development organizations, like the World Food Programme, or governmental organizations, do have programs focusing on long-term adaptation strategies.

Nevertheless, there is a relationship between climate change adaptation and emergency response (see for instance Arnell, 2022). Climate change will lead to more frequent and extreme weather events; hence also emergency response organizations must change their way of working and adapt to these new types of events. Anticipatory action can be seen as a new way of working. Anticipatory action refers to actions taken to reduce the humanitarian impacts of a forecast hazard before it occurs, or before its most acute impacts are felt. The decision to act is based on a forecast, or collective risk analysis, of when, where, and how the event will unfold[4]. Anticipatory action is a humanitarian approach that aims to save lives and livelihoods and reduce losses and suffering, but it can also be seen as climate change adaptation, as it is an adjustment in the existing humanitarian system in response to actual or expected climatic stimuli and their effects.

Table 7 presents an overview of the actions that the LRCS as a public actor takes to reduce, retain, or transfer climate-related risks (Mechler et al., 2019; van den Homberg and McQuistan, 2019). Interviews conducted by the LRCS provided insights into actions taken by individual households to reduce or retain climate risks. Early actions are meant to support these individual actions.

[4] https://manual.forecast-based-financing.org/en/

Risk reduction, retention[5] and transfer are important concepts in current COP/UNFCCC policy developments, in what pertains to loss and damage, and link therefore directly to climate change adaptation. The measures included in the table are grouped in the following categories:

- Risk reduction (short-term)
    - Reduce the risk short-term, for instance through anticipatory action as part of preparedness
    - Reduce the risk long-term, for instance through the introduction of drought-resistant seeds.
- Risk transfer: transfer of responsibility for some or all the financial costs, for instance via insurance, as when a household buys a micro-insurance.
- Risk retention refers to addressing the financial impacts of disasters while retaining responsibility for the financial costs. e.g. humanitarian aid and response.

Figure 18 maps these different ways of dealing with risk on the coping to adaptation scale. Risk transfer is not part of the scope of the Lesotho LL.

Figure 18. Risk management and climate change adaptation

Some actors in the MAP (apart from LRCS) implement long-term risk reduction measures. The government of Lesotho has developed strategies and policies such as the 2017/2027 National Climate Change Policy, the Multi-hazard Early Warning System manual, and the Lesotho National Early Warning System strategy to reduce the impact of climate change. The National Climate Change Committee coordinates actions for climate change adaptation. The Government of Lesotho includes Preparedness and Early Warning Early Action to manage the threat of climate change. District disaster management teams explained that long-term climate projections could be helpful for them to understand if and how to shift their agricultural production. A survey conducted by LRCS showed that most smallholder farmers in Qacha's Nek do not receive information on how to adapt to climate change. However, the Ministry of Agriculture has implemented adaptation measures such as providing climate-resilient seeds in drought years.

[5] Risk retention refers to a risk management strategy that involves a party assuming the responsibility for a certain level of risk or losses. The concept of comprehensive risk management – including transformational approaches – includes enhancing understanding of and promoting both short- and medium-term risk management, including risk analysis, risk reduction, risk transfer and risk retention. See for instance Science for Loss and Damage. Findings and Propositions or the mandate of the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts.

Hazard	Action	Position on the scale from "coping to adaptation"	CRM[1] measures currently implemented	By whom	Climate information required	Effectiveness
Drought	Dissemination of early warning information	Risk reduction short term	Anticipatory action	LRCS	Seasonal outlook in September with below-normal rainfall	Since the approval of the Early Action Protocol for drought in Dec 2022 (LRCS1, 2024), the soft, seasonal trigger was reached in 2023 but not the hard trigger. So not all early actions were initiated; only the dissemination of early warning.
	Unconditional Cash Transfers				October, November, December (OND) rainfall is below normal	
					Vulnerability Assessment Analysis report projects 20% of the population in drought-driven IPC Phase 3 and 4 for the next six months	
	Food distribution Distribution of seeds for vegetable crops	Risk retention	Emergency response	LRCS	No climate information, based on vulnerability assessment (after a drought has occurred)	Multiple activations, such as in 2012 and 2024. Timely short-term relief where many households were reached
	Distribution drought tolerant seeds	Risk reduction short term	Anticipatory action	WFP	Similar trigger model as for LRCS	October 2023 in four districts; Mafeteng, Mohale's Hoek, Quthing Thaba Tseka
	Drought resistant seeds and fertilizer distribution	Risk reduction long-term	Climate change adaptation	Ministry of Agriculture	LMS seasonal outlook, during drought years	No information available
Cold wave	Dissemination of last mile early warning information (EWI)	Risk reduction short term	Anticipatory action	LRCS	A forecast of 2ºC maximum day temperature or less in the highlands for at least two consecutive days with a maximum lead time of four days to the onset.	Early Action Protocol is not yet approved
	Distribution of warm protective clothing to herders					
	Unconditional Cash Transfers (UCT) to poor school children likely to need warm clothes					

[1] Comprehensive Disaster and Climate Risk Management

Table 7. Overview of the climate risk management measures characterized per hazard, actor, the climate information required, position on the scale from coping to adaptation, and its effectiveness

The Early Action Protocol (EAP) for drought has not yet been fully activated and the Early Action Protocol for cold waves has not yet been approved (LRCS1, 2024). In 2023 there was a partial activation of the drought EAP. Following the seasonal predictions issued on October 19th, 2023, indicating expected below-average rainfall for October, November and December, LRCS supported the development and dissemination of early warning messages to over 10,000 individuals across Mafeteng, Mohale's Hoek, Quthing, Thaba Tseka, and Qacha's Nek (LRCS2, 2024). The second trigger was anticipated to be activated in January 2024, upon receipt of a report from the Lesotho Meteorological Services (LMS) confirming below-average rainfall during October-November-December. The LMS report showed that autumn rainfall was above normal and hence the trigger condition was not met. However, the first quarter of 2024 had below-normal rainfall and recurrent heatwaves across the country. These adverse weather conditions resulted in significant crop losses and a resulting increase in the prices of staple foods, particularly maize meal. Furthermore, the dry spell of previous years impacted agricultural production and reduced work opportunities for poor households that rely on agricultural labour opportunities. The 2023/2024 season showed a decline in production of main staple food such as maize and sorghum which has resulted in an increase in staple food prices. In April and May 2024, the prices of commodities such as maize have increased dramatically due to the general crop failure. The likelihood of increased food insecurity is significant. Based on this combination of weather and food security information, LRCS has obtained approval to launch a humanitarian response intervention to mitigate the impacts of drought.

The shift from anticipatory action to "normal response" shows the sensitivity of adaptation actions which are based on (impact-based) forecasts. The trigger model resulted in a failure to act (false negative), whereas it should have triggered action.

Research has investigated how one "cycle" of an Early Action Protocol activation (risk reduction) compares with the response (risk retention) or doing nothing after a disaster has happened (Gros et al., 2019). However, as far as the authors know, it is not yet known whether receiving anticipatory action over many years will increase the coping capacity or resilience of households that receive the anticipatory actions or whether it will just prevent them from "falling further into poverty". It is more difficult to find empirical and longitudinal data on multiple activations to see how this reduces the possibly cumulative impact of a hazard on communities.

From a purely Early Action Protocol design perspective, there might not be a difference in the risk reduction per activation between doing it once or multiple times. The early actions in most EAPs are incremental, short-term actions (coping) and not fundamental long-term adjustments (adaptation) to reduce risk permanently. In the context of Lesotho and droughts, this could mean comparing cash transfers before drought impact has occurred with, for instance, changing farming practices and improving irrigation possibilities.

If we consider it from a private action perspective (as we did in the section above), we evaluate if households after a few activations are going to do things differently. If we consider it from a public action perspective, it means that we evaluate how are organizations (such as LRCS) going to learn from anticipatory action. Are there spillover effects to the normal DRR and response activities? Will it help LRCS also improve these??

9.3. Additional adaptation measures and required context-adapted climate services

The anticipatory action CS for drought is only operational in the Lesotho LL since December 2022. No activation has taken place so no experience with acting on the CS has been acquired. The Early Action Protocol for cold waves has not yet been approved. Overall, this means that anticipatory action is still very much an innovation for the LRCS as well as its partners Lesotho Meteorological Services and Disaster Management Agency. The limited capacity, technology, and funding available to the MAP partners in Lesotho also means that there is limited capacity to absorb and adopt more novel CS for other climate change adaptation applications.

Therefore, the goal of the Lesotho LL currently is to enhance the existing anticipatory action measures, rather than adding new or additional climate change adaptation services. The existing CS for drought and cold waves can be improved in three ways:

- Assess if the current triggers based on forecasts from the Lesotho Meteorological Service can be improved based on global climate models from ECMWF and SMHI.
- Assess if the current triggers based on forecasts can be improved by integrating scientific knowledge with local knowledge.
- Use a better understanding of local knowledge to improve the translation of scientific knowledge into an early warning message that is more understandable and actionable for the end users.

The first two points above relate to reducing uncertainty in decision-making in terms of longer lead times or higher skill of the forecast. The activation of the Early Action Protocol is triggered when a forecast reaches a threshold that indicates there could be severe negative humanitarian impacts. Currently only trigger models that have good forecast skill – that is, with false alarm rates that are not too high – are accepted. If the forecast skill improves, for the same lead time the false alarm rate will improve. Alternatively, the lead time can increase if the false alarm rate currently considered acceptable with the current forecasting model and the initial (shorter) lead time is accepted for other models. More lead time will give the humanitarian agency more time to prepare for early actions. Another way to reduce uncertainty is to use citizen science and crowdsourcing approaches to ground-truth the forecasts coming from global climate models. For example, de Baar et al. (2023) have shown the feasibility of combining high-fidelity official weather data with low-fidelity crowd-sourced weather data and high-resolution covariate information.

The third point relates to the network of interactions. In the CS value chain, the Lesotho Meteorological Services sends weather information in mostly technical language to the Disaster Management Authority. The DMA translates this into early warning information that goes via the LRCS to local actors and communities. This information flow is currently predominantly top-down. By using local knowledge and embedding this into the CS co-creation process, this information flow becomes more bidirectional.

10. Andalusia-Los Pedroches LL

10.1. Methodological approach used to understand the current and enhanced adaptation decision space

The Andalucía MAP is composed of water and natural area managers (3), agricultural and forestry research and outreach organizations (2), environmental information purveyors (REDIAM), farming cooperatives (2), a hunters' association (1) and a rural development organization (1). They represent the agricultural, animal husbandry and forestry sectors. The first 2.5 years of the project (from November 2021 to April 2024) the Andalusia LL area has experienced a prolonged drought (+7 years) that has affected local water supplies and was alleviated by a particularly rainy spring in 2024. Therefore, the information collected from stakeholders often refers to actions that have been carried out to manage the ongoing drought.

10.1.1 Phase I: Climate information needs and the current adaptation decision space

Between February and September 2022, exploratory **semi-structured interviews** (both in person and online) were conducted with key informants and representatives of all the organizations that were invited to join the MAP to explore perceived climate impacts in the region, main response measures and information used for decision making.

In October 2022 an **in-person workshop** served to constitute the MAP and provided an opportunity for its members to get to know each other. Its research objective was to: (a) identify climate services currently used; (b) elaborate on the drought response measures and adaptation options that had emerged in the interviews; (c) identify additional adaptation options; (d) explore the improved CS that could support and/or enable the implementation of these adaptation options; and (e) explore barriers to their implementation.

Figure 19. Plenary discussion of the identified adaptation measures.

10.1.2 Phase II: Understanding adaptation pathways.

Between January and June 2023, **online meetings** with each MAP actor served to discuss progress in the development of the CS and identify CS characteristics that could help improve drought management decisions and longer-term adaptation options.

In November 2023, six **focus groups** were organized with key members of the MAP in Los Pedroches region: dairy farmers, *dehesa* livestock farmers, olive growers, technical staff of the OLIPE olive growers cooperative, and technical staff of the COVAP ranchers cooperative, one with milk production technical staff and one with *dehesa* technical support staff (for *iberico* ham and other meat products). The goal of the focus groups was to characterize their drought and climate change adaptation strategies. The discussion focused on jointly assessing whether the strategies used so far have been effective to reduce their vulnerability to droughts both currently and in light of climate change projections. Focus groups worked on:

- Establishing of annual decision timelines for each activity (milk and *dehesa* ranching, and olive growers).
- The characterization of the temporal and spatial dimension of adaptation measures.
- Understanding the nature of adaptation strategies in terms of their long-term effectiveness.
- Understanding how barriers and levers (institutional, economic, technical, knowledge, etc.) prevent or favour the adoption of adaptation measures that reduce long-term vulnerability.

Figure 20. Working in the focus groups with *dehesa* cattle ranchers.

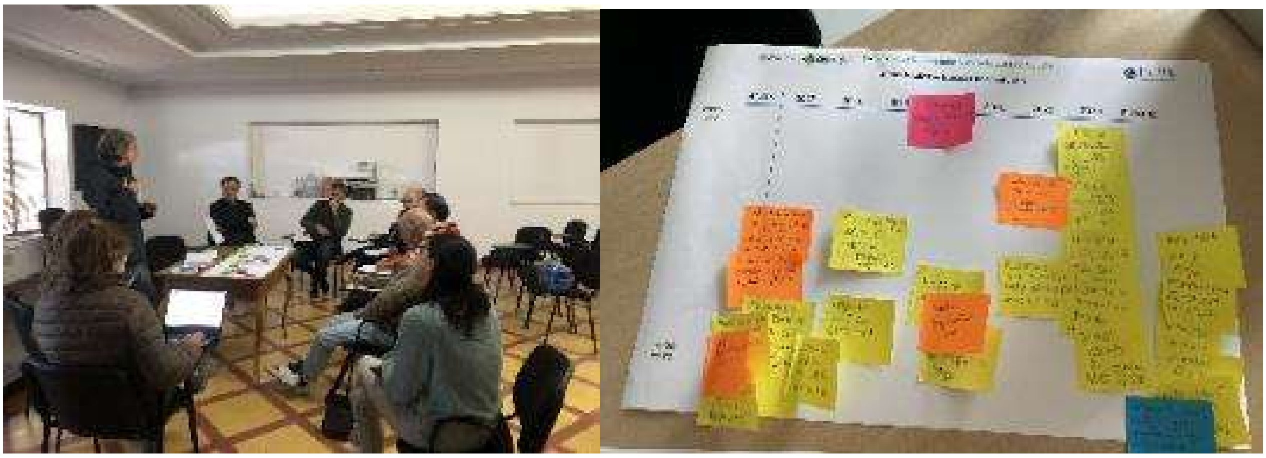

Figure 21. Working in the focus group with olive growers

The results of the focus groups were presented in a MAP **plenary workshop** in March 2024. For the assessment of adaptation or coping actions, we first analysed and grouped previously identified drought risk management measures into strategies and practices. Three main strategies were identified: ensuring water availability, ensuring economic viability of farming, and environmental management and protection. To facilitate the debate among MAP members, the workshop had a **world café** format, with each strategy being discussed in a separate working table. Participants were divided into groups of 4-5 people representing different sectors and MAP actors. They were given individual work sheets that included all the measures included in each strategy. The groups were given 30 minutes to work in each table and had to visit all three tables to discuss all three strategies. At each table, participants were asked to review all proposed measures of the strategy being discussed and identify the 1-2 measures they considered most effective in reducing long-term vulnerability to droughts. The group then had to choose 1 or 2 measures by consensus, and these were then characterized in terms of the following criteria (Magnan et al. 2020):

- Why is this measure considered effective in reducing vulnerability to drought?
- How long does it take to be fully effective?
- How long do the benefits last?
- What is the degree of social acceptability?
- What is the technical and institutional feasibility?
- What are the positive and negative effects on different actors in the territory (environment, livestock farmers, region...)?

Figure 22 shows the results of one of these working groups.

Figure 22. Identifying interrelations between sectors, actors, and spatial scales.

10.2. Characterizing the current adaptation decision space

The measures identified throughout the co-creation process were classified in relation to the objective they seek to achieve, rather than by sector. With this, three broad strategies for responding to drought have been identified:

10.3.1 Ensuring water availability

Measures were grouped into two sub strategies, each of which include measures that could be characterized as adaptation or coping:

Increasing water availability:

- Coping measures include providing water with tanker trucks, rainwater harvesting, or using water from the urban water supply network for livestock.

- Adaptation measures: include drilling wells to improve access to groundwater, improve rainwater infiltration or build new water storage facilities.

Reducing water demand: by optimizing and/or reducing use.

- Coping measures include reducing livestock density to adapt to available water resources in a given year. However, in some cases, these measures have been taken with a long-term perspective, that is, implementing a permanent reduction in livestock density (by 10%-15% in some cases) to adapt to changing climate conditions and reduce water needs or the stress on the *dehesa* ecosystem.

10.3.2 Ensuring economic viability of economic activities:

Measures were grouped into three sub strategies, each of which include measures that could be characterized as adaptation or coping:

- Maintaining productivity of economic activities, by adapting land, forest and livestock management activities to minimize impacts of drought. These can be medium- to long-term adaptive options such as adjusting the timing of crop operations. In this case, the availability of climate information tailored to the users' decisions is key to increase their effectiveness.
- Reducing drought-related economic risks: it includes a set of measures that help minimize production costs, by improving input purchase conditions, adjusting the period of purchase and sale of inputs for the economic activities of farming and livestock breeding, or other activities. Although they have been applied in a short-term manner due to the lack of suitable climate information, improving medium-term climate prediction services can maximize the effectiveness of these measures.
- Improving profitability of economic activities. These actions focus on product quality improvement and quality certification. They are usually promoted and coordinated by the cooperatives that seek to increase the value of the product to ensure its long-term profitability. This aims to be a long-term strategy with a transformational character.

10.3.3 Environmental management and protection:

Measures implemented in this strategy include:

- Adapting the ecosystem to climate change: through the improvement of vegetation cover or appropriate silvicultural treatment as well as the support of tree populations, these measures are aimed at ensuring the integration of the forest into the landscape.
- Reducing pressure on ecosystem carrying capacity is especially focused on livestock and forestry management. As discussed above, depending on the goals and duration of the measure, it can be considered coping or adaptation.
- Control of other climate impact risks related to plagues, wildfires, etc.

In terms of spatial scale, these management options mostly occur at the level of each farm, where farmers or ranchers decide how to respond to or pre-empt unfavourable conditions for their business. However, the COVAP cooperative (livestock ranchers) also plays a very important role in at least three aspects:

- they provide individual ranchers with technical advice on concrete adaptation actions (e.g. water efficiency technology; timing of cattle insemination) to guide their decisions based on the studies and assessment that they carry out as part of their mandate;
- they develop and share with ranchers' long-term strategies based on market trends and other important factors (for instance, adjusting livestock loads); and

- they implement specific actions that are more cost-efficient if made by a cooperative rather than by individuals (e.g. bulk acquisition of fodder; negotiation with the competent authority of dedicated water distribution points for livestock).

10.3. Additional adaptation measures and required context-adapted climate services

Local actors selected the reduction of water demand through reuse and improved efficiency of water use as the preferred strategy to ensure water availability in the present and in the future. Moreover, they indicated that rainfall harvesting has become a very relevant measure due to the severe drought the region has been facing during the past few years. Rain harvesting can contribute to providing water during the dry season, given the limited capacity of the aquifer to store water during long periods of drought and the existence of many areas suitable for rainwater harvesting (e.g. roofs of farms or of livestock shelters). However, this measure does require an initial investment and its implementation is not supported by the water authority, which is concerned about the impact that it could have on natural aquifer recharge. The climate services developed in I-CISK could help to support decision making processes with a forecast that users could understand and use and in terms of understanding of the functioning of the local aquifer system in relation to climate and water uses.

The optimization of the fodder stocking rate was the most relevant strategy to guarantee the economic viability of the most relevant production system, which is the livestock system. This is closely linked to pasture production, which is spatially variable between farms. In terms of barriers, the administrative feasibility may be limited by the EU (European Union) Common Agricultural Policy (CAP), as this policy sets maximum and minimum limits for stocking rates on farms. Moreover, the implementation of this measure requires important investments and therefore cannot be applied in the short term unless it receives public subsidies. Predicting pasture production in relation to climatic variables would be key to estimate the stocking capacity of each farm for livestock. However, we have yet to determine whether I-CISK will be able to make a direct correlation between climatic variables and fodder production and produce a forecast that is reliable enough to support decision making processes on stocking rates.

A third strategy discussed in the LL is related to ecosystem management and protection, and particularly the protection of the agroforestry production system. According to the local actors one of the measures to be prioritized is the reforestation of holm oaks. This is closely linked to the economic sustainability of Iberian pig farming (mostly free ranging, they graze in *dehesa*, an agroforestry system that combines oaks and grass) as well as to the availability of water, which limits both economic and ecosystem sustainability. The impact of prolonged droughts can significantly affect the holm oak population. One of the main disadvantages of planting oak trees (to substitute dead or sick ones) is their slow growth rate, which means that the positive effects of this measure will be felt in decades. In addition, the intrinsic characteristics of the species make it challenging to repopulate despite the research projects underway. This measure should be complementary to measures that seek to maintain the tradition of exploiting this type of ecosystem, which are closely related to ensuring water availability and economic viability of such agroforestry system.

When discussing current and potential adaptation options, local actors emphasized the limited reliability of existing climate forecast and projections and their lack of fit of existing CS with the temporal and spatial scale necessary for decision making. As a result, they to rely on local knowledge to inform management decisions.

11. Discussion

11.1. Methodological approach used to understand the adaptation decision space

In all LL, CS needs, the adaptation decision space and both current and potential adaptation measures have been identified and characterized through an iterative process of interactions between the local members of the MAP and the I-CISK research teams. This means that interactions have occurred in different phases and using different methodological approaches depending on the type and depth of the information required by the research in each LL. The first activities in the LL have been aimed at building the MAP and at collecting basic information about current measures to deal with climate-related climate risks and about climate-related data needed to support and improve them. In this phase, the LL leads have used mainly interviews (in person or online), multi-actor meetings including key local actors and targeted surveys. Then the LL I-CISK teams have often worked at consolidating the MAP and further characterising the requirements for CS through workshops and field visits.

In a second phase, the LL leads have worked collectively with their LL MAP to deepen the understanding of management actions, with an emphasis on the characterization of strategies where measures are embedded, and to explore to what extent they can be considered as coping or adaptation strategies. Moreover, they have explored what additional adaptation measures could be put in place in each LL, considering the barriers that impede and the levers that enable these measures. Also, this second phase has been carried out through methods tailored to the characteristics of each LL (timelines, world café, mock-ups etc).

Discussions and interactions have occurred at different territorial and institutional levels as shown in Table 8. In all LL interactions have involved mainly institutional/organized actors, such as public authorities, cooperatives, sector associations.

Table 8. Overview of the type of actors involved in the LL MAP and in the co-creation process.

	Alzani RB	Budapest	Emilia Romagna	Rijnland	Crete	Lesotho	Andalusia
Agricultural sector	✓		✓	✓			
Livestock sector							✓
Hydropower sector	✓		✓				
Tourist/recreational sector				✓	✓		✓
Municipal government		✓			✓		
Humanitarian aid organizations						✓	
Water managers			✓	✓	✓		✓
Port managers					✓		
Emergency agencies						✓	
Industry			✓				✓
Domestic water utilities							
Climate service developers						✓	
Involvement of actors beyond MAP (e.g. urban citizens, individual water users)	✓	✓				✓	✓

However, the CS developed within the framework of I-CISK at times are also meant for a larger audience (e.g. individual olive grove farmers or livestock farmers in Andalusia LL; irrigation district members in Emilia Romagna LL; individual recreational users in Rijnland LL; urban residents in Budapest LL; or small-scale farmers in Lesotho). The co-design in each of these LL therefore also requires input from these different types of users. Accordingly, while most co-creation activities have been tailored to the characteristics of the organized actors, some have also targeted individuals (e.g. Facebook campaign in Budapest; household interviews in Lesotho; focus groups in Andalusia). Table 9 provides an overview of the tools used in the LL, revealing the high level of interaction between the research teams and the rest of the MAP and a good level of alignment of the tools employed with the characteristics of the MAP and the larger LL.

Table 9. Methodological tools used for interactions with the multi actor platform in the I-CISK living labs.

	Alazani-Iori RB	Budapest	Emilia Romagna	Rijnland	Crete	Lesotho	Andalusia
Individual meetings and interviews	✓		✓	✓	✓	✓	✓
Survey	✓	✓				✓	✓
Focus group / Sector meeting				✓	✓	✓	✓
MAP plenary workshop (in person or hybrid)	✓	✓	✓	✓	✓	✓	✓
Field visits	✓	✓	✓	✓	✓	✓	✓
Problem Tree	✓						
Decision Timeline	✓		✓	✓	✓	✓	✓
World café							✓
Mock ups			✓	✓			✓
User stories				✓			
Online tools or apps			✓			✓	
Facebook campaign		✓					

11.2. Characterization of the current adaptation decision space and potential additional measures

The characterization of current and potential measures across the I-CISK project reveals a variety of approaches used by the actors in the different LL to manage current and expected climate risks, as well as different opportunities and constraints they face in each context.

11.2.1 Current and potential measures to address climate risks

Currently the Alazani-Iori RB LL farmers focus mainly on infrastructural (grey or green) measures such as drip irrigation, the installation of hail nets, planting windbreaks, or the use of water infrastructure operation rules targeted to mitigate the impacts of droughts and flash floods. Moreover, they implement on-farm management strategies such as adaptively adjusting sowing and planting dates, sharing information among them on mildew appearance, etc. Understanding and predicting streamflow and other climate-related variables in the basin would be key for supporting more reliable and robust water resources planning and management both by individual users (agricultural planning, hydropower operation) as well as the basin management level (flood control).

Current measures in the Budapest LL are mainly reactive, seeking to cope with urban heat. Moreover, they are mainly based on individual initiatives rather than coordinated efforts. Additional adaptation measures identified include building a tailored warning system to inform about the occurrence of heat waves. To design and implement these measures, the identification of urban heat islands is key. Interventions on the ground include structural changes in existing buildings to reduce the effects of high temperatures and changing construction protocols and rules e.g. to foster that new buildings are better adapted to summer heat. Barriers associated to these types of measures include their costs, the physical constraints associated to the existing configuration of the city (e.g. height of buildings; availability of space between buildings) and the lack of information tailored to the city to generate awareness about the importance of managing heat in an urban environment.

In the Emilia Romagna LL, current drought management measures are mainly coping mechanisms aimed at the optimization of water withdrawal and storage depending on water availability and water use demands. Adaptation measures are related to enhanced water use planning by different economic sectors, taking into account forecasted river discharge scenarios. In this context, the CS being developed in I-CISK will be key in informing decision-making and enhance strategies for adapting to and coping with climate variability.

In the Rijnland LL, the measures discussed in the MAP focus mainly on coping measures. So far, during drought the water management authority and the agricultural sector have taken measures to mitigate impact – dike inspections, limiting ship-lock operation, adjusting surface water intake and irrigation schedules – and communication for increased preparedness. Long-term strategies are focused on investment in water system infrastructure. In the water recreational sector mitigation actions are still very limited. There is a dependence between actions taken by the water authorities to mitigate the effects of drought on the agricultural and the recreational sectors. Thus, the effect of each operational and strategic measure cannot be considered in isolation.

The Crete LL has taken a multi-sector, multi-hazard approach, as it considers problems associated to drought and water scarcity, heatwaves, floods, sea surges and sea level rises. The measures identified by the MAP are both adaptation and coping ones. They range from investments in structural changes – building dams, installation of renewable energy systems, construction of a breakwater to the development of improved information and studies. Additional measures that have been explored in the context of I-CISK are mainly focused on improving information generation and sharing, such as enhanced seasonal forecasts, early warning systems, better communication with Civil Protection.

In the Lesotho LL, the measures considered in the framework of I-CISK are humanitarian interventions aimed at mitigating the impact of drought and cold waves on the local population. The Lesotho LL has agreed that rather than crafting new adaptation measures, efforts should be placed in reducing the uncertainty associated with the implementation of those that already exist. Moreover, the need of translating technical information into a language adapted to the final users of the CS has clearly emerged and is echoed – with nuances –in other LL. For instance, the visualization of historical climate data with visualization features adjusted to local needs has been prioritized also by the Andalusia and the Crete LL local actors.

In the Andalusia LL, strategies have been identified and characterized at different levels (individual water user, user cooperative, county). Some of the measures in place are coping ones, to deal with the immediate need to ensure water availability for the different economic activities. These include actions such as obtaining water with tanker trucks, adjusting the cropping practices or the size of the livestock herd to seasonal climatic conditions and water availability. Mid- to long-term strategies include measures to optimize fodder production and stocking, improve the use of water resources in terms of quantity and quality, build new water storage infrastructures or ensure the viability of the ecosystem sustaining socioeconomic activities in the LL through the replacement of old/sick oak trees and the continuity of the tradition of exploiting the *dehesa* agroecosystem.

The analysis conducted in each LL has revealed a rich variety of adaptation options, but also features common to several LL (Table 10). For instance, common coping measures include the setting up of early warning systems and the activation of emergency protocols (e.g. Emilia Romagna, Budapest, Lesotho) as a measure used to guide decisions in relation to climatic conditions and the occurrence of extreme events. The CS under development in the different LL are also early warning strategies for floods or drought risks. Another common coping strategy is the adaptation of the calendar of activities – e.g. planting, harvesting, pruning (e.g. Andalusia, Emilia Romagna, Alazani-Lori RB) or recreational activities (Rijnland) – to mitigate the impact of adverse conditions or optimize favourable ones. The construction or upgrade of infrastructure (wells, water deposits, hail nets, green roofs in urban areas, etc.) or the adaptation of the operation of weirs or dams to improved CS, is often implemented or a desired option to reduce vulnerability to climate risks.

Table 10. Overview of current and potential measures across the I-CISK living labs.

	Alazani -Lori RB	Budapest	Emilia Romagna	Rijnland	Crete	Lesotho	Andalusia
Current measures							
Adapting agricultural practices (dates, crops, farming practices)	✓			✓		✓	✓
Adapting dates of recreational activities				✓			
Targeted operation of water infrastructure (e.g. maintain a given water level in channels, moving water across storage facilities)	✓		✓				
Infrastructural measures (e.g. drip irrigation; adaptation of urban areas to heat; construction of water deposits)	✓	✓			✓		✓
Elaboration or revision of master plans			✓		✓		
Prioritization/planning/management of water withdrawals			✓		✓		
Activation of emergency protocols		✓	✓			✓	
	Alazani-Lori RB	**Budapest**	**Emilia Romagna**	**Rijnland**	**Crete**	**Lesotho**	**Andalusia**
Potential measures							
Base decisions on reliable forecast rather than on observations or local knowledge only	✓		✓			✓	✓
Use of long-term climate projections to adapt activities and practices			✓				✓
Use of urban heat island location to design urban interventions to reduce heat risks		✓					
Improved planning and management based on enhanced climate forecasts (water, infrastructure operation, urban, emergency response, risk management)	✓	✓	✓	✓	✓	✓	
Improved decisions based on tailored visualization of historical data			✓		✓		✓
Improved decisions based on better knowledge of the physical system					✓		✓
Enhance climate communication tools and strategies (early warning systems, adapt communication tools to user needs, etc.)	✓	✓	✓		✓	✓	

Green infrastructure		✓			✓		

Existing measures are primarily designed and implemented based on local knowledge and past experience about climatic events and their management (e.g. Emilia Romagna, Alazani-Lori RB, Andalusia), rather than on science-based climate forecasts. This is the result of both the lack of knowledge or familiarity with existing CS, the lack of (spatial and temporal) fit of existing CS with local needs, inadequate communication channels of climate information and risks, and often the distrust of decision-makers at all scales about the reliability and accuracy of existing climate forecasts and projections.

In all LL, coping strategies predominate. In some cases, work with the MAP has revealed that coping activities, while effective to deal with the immediate needs for mitigating the effects of a climate-related extreme event, can contribute to postpone the decision to design and implement long-term adaptation strategies. However, the debate about long-term adaptation exists and intensifies when there is an unprecedented crisis. For instance, Emilia Romagna, Rijnland and Andalusia have experienced an unprecedentedly severe drought over the past several years. Local actors have focused on implementing coping measures while thinking about, discussing and in some cases implementing long-term strategies (for instance in Andalusia a strategic reduction of the livestock load in the *dehesa* was studied and subsequently recommended by the COVAP cooperative to its members) that should be put in place if such extreme episodes become more frequent in the future. In general, the availability of reliable, tailored forecast and projections of climate-related events will help create awareness about the need to increase efforts toward long-term adaptation and will help design adequate adaptation measures. This is because actors often feel that they need more and better information to make decisions that imply large investments or structural changes to their activities. This applies both to organized/institutional actors (e.g. public administration, water managers, NGOs, cooperatives) and to individuals (e.g. urban inhabitants, hotel managers, farmers), as coping and adaptation measures usually happen at different scales at the same time and feed one into the other.

In all LL, the interactions of the MAP have led to defining the adaptation decision space and exploring potential strategies that could be supported by tailored CS. Each LL has reached a level of analysis contingent on the specific characteristics of the members of the MAP and the focus and characteristics of each LL. In this context, LL leads adjusted the conceptual framework defined in Chapter 1 to the interests and possibilities of each LL. For instance, the Budapest and the Andalusia LL used the Fisher et al (2019) classification of measures into strategies-practices-activities, while in the Lesotho LL the research team conceptualized measures in terms of risk reduction, risk transfer and risk retention to match the specific characteristics of the MAP (emergency response organizations) and the co-creation goals in that LL. Moreover, in some cases (e.g. Andalusia and Rijnland LL) the characterization of measures included also the identification of cross-sector impacts, while in other cases the discussion within the MAP referred mainly to the use of improved information for designing or enhancing specific sector-oriented measures.

12.2.1 Existing barriers to implementation of improved adaptation decisions

Barriers to implementation identified in several LL (e.g. Crete, Rijnland, Lesotho, Andalusia) include the uncertainty of available forecasts and the risk of false positive or false negative, that is, that a drought or flood is forecasted and does not take place, or the reverse. Often, however, lack of trust in a CS is the result of a perception of uncertainty, not necessarily a reflection of real skill. In this context, trust in existing CS and an acceptable prediction skill is critical and it is critical to build this trust – for instance through the combination of local knowledge with CS and forecasts. In some LL, there is an identified need (e.g. Budapest and Andalusia) to have climate information tailored to the spatial scale of the LL. The limited capacity (technical, financial or other) of institutions and individuals to implement management measures (e.g. Civil Protection in Crete; water tourism in Rijnland) can also be a significant barrier. Legal or administrative constraints to implement improved adaptation decisions were also identified in some LL.

Table 11 presents a summary of barriers identified in the different LL for the implementation of improved adaptation decisions.

Table 11. Overview of barriers faced to implement additional adaptation measures across the I-CISK LL

	Alazani-Lori RB	Budapest	Emilia Romagna	Rijnland	Crete	Lesotho	Andalusia
Lack of financial resources/high cost of the measures		✓					✓
Coping measures hamper the adoption of adaptation measures			✓	✓			✓
Lack of climate-related information at the required spatial scale		✓		✓			✓
Inadequate lead time of forecasts					✓	✓	✓
Insufficient skill of forecasts and projections	✓	✓	✓	✓	✓	✓	✓
Legal/administrative constraints		✓	✓				✓
Infrastructure constraints		✓					✓
Lack of reliable information about seasonal water availability	✓		✓				✓

Economic constraints is mentioned as a barrier to the adoption of adaptation measures in Budapest and Andalucia LL. At times there are public subsidies to support individuals or organizations in the implementation of climate risk management measures, but they are considered insufficient (e.g. Budapest), or the timing of their availability does not match the needs on the ground (e.g. Andalusia).

12. Concluding remarks

- The ICISK living labs have used an iterative co-creation process of interactions between the local members of the multi-actor platforms and the I-CISK research teams. Interactions have occurred in different phases and using different methodological approaches depending on the type and depth of the information required by the research in each living labs.
- Co-creation activities have been tailored to the characteristics of the organized actors – public administrations, cooperatives, business associations – that constitute the multi-actor platforms in the living labs. However, some activities – focus groups, Facebook campaign, household interviews – have also targeted individual end users of the climate services.
- Measures currently implemented in the LL are mainly reactive and seek coping with current climate risk challenges. Common coping measures include early warning (early action) systems and emergency protocols to guide decisions in response to the occurrence of extreme events; adaptation of the calendar of activities to mitigate the impact of adverse conditions.
- In some cases, coping measures, while effective in dealing with the immediate needs for mitigating the effects of a climate-related extreme event, can contribute to postpone the decision to design and implement long-term adaptation strategies.
- Existing measures are designed and implemented mainly based on local knowledge and experience rather than on climate forecasts (with the exception of the anticipatory action CS in Lesotho that is based on seasonal and sub seasonal forecast information). This is the result of both the lack of knowledge or familiarity with existing CS, the lack of (spatial and temporal) fit of existing CS with local needs, inadequate communication channels of climate information and risks, and frequent distrust of decision-makers at all scales about the reliability and accuracy of existing climate forecasts and projections.
- Interactions with local actors indicate that the availability of reliable, tailored forecast and projections of climate-related events will help create awareness about the need to increase efforts toward long-term adaptation and will help design adequate adaptation measures. Actors often feel that they need more and better information to make decisions that imply large investments or structural changes to their activities. Also, the funding mechanisms for long-term adaptation are/seem to be more complex (as is e.g. the case in Lesotho) than for immediate coping-related measures.
- There is a certain dependence among measures implemented in a given context, so that current measures are influenced by past experience and, in turn, will constrain the options available in the future. For example, this can be seen in current investments in infrastructure, as the characteristics of existing infrastructure will influence the array of options available to make progress toward adaptation in the future. At the same time, if current measures include investments in infrastructure, their effectiveness and maintenance costs will often determine the pathway followed in the future.
- In all LL adaptation options are designed and implemented at different scales at the same time (e.g. individual farmers, urban citizens, tourists, cooperatives, public authorities, building communities) and often they are not coordinated or not even known by actors that can be affected by them. Thus, it is key to frame each adaptation option in the context where it occurs and explore how it interacts with other actions and systems.
- Some LL pointed to the fact that coping measures to deal with immediate impacts of climate-related negative events, if effective on the short term, may reduce the perception of urgency to discuss and implement adaptation measures that will increase the resilience of the system on the long run. Thus, as the work of I-CISK in the different WP progresses, it will be worth further exploring the LL adaptation options from a pathway perspective.

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