Deliverable D2.5

User-Centred Validation of Climate Risk Knowledge Integration Using Decision Timelines for Collecting, Understanding, and Integrating Local Knowledge

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I-CISK

Innovating Climate services through Integrating Scientific and local Knowledge

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Executive Summary

Developing effective climate services (CS) for anticipating and responding to climate change necessitates the considering of a wide array of knowledge bases, encompassing both scientific and local knowledges (LK). Efforts across literature and practice have called for integration of LK within the CS design, development and provision process. However, to date, the integration of LK within CS has remained very narrow. Against this backdrop, the objective of Task 2.2 of the I-CISK project is to identify and collect LK, mainly through participatory methodologies, to link expertise from the consortium scientists and LK from the stakeholders in the Living Labs (LL) and complement climate data from Copernicus and GEOSS and research with local data. As part of task 2.2, the deliverable **D2.2 Concepts and methods to characterize and integrate local and scientific knowledge** was published in March 2023 (van den Homberg et al., 2023). This deliverable, **D2.5 User-Centred Validation of Climate Risk Knowledge Integration -** ***Using Decision Timelines for Collecting, Understanding, and Integrating Local Knowledge*** continues where D2.2 left off and complements the more conceptual D2.2 with grounded information and insights from the seven I-CISK LLs. Task 2.2 closely relates to task **T2.3 Co-identify suitable climate actions by CS, customized to sectors & geographic area** and to **T3.3. Evaluation of tailored information from a user perspective**.

In this deliverable, we build on the characterisation of LK provided in Van den Homberg et al. (2022), emphasizing that LK encapsulates different types of knowledges generated through a variety of processes, ranging from traditions and customs passed down generations, to personal experience, through to knowledge resulting from being embedded in an organisational set up. We focus on LK associated with decision making in an effort to better understand LK in the context of its use and applicability. We use decision timelines as a structured framework to understand the sequence and timing of decisions within a community. By mapping out when and why certain decisions were made, we gain insight into the contextual factors that influence these choices. This includes seasonal variations, cultural events, market fluctuations, and environmental changes. We argue that even in the absence of formal CS, individuals (CS end users) triangulate between their own understanding of the local environment, their practical experience, contextual drivers, and other sources of information. This can also be applied to organisations (CS providers and purveyors), as they too are influenced both by the complex factors that influence individual decision making as well as the structure, mandate and culture of the organisations themselves. This triangulation of information can inform communities' understanding of the local environment, risk appraisal, trigger decision making or influence the choice of adaptation strategy.

To understand how this happens in practice, we present examples here from I-CISK LLs where the use of decision timelines has been piloted to elucidate LK from CS providers, purveyors and end users. We find that stakeholders rely on indicators derived from weather patterns, socio-economic changes, overarching policy contexts, and existing culture of governance to inform their decisions. Linking key decisions and actions to corresponding knowledge and information sources helps in understanding the context in which climate information will be provided. It also provides insight into what channels of information are already regarded as trustworthy by the intended users, existing competency of users when it comes to understanding climate information, and their expectation when it comes to the use of climate information to support the decisions they make.

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Glossary

Acronym	Definition
API	Application Programming Interface
C3S	Copernicus Climate Change Service
CDS	Climate Data Store
CEMS	Copernicus Emergency Management Services
CMIP	World Climate Research Programme's Coupled Model Intercomparison Project
CORDEX	Coordinated Regional Climate Downscaling Experiment
CS	Climate Services
CSIS	Climate Services Information Systems
DRR	Disaster Risk Reduction
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GUI	Graphical User Interface
IPCC	Intergovernmental Panel on Climate Change
LL	Climate Services Living Labs
NHMS	National Hydro-meteorological Service
MOOC	Massive Open Online Course
OGC	Open Geospatial Consortium
S2S	Sub-seasonal to Seasonal
TRL	Technology Readiness Level
UNCCD	United Nations Convention to Combat Desertification
UNDRR	United Nations Office for Disaster Risk Reduction
UNFCCC	United Nations Framework Convention on Climate Change
WCRP	World Climate Research Programme
WFD	Water Framework Directive
WMO	World Meteorological Organization

1 Introduction

Developing human-centred climate services (CS) for anticipating and responding to climate change necessitates understanding end user needs and their decision-making processes. This means a wide array of knowledge bases should be considered, encompassing both scientific (SK) and local knowledges (LK) and integrating LK along the whole CS value chain. Integration of LK has been posited as a way to build human-centred CS, thereby overcoming the 'usability gap' that impedes the adoption of CS by end users (Lemos, Kirchhoff, and Ramprasad 2012). This is attributed to the notion that inclusion of LK can lead to production of climate information that is credible, salient and legitimate. Credible refers to how to create authoritative, believable, and trusted information; salient to how relevant the information is to decision making bodies or publics; and legitimate to how "fair" an information producing process is and whether it appropriately considers the values, concerns, and perspectives of the different actors (Cash et al. 2003). Figure 1 highlights ways through which LK can add value to climate services (Cash et al. 2003). Current evidence, however, points to a limited view and selective integration of LK within CS (Muller et al. 2024; Dube et al. 2024). This has been attributed to a lack of clarity in terms of what constitutes LK cherry-picking of certain dimensions that are more amenable to science-dominated integration approaches (Hadlos et., al 2022; Hermans et al., 2022; Plotz et al., 2017).

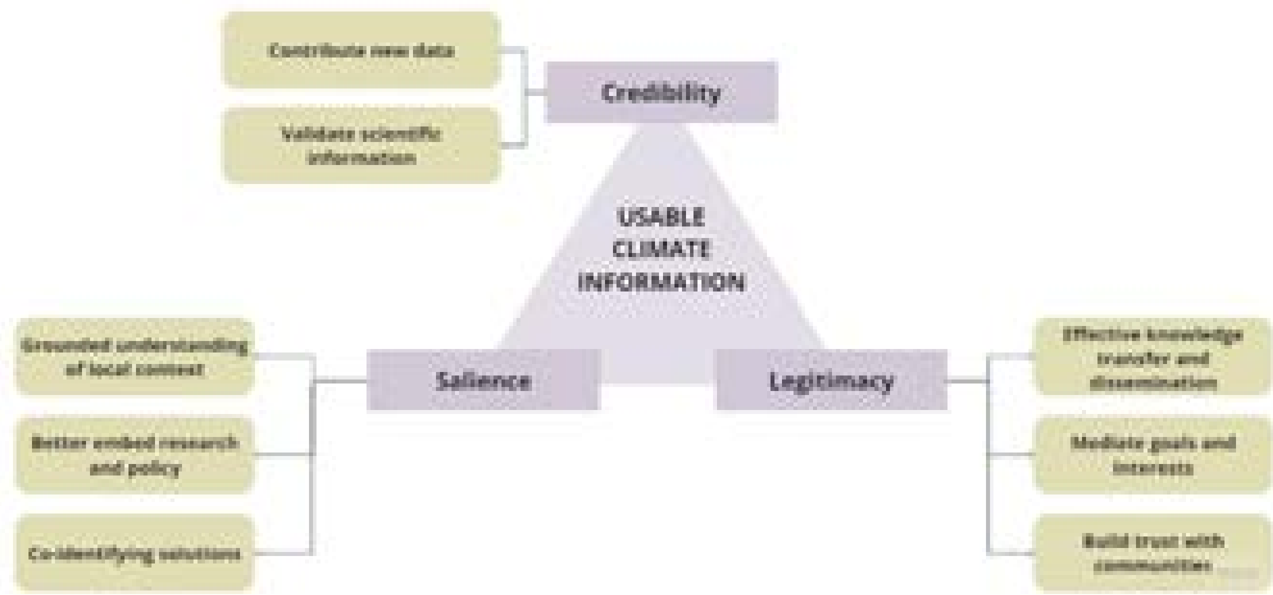

Figure 1 Ways through which LK can inform the development of usable climate information. (Cash et al. 2003;Taylor and de Loë 2012)

One of the key goals of I-CISK is to innovate how climate information is used, interpreted and acted on through a next-generation of CS that incorporates different knowledge systems. To achieve this, T2.2 through deliverable D2.2 and D2.5, sets out to identify and collect LK, mostly through participatory methodologies, to link expertise from the consortium scientists, LK from the LL, and complement climate data from Copernicus and GEOSS and research with local data. D2.2 (Van den Homberg et al., (2022)) titled, 'Concepts and methods to characterize and integrate local and scientific knowledge', provides a conceptual understanding of LK rethinking its application and use within CS. The deliverable proposed a pragmatic rethink of LK for CS - emphasizing that LK be regarded as an umbrella term that encapsulates knowledges generated through different processes, and a range of LK holders; from members of local communities to those involved at different levels of governance (a detailed recapitulation is presented in Chapter 2). This deliverable, D2.5 titled, 'User-centred validation of climate risk knowledge integration', builds on the former with an in-depth survey of LK use across I-CISK LLs.

Climate Services are often produced as a collaborative effort with organisations and individuals from diverse backgrounds. Depending on their role and function, these participating stakeholders occupy different positions along the CS value chain (Figure 2). Adopting the conceptualisation of LK proposed in Van den Homberg et al., (2022), we recognise that LK can be generated through different processes and LK holders can be diverse. We, therefore, theorize that not only the end-users but also other stakeholders on the CS value chain can be regarded as LK holders. These LK holders will have a mid- and downstream position along the CS value chain; as it is reasonable to assume that the data providers, data integrators and modellers at the upstream position hold LK to a lesser extent and have a more predominant focus on SK. Intermediary organizations are the services providers and purveyors midstream, while end users are at the downstream end of the value chain. Most LK studies pay no or very limited attention to the LK of regional and local upstream agents. Exploring LK of end users as well as service providers and purveyors can help unearth how new climate information 'interplays' with their existing knowledge and organisational mandates, highlighting any gaps that may exist in terms of which users are better supported than others.

Figure 2 Climate services value chain

Apart from considering LK use along the CS value chain, LK can also be considered within the different phases of developing CS. Within I-CISK, a co-creation process is followed whereby users are actively involved across all phases, from problem formulation to developing credible and relevant information and establishing practical relevance of the tangible (the actual CS) and intangible (improved understanding, capacity) outcomes (Bremer et al., 2019). Our assumption is that in principle LK can be used in many of these phases.

In this deliverable, we depart from a general exploration of LK to focus specifically on LK underpinning decision making – converging on when and how decisions are made, what knowledge and information is used as an input, and what coping strategies are adopted to manage the risk. We use decision timelines as a tool to gather and understand LK along the CS value chain and in the context of co-creation process. In particular, it aims to understand how LK can be used to improve:

1. Decision making to support sectoral or livelihood processes at the end user level
2. Climate Services provision at the service purveyors and providers level.

We note that if the end users are from the agricultural sector, then the CS should support the farming processes, while if the end users are from the tourism sector, then the CS should support the (commercial) decision making of stakeholders involved in the tourism sector.

Recognising that climate information is not provided in a silo and users rely on different forms of knowing, the goal of D2.5 is therefore to unpack and learn from practice the ways in which LK is made actionable to inform decision making by different stakeholders across the I-CISK LLs. Decision-based exploration of LK can allow for a more pragmatic understanding of the use and applicability of LK without making any assumptions, i.e., under- or overstating its importance. This understanding can inform ways through which LK can add value to CS and support development of climate information that fulfils aspects of credibility, salience and legitimacy, thereby supporting its adoption and use.

The remainder of the deliverable is structured as follows:

- Chapter 2 - provides a conceptual discussion on LK linking it to decision making
- Chapter 3 - presents the methodology and description of the Decision Timelines tool that is introduced and used in this study
- Chapter 4 - presents results from each of the I-CISK Living Labs where decision timelines were developed
- Chapter 5 - provides a synthesis and discussion of findings
- Chapter 6 – summarises concluding remarks and recommendations

2 Background: Local Knowledge and Decision timelines

2.1 Recapitulation of Local Knowledge definition

In this chapter, we recapitulate the definition of LK and introduce the different building blocks of decision timelines. We first give a short recapitulation of what we mean with LK. For a more extensive description we refer to Van den Homberg et al. (2022). Within I-CISK we define LK as an all-encompassing term that includes a range of different knowledges, signifying how individuals perceive their surroundings, validate new information and solve problems. As such, LK holders can range from indigenous, rural or urban communities to professionals working at various levels of governance and boundary organizations. These organizations can be from up- and downstream in the CS value chain. Figure 3 below shows four different ways in which LK can be generated. By framing LK in this manner, our aim is to broaden the scope of LK integration contributing to enhancing the credibility, salience and legitimacy of information provided by climate services.

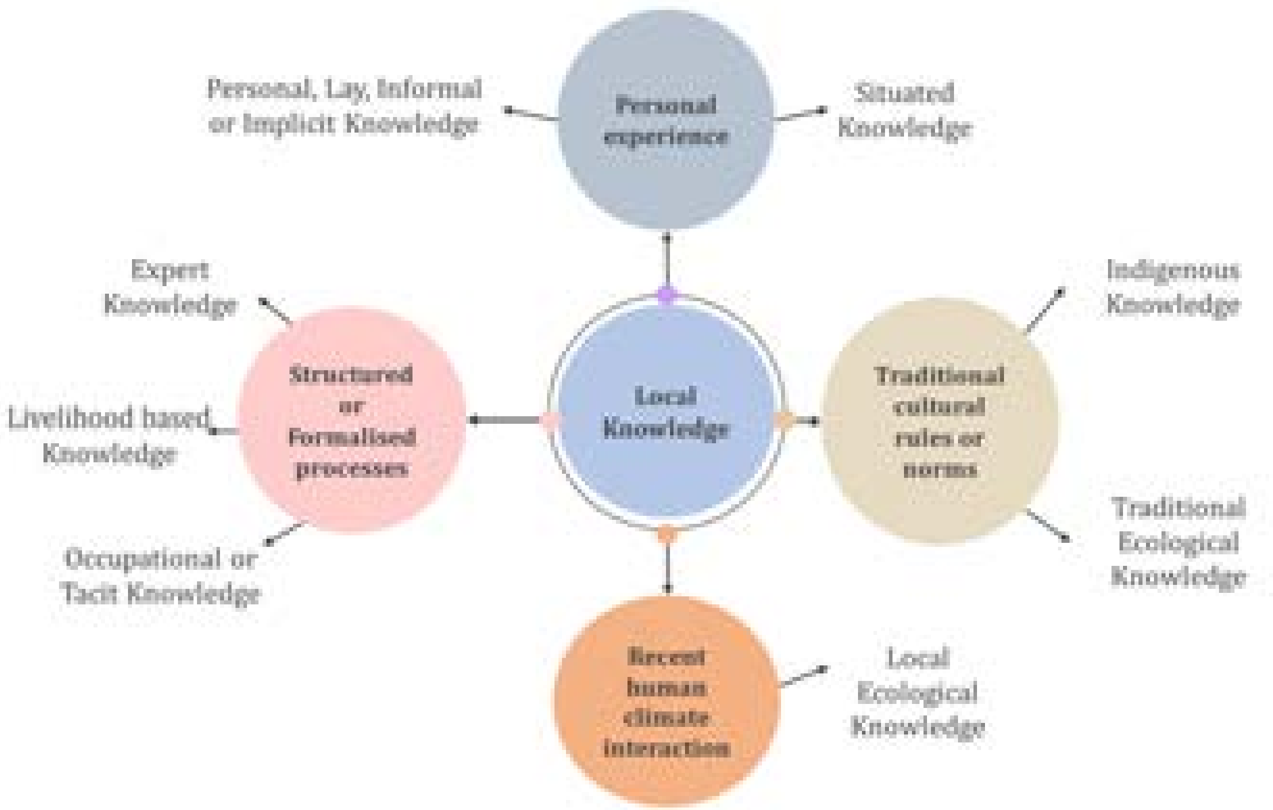

Figure 3 Different ways through which LK can be generated (based on Raymond et al. 2010)

2.2 Introduction to decision timelines

Research has suggested that LK plays a crucial role in livelihood decision-making, providing individuals and communities with an asset to "invest in the struggle for survival, to produce food, provide for shelter or achieve control of their own lives" (FAO, 2004). Decision timelines have been selected as the participatory tool to achieve this objective. Decision timelines, or seasonal calendars, are an effective tool for visualising and understanding the decision-making process by mapping out the various decisions that users take during the season (or seasons), and identifying the factors that influences those decisions. It allows participants to visualise changes and patterns over periods of time (for e.g., months, seasons, multiple years etc). Through visual representations, decision timelines offer an effective way to understand links between different indicators, stimulate discussions, plan for change, and monitor and evaluate the risk management strategies. Decision timelines are a tool to provide insight into the climatic and non-climatic factors that inform decisions. Timelines can also be used to map underlying knowledges and experiences. So far, decision timelines have been used primarily with agricultural users to introduce the topic of climate information and how it relates to key decisions that the farmers need to make (Haigh et al. 2015; Singh, Dorward, and Osbahr 2016). However, the concept of timelines can also be applied in other sectors, such as the tourism sector. In the agricultural sector, such as in the case of livelihoods of e.g. smallholder farmers, there is a large dependence on natural resources. In that case, seasonal calendars (Dorward et al., 2015) can help in discerning community perceptions on time-related variations in indicators such as weather patterns, time spent on labour and other activities, level of food security, nutrition, illness (in people, crops or livestock), cash availability, and production patterns and yield. In other sectors, such as the tourism sector, there may also be clear dependencies on seasonal and sub seasonal variations that can be visualised through decision timelines, such as, for example, tourists will often plan their activities according to the weather characteristics or socio-economic conditions.

In I-CISK, the decision timeline consists of three main building blocks: the **(1) weather and sectoral context**, the **(2) decision making process** and the **(3) coping and adaptation actions** (De Stefano et al. 2024).

The user for which we make the timeline can be a household and their livelihood activities or a MAP actor coming from sectors on which a LL focuses, such as the agriculture, tourism or water management sector. For example, the end user can be the humanitarian actor or subsistence farmer in the case of the Lesotho LL, hotel owners in the Greece LL or olive tree farmers in the Spain LL. The timeline can also be made from the perspective of an intermediary organization in the CS value chain; so, the service providers (e.g., regional Meteorological office) and service purveyor (e.g., agricultural extension worker). For now, to limit the scope of our study, the actors considered are primarily the end users of the CS, though in some of the LL we also address CS providers. The choice of the end user also immediately determines the sectoral context and process. If the end user is a subsistence farmer, the process is at the household level. If the end user is a hotel owner or an olive tree farmer, the process considered is at the business or organisational level, rather than the personal level.

We will use these three main building blocks in the characterization of the LK use in the LLs. Each of these will now be discussed one by one in the following sections.

2.2.1 Weather observations and experiences with climate change

Within this component we aim to capture how individuals or communities describe the (relevant) weather conditions in their local area over a selected time period. This time period may for example be the annual farming calendar, or a selected season. This can help in identifying seasonal patterns.

Additional to the weather observations over a relatively short selected time period (seasonal or yearly), subjects are also asked to share their observations or experience with long-term changes to these weather conditions as a potential consequence of climate change. This is related to their accumulated observations over multiple years. For example, people may observe that the onset and duration of the wet season shifts over the years significantly, beyond what can be explained by normal climate variability. Such shifts have been reported in the scientific literature through analysis of long-term climate data (Guo et al., 2022).

2.2.2 Sectoral activities and socioeconomic context

Next to the weather conditions, subjects (end users) are asked to plot the key activities that make up their livelihood or their sectoral activity. These are the key operational and tactical activities that are carried out across the time period. The intention is to have a month by month breakdown of key livelihood or organisational activities, and where these exist, establish links with the description of weather conditions.

Similarly, this can be done for the experience with climate change over longer time periods, though this is usually linked to more strategic activities, such as investing in long term adaptation measures.

Apart from the livelihood and sectoral activities, also the socio-economic context is important. Seasonal variations in market demand for livelihood and livestock produce or in the labour market are important to characterize as well.

What weather or climate related time scale is the most appropriate will differ per LL, the sectors involved in each LL, as well as between actors that we consider. We will give a few examples: In the case of farming and agriculture-based livelihoods, a 12 or 18-month decision timeline can be considered, while for tourism-related businesses or other types of businesses longer time scales commensurate with business development time scales may be chosen. In the case of urban dwellers, such as those represented in the Hungarian LL, a longer time scale (five years or decadal) may be more useful in understanding how lifestyles and decisions may have changed in response to heat stress (although one can also investigate how people react to heat stress on a day by day basis, e.g. in terms of adapting their work patterns).

Given the diversity of stakeholders and sectors, for most LLs it may be appropriate to identify two decision timelines: one short-term/annual decision timeline for decisions made at the seasonal scale, and one considering adaptation to long-term/decadal climate change projections. This can then also be done for different user groups, e.g. farmers versus non-farmers, or hotel owners versus tourists.

2.2.3 Strategic, operational and tactical decision making

The discussion on LK within CS literature occurs in tandem with, or as part of, a broader discussion on how to make CS more decision relevant, particularly supporting adaptation decision making. Previous research has described adaptation decision making as an interaction between roles, values, rules and knowledge (Muller et al., 2024). Recognising that climate information is rarely the only factor guiding decision making (Goddard 2017), through this deliverable we aim to understand the sense making and decision-making process of different stakeholders across the I-CISK LL and the role of LK within that process. We posit that local actors, communities or organizations rely on different types of LK (see Figure 1) gained through practice, experience and local context. We argue that, even in the absence of formal CS, individuals (CS end users) triangulate between their own understanding of the local environment, practical experience, contextual drivers and other sources of information (as part of the sense making process). This can also be applied to those taking decisions in organisations that are upstream in the climate services value chain such as CS providers and purveyors, as they too are influenced both by the complex factors that influence individual decision making, as well as the structure, mandate and culture of the organisations themselves (Siders and Pierce, 2021). This triangulation of information can inform communities' understanding of the local environment, risk appraisal, trigger decision making or influence the choice of adaptation strategy.

Hernández-Mora et al. (2023) uses the concept of adaptation decision space to characterize factors influencing adaptation decision making and consequently adoption of adaptation strategies (see Figure 2). We add to this characterisation by adding a “knowledge layer”, which is the filter through which these factors are interpreted and triangulated to trigger decision making. We term these triggers as “cues” (see section 2.5). In this deliverable, we aim to understand how these local knowledge-based cues are used within each of the I-CISK LLs to inform decision making.

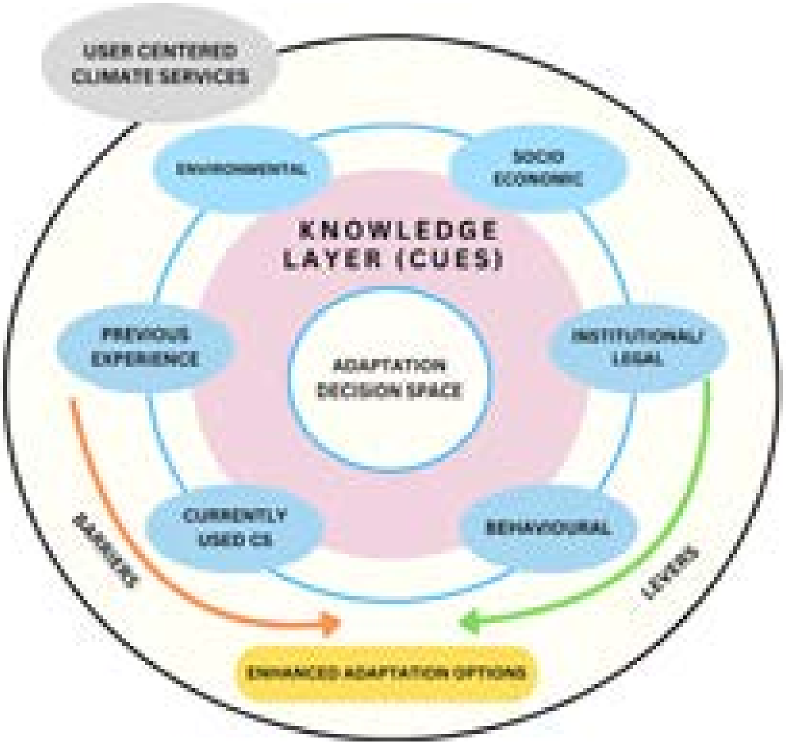

Figure 4 Adaptation decision space including the knowledge layer, adopted from D2.3 (Hernández-Mora et al. 2023) by adding the knowledge layer and environmental.

When talking about decision making, we distinguish between the different time scales across which these decisions are made, namely tactical (day to day), operational (short term or seasonal) and strategic (long term). Similar categorizations were initially developed to understand adaptation decision making within agriculture (Risbey et al. 1999). In this deliverable we extend this to consider other, non-farming livelihoods, for example, for resort managers in the tourism sector in the LL in Greece we distinguishing between tactical (e.g. tourism period) vs. strategic decisions (long term investments). This distinction allows us to unpack differences in LK use and triangulation across timescales. For instance, tactical decisions may rely upon weather related cues or other short-term cues while strategic decisions may be a result of longer-term trends.

Clearly, the sensemaking and decision-making process is a quite complicated process (Walle and Comes 2014). We simplify by focusing on two parts:

- The triangulation of information, in particular between LK and SK.
- The changes in the context (the external factors and overall risk) and how specific environmental and socio-economic cues (or risk accelerators) can be extracted at specific moments to trigger decisions.

Triangulation of information

Users will leverage the knowledges available to them to make decisions. This means that users triangulate the SK provided through a CS with their LK of their environment (the knowledge circle in Figure 2). This could include comparison of (seasonal) forecasts the CS provides with environmental or socio-economic cues observed by the user (Van den Homberg et al. (2022)). The process of triangulation will be largely location and user dependent. At an individual level, it may depend on several factors, including age, livelihood, gender and educational level. At an organisational level, it may depend on the years a business is already active in a certain location and on the sector (e.g. a generational farming business may have more LK of the environment than a recently established hotel chain). Possibly, it is also time dependent, whereby people or organisations triangulate differently depending on where they are in the season and whether it is shortly before or after a disaster or extreme weather event. For example, before an extreme weather event arrives, the triangulation can only be done using forecasts from SK or from early warning indicators that an end user observes, such as wind directions and the darkening of the clouds (Bucherie et al., 2022), or of a river signifying a flood might come (Sakic Trogrlic et al., 2019). However, despite these different dependencies, we hypothesize that there are overarching principles of triangulation that are generic and replicable from one area to another and that understanding these will be useful in the design of CS.

Changes in the context: risk accelerators and cues

Important in the design of the CS is to understand when the end user will go from a more general observing of the weather to the taking of action. Hereby we can also distinguish between a "normal" season where most sectoral or livelihood activities take place according to a yearly recurring pattern and a season where more extreme weather events take place. Also, changes in the socio-economic context can influence the normal activities; for example, changes in the market demand due to e.g. political or macro-economic impacts.

Any precursors or actual changes in the weather or socio-economic context can result in enhanced risks to the livelihood or sectoral activities. These risks can be purely weather-based, such as prolonged cold waves impacting the agricultural activities, or purely socio-economic, such as COVID-19 epidemic leading to markets being shut down. Often risks are also based on a combination of socio-economic and weather changes, where e.g. weather conditions can hamper access to markets, leading to less demand. End users will identify and characterize risk in order to understand the potential negative impact, such as loss of livestock or a diminished harvest. They will try to identify risk drivers or risk accelerators (Walle and Comes, 2014).

The role of cues is a key concept to link the different building blocks in the decision timeline and to go from the more general risk identification to an actionable indicator. Actors will decide to act if they consider there is enough evidence to sway a decision, and this evidence is provided through environmental and social cues. Environmental cues are environmental indicators that exhibit the hazard. Social cues relate to indicators present in the social environment of the person (Choo, 2009). How people and actors act on a cue depends on the information they receive, their coping capacity as well as their knowledge of the hazard (Choo, 2009; Parker et al., 2009). In some cases, the cue results from an index or variable being evaluated against a threshold. For example, in anticipatory action, humanitarian organizations will take early action if a threshold of an impact-based forecast is surpassed. Cues can be intertwined. An example of when environmental and economic cues are intertwined is where work on the land cannot take place due to flooding. This might mean that work has to take place in a shorter time window, leading to an increase in demand and labour availability and price. A proper understanding of the cues is essential for the development of a climate service that is usable and that will be used.

Better understanding existing social and environmental cues can help to co-create the CS in such a way that end users can make decisions more pre-emptively and faster. Also, CS can incorporate these cues to provide information that is more salient to the needs of the user and is perceived as more trustworthy. Thus, improving last mile access.

It is important to realise that environmental and social cues do not only occur in exceptional seasons, but also that these occur in normal seasons, leading to end users to take a specific action. However, in this case, these cues are ingrained in the normal way of working and the sectoral and livelihood activities can also be executed largely routine-based. In this paper we focus on those cues that lead to the taking of a coping or adaptation action. In other words, these are the cues associated with a departure from the normal circumstances and weather that when observed may lead to users taking such action.

2.2.4 Coping and adaptation actions

The coping and adaptation options can be, as explained in the section before, at the tactical (day to day), operational (short term or seasonal) and strategic (long term) level. The actions can also be at the livelihood (household level), the business (organizational level) or the policy making level. De Stefano et al. (2024) define coping and adaptation options as follows:

- Coping options: 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).
- 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.

3 Methods

3.1 Decision Timeline tool

A number of participatory methods have been used across literature to collect local knowledge and data. De Stefano et al. (2024) provides an overview of what these methods are and their relevance in gathering LK. While the ways in which LK adds value to individuals and communities are diverse and change depending on the context, in this data collection effort we will particularly focus on the use of decision timelines to elucidate LK associated with livelihood or sector-specific decision making. Decision timelines provide a structured framework to understand the sequence and timing of decisions within a community. By mapping out when and why certain decisions are made, we can gain insights into the contextual factors that influence these choices. These factors may vary from seasonal variations, cultural events, market fluctuations, and environmental changes. This temporal mapping is crucial for identifying patterns and trends that might not be apparent through other data collection methods, such as surveys or interviews.

We build the template for decision timeline and related interview questions based on the concepts discussed in chapter 2. As described in the previous chapter, the decision time-line consists of three main building blocks (see Figure 3a and b): the **(1) weather observations and sectoral activities**, the **(2) decision making process** and the **(3) coping and adaptation actions** (De Stefano et al. 2024).

3.1.1 Weather observations and experiences with climate change

In this first component of the timeline we aim to capture how individuals or communities describe the weather conditions in their local area over a selected time period. This time period may for example be the annual farming calendar, or a selected season, depending on what is relevant to the livelihood or business process of the community or sector for which the timeline is established. Through these seasonal patterns, weather events that are considered relevant as well as key periods of socio-economic importance to local communities and sectors are identified.

Additional to the weather observations over a relatively short selected time period (seasonal or annual), LLs are also asked to share their observations or experience with long-term changes to these weather conditions they have observed or perceived, potentially as a consequence of climate change. This is related to their accumulated observations over multiple years. For example, people may have observed that the onset and duration of the wet season has significantly shifted over the years, beyond what can be explained by normal climatic variability.

Aligning with the timeline of weather conditions, actors are then asked to plot key operational and tactical activities and/or operations that are carried out across the selected time period. The intention is to establish a month by month breakdown of key livelihood or organisational activities, and where appropriate establishing links with the description of weather conditions and/or the key periods of socio-economic importance. A similar exercise, mapping out activities against the weather and climate timeline can be done for the experience with the changing climate over longer time periods. However, as mentioned in Chapter 2, this is usually linked to more strategic activities, such as investing in long term adaptation measures

3.1.2 Decision making process

Based on the sectoral activities identified, participants are then asked to identify external factors in time that pose an enhanced risk (i.e. act as an accelerator of risk, or risk accelerator) to livelihood or organisational activities, which may lead to a departure from the normal (business as usual). These risks can be weather or climate related, but may also be based on other external factors (e.g., socio economic, institutional factors). Identification of these risks in time is useful in understanding from the user perspective the risks (climatic or non-climatic) that may impact on livelihood and sectoral activities and any seasonality associated with these risks.

As a part of the decision-making process, we also try to understand if participants have any way of pre-empting above mentioned risks based on their knowledge of the local weather and environmental conditions (environmental cues), through their knowledge of the socio-economic context (socio-economic cues), or through the use of (existing) climate services. We hypothesize that local communities continuously triangulate between different types of cues in their daily life.

3.1.3 Coping and adaptation strategies

Finally, related to the risk, in the last component of the decision time-line, participants are asked to identify coping and/or adaptation strategies that they adopt or consider adopting. These strategies can range from modifications to the planning of activities, or changes to investments in new infrastructure. Participants are also asked to identify knowledge or information sources that are used to inform the choice or implementation of these coping and adaptation strategies.

Figure 5 Components of the decision time-line

3.2 Developing decision timelines in each I-CISK Living Labs

Although the structure of the decision timeline established in each LL followed the template provided, the approach taken to the creation of the decision time-line itself (i.e. data collection) was not bound to a strict guideline. This was predominantly done because of the different context of each LL and how the MAPs in each are constituted. It is also important to consider that each LL is in a different phase of the co-creation process.

Note that in the development of the decision timelines, decision made considering both coping and adaptation strategies are considered. As the Living Lab in Budapest, Hungary focuses primarily on the adaptation space, this has not been included in this analysis, with the focus on the other six Living Labs. In these it should also be noted that though a representative sample of of livelihood types and sectors are considered, this is not necessarily exhaustive of all livelihoods and sectors present in each Living Lab.

4 Results: Characterisation of local knowledge across the Living Labs

In this chapter the results of developing the decision time lines in each of the LL are summarised. For each LL, the general context of the LL and the main stakeholders in each LL are briefly described. Decision timelines are established for selected main stakeholders in each of the LL. While the decision timelines developed for each of these follow a common structure, additional details where relevant have been included, and these may differ between LL.

For each of the decision timelines, a visual representation of the timeline is first presented, following by a short narrative on each of the three components;

I. Weather observations and sectoral activities. This forms the basis of the timeline, describing the “normal” weather patterns, or the aspects of the climate that are relevant to that stakeholder. The second part of the basis of the timeline outlines the current “normal” livelihood and business processes of the stakeholder. Climate related risks identified from the LK of stakeholders, focussing on climatic patterns and extremes that impact livelihood and business processes are included, as well as any relevant long-term changes and trends that are observed or perceived. Socio-economic risks that may also impact livelihood and business processes are also included.

II. The second component of the time line considers the decision-making processes of the stakeholder, including key decision points, and the environmental cues (which includes weather and climate) or the socio-economic cues that are recognised as relevant to the decisions made. These may be qualitative or observational cues, but may also consider observation of a indicator or variable crossing a defined threshold value. This section, where relevant also includes the current use of CS and how information is used and triangulated (of local and scientific knowledge)

III. The final component describes the coping and adaptation strategies recognised by stakeholders that can be taken in response to the environmental and/or socio-economic cues.

4.1 Living Lab in Crete, Greece

The main weather and climate related hazards faced by stakeholders in the Crete LL include heat waves, floods, wildfires and droughts. The stakeholders involved are from the tourism, transportation (ports and roads management), and water management sectors. These sectors are represented in the MAP by three organisations; the Greek National Tourism Organization (tourism sector), which is a public body; the Organization for the Development of Crete S.A. (transport, hydraulic/agriculture/water supply infrastructure) and the Municipal Port Fund of Rethimno (port management and related activities) are involved. The Regional Development Company of Crete SA. operates in the private sector, while the Greek National Tourism Organization operates in the non-governmental sector. The main end users of the CS identified in the I-CISK project include tourism enterprises, tourists, users from the water management and transportation enterprises. Decisions related to climate hazards are linked to water allocation in periods of droughts or significant water stress (i.e. summer, and in particular the end of summer period); wildfires and heatwaves for the planning of tourist activities and energy demand (due to higher usage of cooling systems); and tourism and transportation disruption related to flash floods, landslides and unfavourable wave conditions at ports.

The members of the Crete LL MAP are generally characterised by having a high educational background, with a 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. The ability of the different members to engage productively in the CS co-creation process therefore 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 their own past experience.

In the case of the Crete LL, the decision timeline was used as a tool to understand the decision-making process of the various stakeholders within the MAP. Decision timeline exercises were developed with the three main actors represented in the MAP, which for brevity we refer to here as Tourism Resort Managers, Water managers and Port Managers. With each of these a decision timeline was developed with the objective to identify information gaps and adaptation needs. Interviews were structured following an interview matrix. An example of the kind of information gathered during the exercise with one of the MAP members can be found in Appendix II. 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, heat waves, sea surges and sea level rise, and specific wind patterns.

4.1.1 Decision Timeline: Water managers

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Climate Characteristics	Winter (wet & mild)		Spring (transition)			Summer (hot & dry)			Autumn (transition)			
& Weather observations	Surface flow in rivers											
Sectoral activities			Allocation decision (public clients)						Allocation Decision revision (public clients)			
	Allocation decision (private clients)											
	Storage or release of water to the environment											
Climate related risks						Heat waves & extreme weather events						
	Meteorological Drought: lack of precipitation											
Socio-economic factors					Demand due to new or increased number of water users (e.g. tourism)							
								Demand due to extended tourism season / increased visitors				
Environmental cues	Past experience of precipitation patterns											
			Low Flows						Low flows			
Socio-economic cues					Changes in demand due to tourism							
	Demand from agriculture due to new investments											
	Available funding and tools											
	Long term strategies of the water management organisation											
CS & information sources	Operational early warning systems (short term) - cimate studies and projections (long term)											
Coping Strategies						Changing allocation of water resources based on priorities						
Adaptation Strateges				Investment in new reservoirs, change of water planning, using alternative water sources								

Figure 6 Decision timeline for water managers in the Crete LL

Figure 6 presents the decision timeline that was identified with water managers in the Crete LL. The timeline focuses on the decisions they take that are related to water allocation and distribution to public and private clients, as well as decisions on storage or distribution of excess water and longer-term investment decisions. 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 in climate information.

Water managers, as all stakeholders in the Crete LL, triangulate between different sources of information when taking decisions associated with key activities. The decisions water managers make on water allocation and distribution are influenced by factors such as water availability and information on expected demand. Technical information such as monitoring of low flows across crucial points in the year (Nov-Dec (wet period) and May-June (dry period)) and precipitation measurements (May - June, Sept - Oct) are used by water managers as environmental cues to decide regarding water allocation and distribution. This information is provided by monitoring stations and in combination with past experience, are used for seasonal and annual planning. For longer term information water managers rely on climate studies and projections of climate change as a way to inform strategic decisions. The water management organization (OAK) is a high-capacity organization 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. Alongside this, water managers also rely on their past experience and knowledge of annual precipitation patterns as well as socioeconomic cues such as demand changes due to tourism (May - Sept) to anticipate water availability.

The main climate-related risks identified by water managers are drought, water scarcity and floods (see Table 1). They address these risks through the implementation of a range of options, each with different associated costs and time horizons. Short-term challenges are addressed using 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.

Table 1 Characterization of the current LL adaptation decision space for Water Managers (Source: De Stefano et al. 2024)

Problem addressed	Type of measure	Information /knowledge used	Adaptation scale
Drought and water scarcity	Invest in new reservoirs	This is based on well-constructed studies that 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 judgement.	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
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
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

4.1.2 Decision Timeline: Tourism resort managers

Figure 7 Timeline for tourism resort managers in the Crete LL

Tourist resort managers expressed two very specific climatic challenges related to the management of their facilities. One is related to the annual needs of 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 is related to seasonal planning needs of outdoor activities offered to the customers. Extreme weather events such as heatwaves or summer heavy precipitation and/or floods hinder such outdoor activities.

For resort managers, planning of outdoor maintenance in the autumn months is a key activity often coinciding with periods of high winds and heavy precipitation. 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 for 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 has an important role. Port and resort managers both rely predominantly on their past experiences and forecast information on, for example, wind, storm surges and temperature to inform their actions.

Tourist resorts are also high-capacity actors that address climate challenges on a more operational basis, utilizing 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 2) 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 2 Characterization of the current LL adaptation decision space for Resort Managers (Source: De Stefano et al. 2024)

Problem addressed	Type of measure	Information /knowledge used	Adaptation scale
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
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

4.1.3 Decision Timeline: Port managers

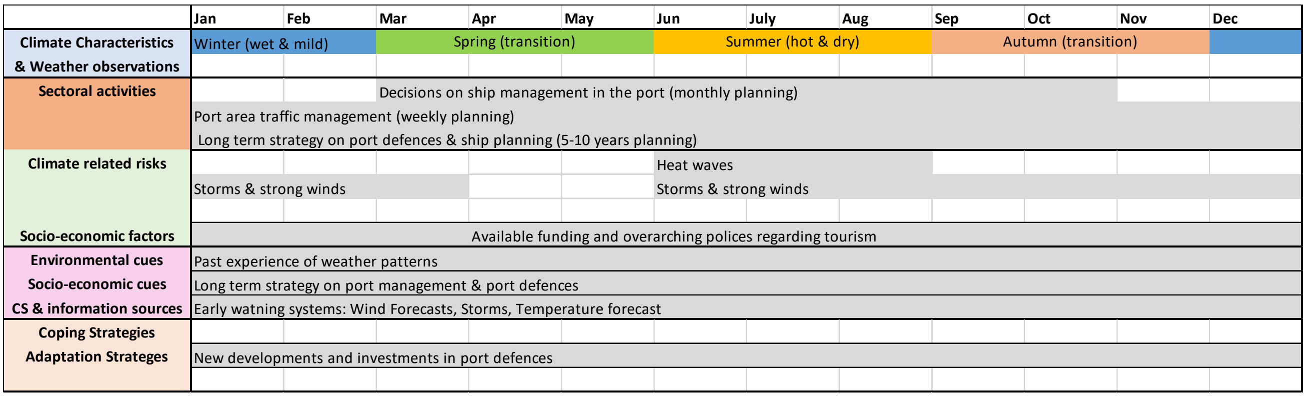

Figure 8 Decision timeline for port managers in the Crete LL

For port managers, the key activities represented on the timeline include decisions that are taken on a shorter-term time scale related to traffic management in the port, which is done on a weekly basis currently. Ship management in the port is another activity requiring port managers to plan on medium to longer term timescale (monthly to 5 - 10 years). Longer term planning (5 to 10 years) is also done for decisions related to port defences.

Climatic as well as non-climatic activities impact the activities of port managers, for example, ship management is impacted by wind patterns and speed, traffic management at the ports is impacted by storms and heat, while decisions related to port defences are impacted by availability of funding and overarching policies regarding tourism. In response to this port managers had identified the need to invest in seasonal and decadal forecasting services.

Table 3 Characterization of the current LL adaptation decision space for Resort Managers (Source: De Stefano et al. 2024)

Problem addressed	Type of measure	Information /knowledge used	Adaptation scale
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

4.2 Living Lab in Emilia-Romana, Italy

The Emilia-Romagna LL 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.

Local Knowledge (LK), as gathered from the Emilia-Romagna LL activities and stakeholder interactions, encompasses diverse understandings and practices related to weather and climate impacts. This knowledge spans from specific observations (particularly river discharge monitored from ARAPE gauging stations) of seasonal changes and weather patterns (forecast of meteorological variables from commonly used weather services and more specialized irrigation demand forest from ARPAE), to community and professional insights into water management and storage/distribution and usage practices and needs, to emergency protocols for withdrawals reduction during drought.

4.2.1 Decision Timeline: All stakeholders

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Climate Characteristics	Winter (wet & mild)		Spring (transition)			Summer (hot & dry)			Autumn (transition)			
& Weather observations	Low flows (groundwater/occasional rain)			High flow (snow-melt season)			Low Flows (recession)		High flows due to rainfall			
Sectoral activities												
Agriculture			Planting							Planting		
Agriculture						Harversting (Fruit early; wheat, corn and last grapes)						
Industry	All year activities. Food and Agricutlure industry follows agriculture seasonality. Manufacturing less influenced by weather and more by econimic factors											
Hydropower	Stable operation & maintnance											
Hydropower				High flows: Peak operations					High flows: increased operations			
Environment & bathing						Bathing linked to tourism/holiday season						
Climate related risks				Very high flows / floods								
						Low flows due to drought / low water availability						
Socio-economic factors						Increased demand due to increased use / consumption						
	Fluctuating market demands due to economic circumstances											
Environmental cues				Crossing of yellow & red alert thresholds								
	Long term changes in historical river discharge patterns											
CS & information sources	Monitoring of discharge and precipitation stations, early warning systems											
Coping Strategies				Activation of water withdrawal guidelines and conservation protocol								
				Storage in channels/use hydraulic nodes								
						Prioritize water users (demand re-allocation), emergency protocol, communication						
Adaptation Strateges	Infrastructural modifications in distribution networks and new storage solutions											

Figure 9 Decision timeline for all stakeholders in the Emilia-Romana Living Lab in Italy

Weather observations and sectoral activities

The decision timeline in the Emilia Romana LL was developed based on a synthesis of the interactions and inputs from the stakeholders in the MAP from the interactions over the first two years of the project. Rather than establish a separate timeline for each of the sectors involved, in this case a single timeline was developed to reflect the sectoral activities of the three main users; agriculture, industry, hydropower and the environment; and incorporating the water management challenges these actor face. These sectors are represented by members of the MAP (Regional Authority and Environment Agency, Irrigation Consortia, Multiutility Company and Private Hydropower Company) and inputs were collected during online workshops and a field visit. The feedback provided has been separated between suggestions oriented to coping and suggestions oriented to longer adaptation. One of the stakeholders (ARPAE) is a service provider, so their inputs reflect a particular view, as they do not take decisions on the needs for new CS but reflected more through the possible integration of the identified needs for CS in the current “public institutional offer of knowledge“ that they represent.

In the Emilia Romana LL, the only variable that is provided through the CS considered in I-CISK is river discharge. In terms of timescale of interest, we have two perspectives:

- sub season to seasonal forecasts (weeks to months), which are more of interest for coping and short-term management, to inform and help evolve the current coping strategies.
- the long term (climate projections) which go beyond the months included in the service and are more of interest to the Regional government to deal with water resources planning.

Stakeholders, including irrigation consortia, and regional agencies/authorities, private companies in the hydropower business and multi utility companies, contribute to a rich palette of local expertise, which informs decision-making and problem-solving at both the operational management (before and during drought) and planning (setting the rules to reach long-term sustainability goals). This collective wisdom is based mainly on experience and shared within the community during crucial moments, such as with the “Drought Observatory Table”, which is established during emergencies, or translated into drought emergency protocols to improve the coping measures for upcoming droughts. As an example, irrigation consortia anticipate shortages through increasing the storage of water in channels when the condition are expected to get worse, based on previous experience of similar events, and specific extraordinary regional authorisations. The multi utility company sends out warning letters to users when a stop of water provision is approaching. Direct experience from the past (e.g. the extreme drought in summer 2022) plays a crucial role in adapting to and coping with climate variability, as well as soliciting interest into new potential strategies supported by climate knowledge.

Decision Making Process

Decisions that the service that is developed in the I-CISK project is intended to support have been included in the timeline. These are related to the internal processes of the MAP stakeholders. The upper part of the timeline focuses on the past (and present) decision that are supported with actual information and knowledge. Long-term adaptation strategies in the Emilia-Romagna region involve infrastructural changes such as distribution network modifications and storage solutions, often backed by public funding and insights from R&D. This demonstrates an effort to innovate for sustainability. Short-term coping mechanisms are largely reactive, based on monitoring network data for immediate responses to climatic events, with efforts like the "drought observatory" going in the direction of collaborative decision-making. The gradual inclusion of climate projections in strategic planning (that is the long-term part of the strategy) is ongoing, but real-time data and historical patterns remain the primary basis for action, even when facing unprecedented challenges like the 2022 drought. Decision points for water withdrawal, storage, and emergency responses, align for the moment with observed more than forecasted climate conditions. The current approach is based on a traffic light style alert system, which is also the baseline for the evolution supported with CS.

Critical values that trigger decisions or strategic information to final water users have been outlined in the timeline, such as Minimum Environmental Flow or number of days the drought is going to last (with subsequent stop of withdrawals). We could separate between:

- Environmental/Climate/Weather Cues: Stakeholders rely on river discharge data, weather forecasts, and ARPAE's specialized irrigation demand forecasts for making short term decisions regarding water management. Seasonal changes and extreme weather events like droughts trigger emergency protocols and adjustments in water usage, when threshold values like minimum environmental flow are reached. ARPAE provides traffic light style maps covering wide areas that must be checked by users to start protocols.

- Social/Economic Cues: Economic pressures from final users, particularly agriculture and industry to maintain productivity and, on the opposite side, the need for water conservation, drive decisions on water allocation and usage. Legitimate user demands for water resources, particularly in times of scarcity, influence the collaborative decision-making processes, such as within the "drought observatory table," to balance between agricultural needs, industrial requirements, and environmental conservation.

In the Emilia Romana LL, stakeholders have had some experience in integrating LK and current adaptation strategies with new scientific knowledge on forecasts (partially in the case of irrigation consortia) and (mainly) current state monitoring data to inform water management decisions. This is the crossroad where the value of the new CS may be found. This triangulation evolved in comparing historical patterns, current environmental data, and future climate projections to boost and anticipate decision-making processes.

Coping and adaptation strategies

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 experience from past drought episodes overshadows, in general, the use of direct climate predictions or forecasts in shaping responses.

Currently, coping mechanisms are 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 diversions of water from rivers. Efforts to establish a "drought observatory table" for collaborative decision-making between water authorities and users often culminates in either halting or reducing withdrawals or, alternatively, granting exceptions. In practice, this means that during droughts the main choice is between prioritising 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 management master plans, signalling a shift towards incorporating these insights into strategic planning. Furthermore, during a drought, the authority is also responsible for implementing extraordinary measures, like authorizing through specific administrative procedures the creation of pre-emptive storages outside the usual withdrawals permissions.

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 use, albeit limited, by irrigation consortia of ARPAE supported water demand forecasts (rather than water availability) to pro-actively 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). Revised by the Regional Government every six years, incorporating discharge projections for selected climate scenarios for the 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 ARPAE 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 Table'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 every time.
- 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.

4.3 Living Lab in Qacha's Nek, Lesotho

The decision processes of the Lesotho LL end users are either the decisions that humanitarian actors take as part of the Early Action Protocol for drought and cold waves (periods of exceptionally cold weather during the cold season), or the decisions that poor and vulnerable communities have to take when exposed to drought or to cold waves. The decision timeline that was developed in the context of this research resulted from the interactions within the Technical Working Group in Lesotho, which was also responsible for preparing the Early Action Protocol for drought. Several of the MAP actors are also part of this Technical Working Group.

Data on local knowledge was collected through participatory methods. For Lesotho, data has been collected with a focus on understanding the use of LK in livelihood decision making at the end user level. Data was collected by Lesotho Red Cross using a team of five enumerators. Questionnaires were administered to households living in the district of Qacha's Nek, Lesotho. The data that was collected included socio-demographic characteristics of the households and livelihood information. A decision timeline integrated into the questionnaire was used to understand decisions made by farmers in Qacha's Nek throughout the year and the information that is used to make these decisions. Respondents were also invited to provide their perspective on observed past and perceived future changes in climate and the implications these changes have on livelihood activities in the area.

Based on the data collected, we developed two decision timelines; one for farmers and one for non-farmers, given that these are the two main groups of livelihoods in the community of Qacha's Nek.

4.3.1 Decision Timeline: Farmers and Non-Farmers

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Climate Characteristics	Warm & Wet Season			Cool & Dry Season						Warm & Wet Season		
& Weather observations	Rain with intermittent dry spells						Coldest Month			Rain with intermittent dry spells		
Livelihood activities	Weeding Crops (Maize & Sorghum)										Weeding	
					Harvesting (Maize & Sorghum)				Planting (Maize & Sorghum)			
								Land Preparation				
	Livestock breeding and selling							Wool Shearing				
Climate related risks				Cold Waves leading to reduced agricultural yield (2)								
	Dry spells (earlier and longer, more frequent)											
Socio-economic factors									Declining Foodstocks			
									High Crime Rates			
										Less Active Markets		
Environmental cues	Earlier onset and longer dry spells											
				Early arrival of frost & mist on top of mountains								
Socio-economic cues										Low Market demand		
CS & information sources		Radio		Social Media		Public Gatherings						
Coping Strategies	Use Shading nets											
	Water conservation & alternate water sources (lakes & GW)								Buy food on credit			
								More dificult to plough				
Adaptation Strateges					Buy drought tollerant seeds							
	Protection of wells and construction of dams											

Figure 10 Decision Timeline for Farmers in the Lesotho Living Lab

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Climate Characteristics	Warm & Wet Season			Cool & Dry Season						Warm & Wet Season		
& Weather observations	Rain with intermittent dry spells						Coldest Month			Rain with intermittent dry spells		
Livelihood activities					Brewing & Selling Firewood							
					Stokvel (save every month & buy e.g. groceries in large quantities at the end of the year)							
Climate related risks				Cold Waves - making it more difficult to get firewood								
Socio-economic factors									Declining Foodstocks			
									High Crime Rates			
										Less Active Markets		
Environmental cues	Earlier onset and longer dry spells											
				Early arrival of frost & mist on top of mountains								
Socio-economic cues										Low Market demand		
CS & information sources				Radio		Social Media						
Coping Strategies						Use stokvel to buy food for the family						
										Doing piece jobs (casual labour)		

Figure 11 Decision Timeline for Non-Farmers in the Lesotho Living Lab

Decision timelines for farmers and non-farmers are shown in Figure 10 and Figure 11 respectively. In each of the decision time lines developed, the top row shows the weather forecast and weather observation data that is used in decision making. The second row shows the livelihood activities across the season, which for farmers includes the farming season, such as the lean season and the green to dry harvesting season. The third row explains the decision-making process. The first decision is when the pre-activation trigger is reached. This is the case when the Lesotho Meteorological Services issue the seasonal outlook in September, with the trigger being below normal rainfall. The second trigger is reached in case that the October, November, December (OND) rainfall is below normal and the Vulnerability Assessment Analysis report (by the Lesotho Vulnerability Assessment Committee) -issued in January- projects that 20% of the population will be in drought-driven IPC Phase 3 and 4 for the next six months. IPC phases are an indicator of the level of food security, where IPC Phase 3 is defined as the Crisis Level, while IPC Phase 4 is defined as the Emergency level.

Weather observations and sectoral activities

Throughout the year, various livestock and farming activities are undertaken by farmers. The farming season begins in August, following the cold season, with land preparation as the primary focus. Planting starts in September and continues until December. As crops begin to grow, weeding becomes the main activity, lasting until April. The harvest period then runs from May to July. For livestock farmers, the breeding and selling of livestock typically occur between October and January. The income from livestock sales is reinvested into agricultural production and used to purchase food for household consumption while crops are still being planted.

Non-farmers engage in activities such as brewing alcohol, fetching and selling firewood, and participating in an informal savings pool called stokvel, which is redistributed at the end of each year.

Both farmers and non-farmers perceive significant weather variability throughout the year in Qacha's Nek. Typically, the region experiences rainfall and high temperatures at the beginning and end of the year. The cold season traditionally spans from April to July, but in recent years, households have observed that the cold period now extends into September. Strong winds are a constant throughout the year, with particularly intense gusts occurring between August and November. This increasing weather variability, including extreme weather events, has adversely affected agricultural production. For instance, farmers have reported more frequent outbreaks of livestock diseases and, in some cases, livestock deaths due to extreme heat. Additionally, prolonged cold waves have led to a reduction in agricultural yield.

Decision making process

A number of factors affect the timing of the key livelihood activities for both farmers and non-farmers. For example, for farmers in Qacha's Nek, changes in weather such as prolonged cold waves impact the ability to carry out certain activities such as ploughing to prepare the land for cultivation. Other factors that affect the timing of activities include low markets for livestock and crop sale which in turn contribute towards low income. Low rainfall, which results in water shortages for both livestock and crop production, and a decline in food stock which typically occurs between September and November which is the planting period, also affect the timing of activities.

For non-farmers engaged in activities such as alcohol brewing, extended periods of cold waves affect their ability to brew since it is difficult for them to fetch firewood during this period.

Farmers and non-farmers rely on both environmental and social cues to anticipate dry spells or changes in rainfall patterns. For instance, they interpret frequent mist on top of mountaintops and along rivers as a precursor to colder periods. Farmers also observe dry wetlands to gauge an onset or the intensity of an ongoing dry spell. Observations of the moon are also used to predict weather changes: a clear, bright moon suggests fair weather, while a hazy or ringed moon indicates moisture in the air, often preceding rain. In addition to this, observing the halo around the moon which is caused by moonlight refracting through ice crystals in the upper atmosphere also signifies imminent rain or snow.

Aside from the environmental and social cues, households access climate information via the radio, phone messages and social media. This information, including seasonal outlooks informs decisions such as choosing planting times, selecting weather-resistant seeds, implementing water conservation measures and planning rotational grazing schedules. These practices highlight the blend of traditional knowledge and modern forecasting methods that farmers utilize to inform livelihood decision making.

Coping and adaptation strategies

In response to frequent weather changes and prolonged extreme conditions, farmers have adopted various coping and adaptation strategies to maintain their agricultural productivity. These strategies include protecting wells to secure water sources, rationing water to extend its availability, and purchasing drought-tolerant seeds to ensure crops can withstand dry spells. During periods of food stock decline, households often buy food on credit, deferring payment until they have the means to settle the debt, or they use funds from communal savings schemes (stokvels) to purchase food. Additionally, when water shortages occur due to drought, farmers turn to alternative sources such as groundwater and lakes to provide drinking water for their livestock. These measures highlight the resilience and resourcefulness of farmers in the face of challenging environmental conditions.

4.4 Rijnland Living Lab, the Netherlands

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

In the Netherlands LL (Rijnland), user needs are centred around water resource management. Surface water is highly controlled in Rijnland and is used for both irrigation and drainage. Drought has been identified as the key focus of the LL under I-CISK, as its impact on surface water availability affects agriculture, water quality (salinity) and water tourism/recreation in the region. The ambition of the LL is to influence public and organisational preparedness and adaptation strategies to drought at the sub-seasonal to climate-change timescales. User needs for a CS to support this include longer forecast lead times (sub-seasonal, seasonal and climate projection) and strengthening stakeholder engagement/communication.

In the Rijnland LL, the information that has been used to develop the decision timeline has been gathered in several meetings and workshops with the MAP, focusing on current drought measures, current information on hydro-climatic impacts, and potential drought adaptation actions. In a next phase, the decision timelines were then refined and complemented where required with information through one-to-one discussions with MAP members, in combination with feedback meetings on the prototype of the climate service under development within the I-CISK project individual.

4.4.1 Decision Timeline: Rijnland Regional Water Authority

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Climate Characteristics & Weather observations	Winter (mild & wet)		Spring			Summer (mild & humid)			Autumn (wet & windy)			
				Evaporative demand exceeds precipitation, seasonally low flows								
Sectoral activities			Prepare Water System for Drought								Evaluation	
			Ensuring availability of freshwater in Rijnland system to meet needs (agriculture)									
				Flushing water system to keep salinity levels low								
				Providing information bulletins to users (agriculture, recreational shipping)								
Climate related risks				Reduced freswater availability in Rhine, high salinity at main intake at Gouda								
				High evaporative demand (high temperatures) and low precipitation								
Environmental cues				Discharge in the River Rhine at Lobith below threshold (freshwater availability) *								
				Accumulated precipitation deficit above threshold (potential evaporation - precipitation) **								
				Changing discharge regime of the Rhine (longer and more extreme low flows)								
				Increasing temperatures and reduced summer precipitation, rising sea levels								
Socio-economic cues												
Coping Strategies			Prepare Water System for Drought									
						Inspection of embankments						
					Use alternative route for freshwater intake							
					Reduce water-use in agriculture: irrigation bans							
					Avoid saline intrustion by reducing / stopping lock movement							
Adaptation Strateges				Increasing storage of freshwater in the Rijnland area								

Notes: Coping measures are enacted when the accumulated precipitation deficit exceeds 150mm, and/or when the discharge in the Rhine at the gauging station at Lobith is lower than a defined thresholds, which varies per month (April: 1000 m3/s; May: 1400 m3/s; June: 1300 m3/s; July: 1200 m3/s; August: 1100 m3/s; September: 1000 m3/s)

Figure 12 Decision Timeline Rijnland Living Lab

Climate Characteristics, weather observations and sectoral activities

Figure 12 shows the decision timeline that was established for the Rijnland water authority. Note that this timeline has been established for the activities of the water authority that are related to the management of freshwater availability. The water authority has several other tasks and activities related to the management of water resources, which are not considered here. From the decision timeline, it can be seen that decisions on the implementation of coping strategies in case of an (imminent) drought start in March and then concentrate on the first summer season months April through to May, with weekly re-evaluation of actions to be taken or (dis)continued.

Drought coping strategies that have been implemented, in years that these were required, are generally discontinued at the end of the summer season, typically in the months of August and September. These are largely operational drought impact mitigation measures. Around November there is an evaluation meeting by the drought- emergency management team of the water authority, including discussion on potential drought and action scenarios for the next years.

Decision making process

The water authority intensively uses monitored and predicted hydro-climatic information with an up to two-week prediction lead time to support the decisions for taking coping measures, while information from climate scenarios may be used to support investment decisions on long-term drought risk management (adaptation). Several observed data sources and derived indicators are used. This includes river discharge in the Rhine, accumulated precipitation deficit, and the Standardised Precipitation Index (SPI). A two-week outlook of precipitation, temperature and discharge is also used, and both these and the observed data are consulted. There is also reliance on local (expert) knowledge to predict drought, though in the holiday season it is reported that those with this expertise may not always be available. Information that the water authority feel they lack, includes an outlook with longer lead time, an earlier start of monitoring of precipitation deficit (this now starts on April 1st), and information on the water demand from crops.

In the discussions with the water authority, several concerns were identified. Before the start of the drier season (February-March), groundwater levels may be high, which could lead to an increased risk of flooding in case of a critical rainfall event. There is also uncertainty around the taking of the decision to start the taking in of water through alternative routes, which are used when the main intake of freshwater at the city of Gouda becomes too saline as a result of low flows in the Rhine, which results in an enhanced incursion of salt water from the North Sea. The alternate route requires the water authority to liaise with neighbouring authorities, and if it turns out that if this measure was not required (in retrospect), then that could lead to a loss of trust. The same uncertainty also holds when deciding when to stop the measure. If the end of the summer is marked by intermittent rain then the decision is difficult. Also, once stopped it is not easy to restart the measure.

The agricultural sector intensively uses monitored and short-term predictions with up to a week lead time, and strongly relies 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 such as reduced locking, or locking bans. Part of the reason seems to be a lack of awareness of the hydro-climatic predictions that are being used by the water authority. Long term drought risk information with climate projections have also not yet been considered by this sector.

Coping and adaptation strategies

Measures taken in the past in the Rijnland LL to manage drought risks, include both operational drought event management (coping), and, to a limited extent, long-term strategic drought risk management (adaptation). Operationally, during an imminent or ongoing drought, the water management authority and the agricultural sector have taken various coping measures. The water recreation sector does not seem have taken mitigation actions during 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:

- 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.

4.5 Alazani-Iori Living Lab, Georgia

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 and groups representing the interests of 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. Preliminary insights from the data collection process conducted in August 2023 and March 2024 are presented below. The decision timelines presented here (Figure 13) represents operations related to winemaking, wheat farming and Georgian Amelioration (irrigation provider).

4.5.1 Decision Timeline: Wine Makers

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Climate Characteristics & Weather observations	Winter (cool & mild)		Spring (transition)			Summer (hot & humid)			Autumn (transition)			
	Rain with intermittent dry spells					High Temperatures & Low precipitation				Rain with intermittent dry spells		
Sectoral activities	Trimming and Pruning Vines											
					Pesticide Operations							
									Harvest			
											Wine Production	
Climate related risks	Frost & excessive precipitation											
						Water shortages & high temperatures						
						Hail & intense precipitation						
									Too much precipitation			
Socio-economic factors	Availability of human resource (labour)								Availability of human resource (labour) & machinery			
Environmental cues	Movement of the clouds (direction of movement as a precursor of weather conditions)											
Socio-economic cues	Consultation with other farmers & farmer associations											
									Demand from wine companies			
CS & information sources	Google weather, yr.no (relying on weekly forecasts) and various websites offering farming advice											
Coping Strategies	Delay trimming and tying up of vines											
						Use water from irrigation or wells						
Adaptation Strateges				Invest in drip irrigation systems								
				Combine wine making with agro-toursim								

Figure 13 Decision timeline for winemaking in the Alazani-Iori Living Lab

Climate Characteristics, weather observations and sectoral activities

The key activities mapped here were based on the input received from winemakers interviewed in the Alazani-Iori LL. The key activities associated with winemaking include - pruning and trimming of vines (Jan - April), pesticide operations (May - Aug), harvest (Sep - Oct) and wine production (Nov - Dec). A detailed decision timeline is presented in Figure 13 and discussed in detail below.

Decision making processes and cues

Winemakers in the Alazani-Iori basin rely on local weather conditions to plan their activities. All farmers interviewed mentioned the late arrival of winter and frosts in early spring ("Spring freeze") impacting their pruning activities. Additionally, depending on the size of the vineyard the timing of operations is also determined by the availability of labour. Winemakers also closely monitor temperature especially during late spring and summer. High precipitation combined with high temperatures pose a severe threat to the vineyards. Lack of water, particularly during droughts, typically happen around June – August. However, vineyards can typically withstand water stressed conditions. Winemakers also rely on information and advice from farmers' associations or their own social network to decide on pesticide operations. Winemakers mentioned sharing information among their peers about the appearance of pests or fungus and treatments related to the same. Finally, winemakers reported changes in the harvest period, the harvest period moving up to a month earlier (from Sep-Oct to late August). For farmers supplying grapes to commercial winemakers, there is pressure to delay the harvest in order to have high sugar content, however, this delay tends to make the vineyards more susceptible to damage by hail, which typically happens at the end of summer - autumn period. Winemakers reported using several web-based applications to obtain information on weather conditions. This reliance on CS was limited to planning day-to-day tactical operations. For longer-term planning farmers relied on their own practical experience.

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 comes to on-farm management strategies such as sowing and planting dates, sharing information on mildew appearance etc.

Coping and adaptation strategies

In terms of coping and adaptation strategies, Georgian winemakers tend to rely on varying the timing of their farming actions, for example delaying pruning till after the spring freeze or harvesting wine early in an effort to avoid the period in which hail storms are most frequent. For farmers with access to irrigation channels, paying for irrigation in case of precipitation deficit during the growing season has always been 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. Beyond these, many farmers also mentioned 'doing nothing and accepting losses' as a response to climate related stressors.

Long-term adaptation strategies reported by farmers included investing in infrastructure measures such as drip irrigation, digging wells to compensate for the lack of water or investing in hail nets to protect the vineyards. 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 agro-tourism (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).

4.5.2 Decision Timeline: Wheat Farmers

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Climate Characteristics & Weather observations	Winter (cool & mild)			Spring (transition)			Summer (hot & humid)			Autumn (transition)		
	Rain with intermittent dry spells					High Temperatures & Low precipitation				Rain with intermittent dry spells		
Sectoral activities									Land Prep.			
										Sowing (winter wheat)		
	Pesticice Operations											
						Harvest (winter wheat)						
Climate related risks									Lacking/delayed autumn rains			
				Spring Frost								
						Hail & intense precipitation						
						Very high temperatures						
Socio-economic factors					Pests and Rodents				Pests and Rodents			
				High cost of inputs (seeds, pesticides, water, machinery and labour)								
						Lack of resources (delay harvest)						
Environmental cues	Movement of the clouds (direction of movement as a precursor of weather conditions)											
Socio-economic cues	Consultation with other farmers & farmer associations											
						Availabiliy of labour & machinery						
									Expected price on local markets			
CS & information sources	Google weather, yr.no (relying on weekly forecasts) and various websites offering farming advice											
Coping Strategies									Deeper tilling			
										Delayed sowing		
	Increased use of pesticides											
Adaptation Strateges				Investment in short cycle wheat (harvest in May to avoid hail)								

Figure 14 Decision Timeline for Wheat Farming in the Alazani-Iori Living Lab.

Climate Characteristics, weather observations and sectoral activities

Farmers involved in wheat farming in the Alazani-Iori basin were also consulted. The decision timeline (Figure 14) presented here elaborates the activities and decision-making process of farmers growing winter wheat. The key activities of wheat farmers includes the preparation of the land and sowing (Sep – late Nov), pesticide treatments throughout the growing phase of the wheat and harvest in the summer (Jun – Jul).

Decision making processes and cues

Winter wheat farmers in the Alazani-Iori basin rely on autumn rains to inform their land preparation activities and sowing strategy. Farmers wait for the cessation of the autumn rains to begin sowing so as to prevent any damage by fungi or pests. Farmers have mentioned the unpredictable nature of these rains, remarking that autumn rains are either delayed and lacking, or are too heavy. Combined with warmer temperatures this can lead to infestation by pests or rodents. During the growing cycle of the wheat, farmer perform several tactical operations include using pesticides to manage the crop. Farmers have reported that the delayed arrival of winter and spring frost are detrimental as it destroys the young plants that resume growth in early spring (following a vegetative phase during winter). Wheat farmers in the Kakheti region typically harvest in June – July. The timing of the harvest depends largely on whether farmers have sufficient human resources and required machinery for harvest. Many farmers in the region do not own their own labour or machinery, and as such rely on being able to rent these resources. Farmers have reported that increased demand can put pressure on the prices and availability of these resources, thereby impacting farmer decisions. Wheat harvest are also extremely vulnerable to hail and extreme rainfall. Occurrence of the latter during the summer months can lead to infestation by pests and rodents, and create flood-like conditions that makes operating machinery extremely difficult.

In terms of environmental cues wheat farmers rely on their weather observations, particularly those pertaining to the movement of clouds to plan their day to day activities. Generally, when the clouds move from a south-easterly to a north-westerly direction then this is associated with dry conditions. Farmers also reported using weather applications on their smart-phones to inform themselves about weather conditions to plan their tactical operations. Farmers also relied on their own networks as well as farmer associations gain advice and to decide on their operations. Lastly, the choice of growing wheat over another crop (operational decision) depends upon the price offered in the local markets. Georgian wheat farmers mentioned the low economic productivity of wheat caused by the high cost of inputs, low yields per hectare and cheaper varieties of imported wheat available on the market. External factors such as global affairs and subsequent (national) policy shifts can also impact farming decisions. For e.g., in 2022 the Russian invasion of Ukraine led to a grain crisis, which benefited Georgian farmers as their wheat could fetch a higher price on the market. This led to many Georgian farmers choosing to grow wheat over other crops.

Coping and adaptation strategies

Farmers mentioned using several coping strategies to manage climate related and non-climate related risks. In case of drought conditions farmers reported using deeper tilling strategies to ensure enough soil moisture. Farmers also reported delaying sowing to December as a way to cope with too much precipitation in Autumn and/or warm temperatures. Farmers also reported increasing the frequency of pesticide application several-fold to manage the threat from pests and rodents.

In terms of adaptation strategies, only a couple of wheat farmers mentioned switching to short-cycle wheat varieties, which can be harvested in May as a way to avoid hail damage (Jun – Jul). Most farmers diversified from wheat to include other crops that provided better returns.

4.5.3 Decision Timeline: Georgia Amelioration

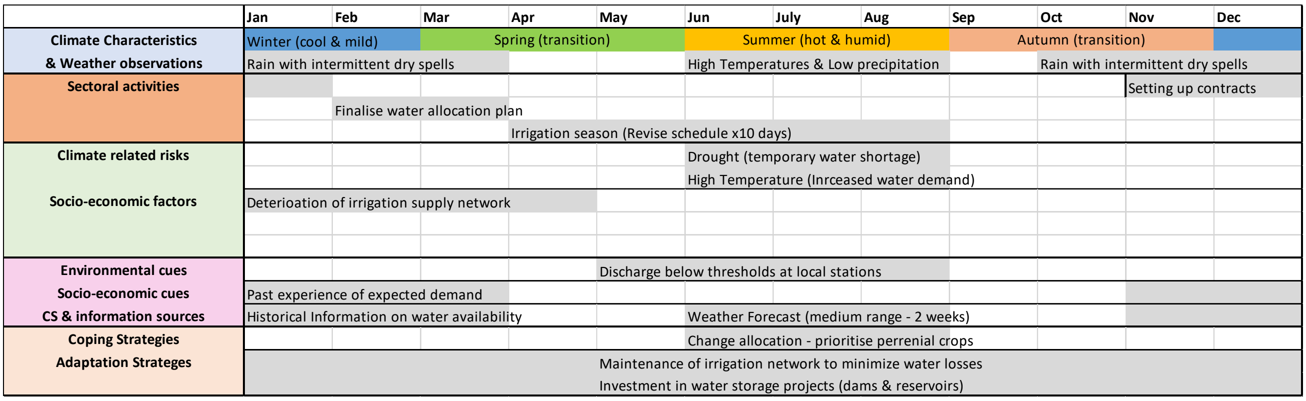

Figure 15 Decision timeline for Georgia Amelioration in the Alazani-Iori Living Lab

Climate Characteristics, weather observations and sectoral activities

A decision timeline was also created based on inputs from Georgian Amelioration, an agency falling under the Ministry of Agriculture and responsible for managing irrigation infrastructure and supplying water for irrigation across the country. In contrast to the winemakers and the wheat farmers these are consider as service purveyors. The provision of irrigation is managed through a contract system, whereby, Georgian Amelioration, based on requests from farmers, sets up contracts for the coming irrigation season and a water allocation plan for the year. During the season this irrigation schedule is revised every 10 days in response to the actual conditions.

Decision making processes and cues

As mentioned above, Georgian Amelioration provides irrigation services through a contract-based system. These contracts are set up based on the number of intended beneficiaries, which includes farmers who apply for irrigation services from Nov – Feb. The final water allocation plan is informed by this demand as well as historical information on water availability and demand. During the season, Georgian Amelioration relies on weather forecasts (up to 2-weeks) as well as real-time information from the local stations. Through this they determine the expected availability of water to revise the irrigation schedule every 10 days. During discussions with Georgia Amelioration they indicated that information on the expected cumulative volume of available water in the river with a lead time of 1-month would greatly aid in their operations. This need is strengthened by a change in the water allocation policy. In the old policy, farmers would be charged based on the contracts that were made before the start of season, irrespective of the water being delivered. In the new policy there is a shift towards payments for water actually delivered, thus posing additional importance to the forecast of weather conditions and accumulated streamflow.

Coping and adaptation strategies

Current practice followed by Georgian Amelioration dictates that in the event of a drought, as a coping measure, water is supplied on a priority basis, where perennial crops (like vineyards, walnuts etc) are prioritised over seasonal crops (like wheat, maize etc). In terms of adaptation strategies, Georgian Amelioration is also investing in the renovation, expansion and maintenance of the irrigation channels in order to avoid water losses. Furthermore, Georgian Amelioration is also investing in infrastructure such as reservoirs to increase the resilience of the system.

4.6 Los Pedroches Living Lab, Spain

The Andalucía MAP is composed of water managers, managers of natural areas, agricultural and forestry research and outreach organisations, environmental information purveyors (REDIAM), farming cooperatives, a hunters' association, and a rural development organisation. Together they have a broad representation of the agricultural, animal husbandry and forestry sectors in the Los Pedroches region. In 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. This drought was alleviated by a particularly rainy spring in 2024. As a result of this, the information collected from stakeholders often refers to actions that have been carried out to manage the ongoing drought.

The timeline exercise was developed in six focus groups that were conducted with olive growers, dairy farmers and dehesa[1] livestock farmers, as well as technical staff from the OLIPE olive growers cooperative and from the COVAP livestock (both dairy and dehesa) farmers' cooperative. The discussions helped the LL research team better understand the decision-making process at different geographical scales, the adaptation options being used and considered, and the climate information that could help improve adaptation decisions. The work in the focus groups had several benefits for the work of the Andalucía LL:

- Validate and help adjust the scale - temporal and spatial - of the CS under development to the needs of the end-users.
- Improve understanding of the decision-making process and the potential adaptation pathways available for different actors in the LL acting at different scales - farm level and cooperative level.
- Enhance the understanding of the users regarding the way climate information can be used to inform management decisions at the farm level.

[1] The d*ehesa* is an agropastoral system unique to the Iberian Peninsula where oak trees, primarily holm oaks, native grasses and free-range livestock, primarily Iberian black pigs, sheep and cows, interact under the management of farmers.

4.6.1 Decision Timeline: Olive Growers

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Climate Characteristics & Weather observations	Winter (wet & mild)		Spring (transition)			Summer (hot & dry)			Autumn (transition)			
Sectoral activities											Harvest	
	Pruning (Felling)											
			Conventional Fertilisation									
									Organic Fertilisation			
				Conventional Fumigation						Fumigation		
Phenological Events	Hibernation						Hibernation					
					Flowering				Fruit Development/Maturation			
											"Veraison"	
Climate related risks			Too low rainfall						Too low rainfall			
			Frosts									
					Rain (1)						High rainfall	
			Heat Waves or "warm spells" (2)									
Socio-economic factors											Previous year's harvest	
Environmental cues	End of frost period										"Veraison"	
			Temperatures below 5°C or above 30°C									
			Low rainfall < 200 mm						Low rainfall < 200 mm			
Socio-economic cues												
CS & information sources	Medium range forecasts (rainfall and temperature), 15 days lead time provided by AEMET. Online weather data (tiempo.es), limited use of seasonal forecasts											
Coping Strategies			Change timing of fertilisation						Change timing of fertilisation			
									Mix Organic & chemical fertilisation			
Adaptation Strateges	Erosion reduction: Type of ploughing, terracing, tillage practices											

Figure 16 Decision Timeline for Oliver growers in the Los Pedroches Living Lab

Climate Characteristics, weather observations and sectoral activities

Activities on the decision timeline developed for olive growers (Figure 16) were mapped based on the inputs from olive growers belonging to the OLIPE cooperative. The cooperative brings together olive growers primarily from the Sierra de Córdoba (mountain) and also some from the plains. For 35 years, the cooperative's production has consisted of 70% organic olives, with the remaining 30% being conventional. Depending on the type of crop (organic or not) and the location of the farms (in the plains of the region or in the mountains), there are different needs and work schedules. In the case of farms on the plains, treatments are typically delayed by up to one month compared to those in the mountains.

The on-farm activities of olive growers include: year-round fertilization, harvest (Nov-Dec-Jan) and pruning (Jan-Feb-Mar; post-harvest). The type of fertilization applied depends on the timing: for instance, in Sep-Oct organic fertilization is carried for which rains are essential for the organic matter to decompose and the nutrients to infiltrate. In addition, because the roots are close to the ground (about 30-40 cm deep), organic matter is essential to retain moisture and protect the tree from frost. In conventional crops, chemical fertilizers are also used, and are applied in autumn, winter or spring, depending on the compound. For chemical fertilizers, the need for rainfall is more flexible. For this reason, during years of drought, fertilization with organic matter is not carried out because if it does not rain it does not decompose, but chemical fertilizers do. Therefore, the olive growers require information on cumulative and distributed autumn precipitation to inform actions related to fertilization. Harvesting normally begins during or after veraison (Nov/Dec) and is usually completed by January. Veraison is a term used to describe when the tree has green, red and black olives. The optimum for harvesting is that there should be ⅓ of red, ⅓ green and ⅓ black olives. Pruning (felling) is always carried out after harvesting (from January to March).

Decision making processes and cues

Oliver growers use their knowledge of the olive grove to identify critical moments in the phenological cycle and plan their actions accordingly. For example, if it rains when the olive tree is flowering, it will lose its flowers. It should also not rain during May-June. The ideal temperature for flowering is 20°C, while temperatures above

30°C in May-June are detrimental. Fruit development and ripening takes place in September, with Veraison taking place from November to January. Harvesting takes place in December. This timetable is delayed if the trees are older, while climate change induces earlier ripening, e.g. fruit ripens earlier. The olive tree has two periods of dormancy, one in summer and one in winter, coinciding with the hottest and coldest periods respectively. Rain is important when the tree comes out of dormancy ("like a coffee in the morning"). Water stress on the tree has a negative effect on the fruit. Normal rainfall is 350-400 mm per year on average, although there is great variability between different places in the region. 500 mm would be a good year, with 200 mm in autumn and another 200 mm in spring. However, rainfall amounts also vary across the region. In Hinojosa 350 mm per year is normal, while in Cardeña this would be 800 mm. Rainfall is useful for olive production in September-October and February-March-April.

For fertilization (frequency and quantity), the economic criterion is fundamental and it is not necessary to fertilize every year, as fertilization is based on the previous year's harvest. Olive growers report that it helps the olive tree to recover the energy lost during the previous year's harvest. To obtain a medium production, a rainfall amount of about 300 mm per year is sufficient. The precise time of harvest depends on the ripeness of the olive and rainfall from September onward. A drop of temperatures to 7ºC in November is ideal for veraison. It is also considered better to have moderate harvests to avoid "vecería", a term that refers to when the olive tree produces too much, then in the following year it will not produce well. The farmer could lose the benefits of a good hydrological year because the trees are not strong enough to produce a good harvest the next year. The autumn rains have to fall between September-October and then rain in February-March and April. If it rains more in November, the olives are fattened with water, not oil. Ideally, 200 l/m2 should fall in autumn and 200 in spring. In the highlands it rains more. In the past, the ideal rainfall for a good year was 500 l/m2 (no longer the case). For budding (March-April) it is very negative if it is below 5°C or above 30°C in March-April. High temperatures in this season cause fungus that affects the flowers. The ideal is between 20-22ºC.

Frost is a key factor determining the timing of pruning post-harvest. In areas with frost, pruning is done later, also because in these mountain areas the olives are harvested when they are all on the ground. It is important that there is no longer a risk of frost when pruning. For example, pruning in February can cause the plant to start to re-sprout, and if there is a frost in March, then these new branches will be damaged.

Olive growers and the OLIPE cooperative currently rely on short term climate predictions - 15-day rainfall and temperature forecasts - to make their decisions. These climate services are provided by the Spanish meteorological services - AEMET - and by the online service tiempo.es. AEMET also provides three-month seasonal predictions for P and T and a drought monitoring service. However, most olive growers rely on the 15-day forecasts for their decisions since they question the reliability of longer-term predictions and projections.

Coping and adaptation strategies

In case of a drought, olive growers use strategies like digging boreholes or the construction of ponds or ditches (in a few cases) to improve the infiltration of runoff. Earth mounds are made on the slope just before the tree to allow water to accumulate. With climate change, drought alternates with torrential rains and much of the land is being lost to erosion. Terraces and tillage methods can help to slow down erosion. Farmers also use ploughing as a technique to minimise water loss during droughts. This strategy is, however, more suitable for farmlands that are not located on steep slopes. Furthermore, in times of drought, organic fertiliser combined with inorganic fertiliser can be used, because of the lack of moisture that is needed for the nutrients in the organic fertiliser to be released. Farmers also vary the timing of fertiliser application, for instance, treatment is usually applied in January. However, if it is known that spring rains are not likely then it is better to not fertilise (thus saving money). Soil moisture is also maintained by leaving the brushwood on the ground after pruning.

4.6.2 Decision Timeline: Dairy Farmers

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Climate Characteristics & Weather observations	Winter (wet & mild)			Spring (transition)			Summer (hot & dry)			Autumn (transition)		
Sectoral activities										Sowing winter crop (fodder)		
				Harvest (fodder)								
					Estimate herd size							
Climate related risks						Heat waves						
	Low precipitation											
	Insufficient recharge of aquifer											
Socio-economic factors												
Environmental cues				Timing of rainfall				Accumulated precipitation forecast				
			Sufficient rain > 200 mm							Sufficient rain > 100 mm		
	Low flows in streams											
	Low groundwater levels											
Socio-economic cues												
CS & information sources												
Coping Strategies						Cooling/Air conditioning of cattle sheds						
						Purchase of fodder						
				Builidng wells/boreholes & reservoirs								
							Rainwater harevsting & water re-use					
Adaptation Strateges							Buying and selling livestock					

Figure 17 Decision timeline for dairy farmers in the Los Pedroches Living Lab

Climate Characteristics, weather observations and sectoral activities

Figure 17 shows the decision timeline that was developed with dairy farmers in the Los Pedroches Living Lab. The key agricultural activities for dairy farmers include sowing and harvesting of winter fodder crops. For farmers to know which crops to plant it would be useful for them to know in August - September how much rain will fall until mid-October. Similarly, the timing of the harvest is also dependent on the amount of rainfall. A good harvest is necessary to produce fodder. This is then an important input that dairy farmers use to be able to size the livestock herd that can be fed and, based on that, estimate how much additional feed will need to be purchased, or if livestock should be bought or sold.

Decision making processes and cues

In terms of cues dairy farmers rely on the amount of precipitation to decide which crops to plant and when to plant them. Farmers identified the threshold of an accumulated 100 mm of water in the first two weeks of October as ideal conditions for planting. Similarly, for a good harvest, a rainy March is necessary, with at least 200 mm of rainfall between March and April. To ensure the recharge of the aquifer, 600 mm are considered to be needed throughout the hydrological year, distributed in stages and with a preference for more rainfall in autumn and spring. Other environmental cues that the dairy farmers rely on include: observing flows in the stream as a cue to ascertain whether they will have enough fodder for livestock; recharging of the aquifer (if the aquifer has not been replenished by spring then this is considered a sign of water shortage as rainfall in spring and summer evaporates more, as the days are longer and the temperature is higher. This means there is practically no recharge. If it is over 20ºC in spring, then much more rain is needed for it to infiltrate. Temperatures in April should also not exceed 30°C, as it is then very likely that there will be problems with water availability and fodder production.

In January, the production forecast is assessed, and the appropriate number of heads of livestock is estimated based on the expected availability of fodder, risks of water shortages, and risk of extreme temperatures. Based on these assessments, the most appropriate time to buy or sell livestock can be estimated. Although decisions are made on the spot, dairy farmers voiced that it would be ideal to have information on rainfall, both in terms of quantity and seasonal distribution.

Coping and adaptation strategies

When the harvest has been insufficient and the spring has been bad, livestock farmers need to stock up on fodder to feed their livestock. They rely on COVAP to do group purchases from third parties for this supply. Dairy farmers also adopt strategies like installing fans, air conditioning or watering livestock in order to cope with heat stress.

With dairy cattle farming, decisions can often not be taken in the short term (3-6 months), but planning has a 4-year horizon. This means that when there is a drought or some other emergency, decisions are generally taken defensively or as a matter of urgency. In this sense, there is a lot of interest in improving the information needed to assess production with more foresight and address the major uncertainties facing the livestock farmer. The choices to be made are closely related to the biophysical characteristics of the farm (possibility of cultivation, fodder production, ...), but in all cases the availability of water is essential. Strategies implemented prior to a drought include the construction of wells/boreholes and reservoirs to collect and store water. While during the drought strategies like water reuse (through double circulation circuits), rainwater harvesting, reduction in livestock numbers and adjusting the nutrient mix of the feed are employed.

4.6.3 Decision Timeline: Dehesa Farmers

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Climate Characteristics & Weather observations	Winter (wet & mild)		Spring (transition)			Summer (hot & dry)			Autumn (transition)			
Sectoral activities									Crop Decision			
					Harvest winter crop (fodder)					Sowing winter crop (fodder)		
								Birth of piglets				
	"Montanera" (fattening)										"Montanera" (fattening)	
			Purchase pigs (for "Montanera")									
Phenological Events	Flowering of winter crop											
				Flowering of holm oak								
Climate related risks	Warm winter					Heat waves						
	Low precipitation									Low precipitation		
			Frost									
Socio-economic factors												
Environmental cues				Timing of rainfall				Accumulated precipitation forecast				
	Sufficient rain > 200 mm			Sufficient rain > 400 mm						Sufficient rain > 200 mm		
	15-20 days with cold hours											
Socio-economic cues												
CS & information sources												
Coping Strategies						Cooling/Air conditioning of cattle sheds						
						Purchase of fodder						
				Builidng wells/boreholes & reservoirs								
							Rainwater harevsting & water re-use					
							Buying and selling livestock					
							Alternative sources of feed / changing feed mix					
Adaptation Strateges												

Notes: *Montanera* refers to the last fatting of the Iberian pig in which it is only fed acorns

Figure 18 Decision Timeline for *dehesa* livestock farmers in the Los Pedroches Living Lab

Climate Characteristics, weather observations and sectoral activities

Livestock farmers in a *dehesa* production system focus on free-ranging pigs that depend on the acorns that are naturally produced by the oaks (*encinas*). The nutrition of the pigs can be complemented by grain but the price of the products derived from the pigs (ham, chorizo, etc) is proportional to the percentage of food that comes from acorns versus other complementary fodder. Iberian pigs that are fed 100% with acorns are the most valuable. In a *dehesa* agro-forestry production system, pigs are complemented by different combinations of cattle, sheep and goats, depending on the natural pasture and complementary fodder.

The key agricultural activities of *dehesa* livestock farmers include decisions on the type of crop to be grown for pasture (for e.g., legumes, cereals etc) in September, and subsequent sowing in October-November, and fertilisation operations in September. Rainfall in autumn (for the seed to grow) and in spring (for the crop to grow) is important for the crop to develop well (in March-April), which is harvested in late spring (May-June). Late frosts in March-April on the other hand are detrimental to the crop, so having information about the possibility for frosts in this period can allow measures to be taken, such as delaying sowing or bringing forward harvesting.

In terms of managing the pigs, farmers take decisions regarding the buying or selling of pigs based on the production of acorns, which in turn is dependent on weather conditions. The availability of data on expected rainfall can help estimate acorn production and make decisions on stocking density adjustments, allowing better prices for the animals to be obtained. Additionally, livestock farmers also manage the feeding of ruminants year-round. Rainfall from September onward determines a good production of fodder and straw for ruminants. Most of the farms produce their own grass, but if production is expected to be poor, it has to be supplemented with purchased fodder. The price varies greatly and the timing of the decision when to buy additional fodder is very important for the profitability of the farm.

Decision making processes and cues

Livestock farmers use their knowledge of the crops and local weather conditions to take advantage of the differing resilience of different varieties and crop types depending on whether a wet or dry autumn is expected. Sowing has to be done when the soil is wet, so knowing a month in advance if it will rain helps to decide the sowing date. In case an extremely dry year is expected, it can be decided not to sow the fodder and as an alternative explore the best suppliers to buy it from.

The availability of acorns determines the number of pigs that can be fed during the montanera, and to calibrate these variables, farmers combine the management of pig farming on the farm with the purchase and selling of animals. If a good production of acorns is expected (by November) and the farm does not have enough pigs, it is possible to purchase. However, in times of drought, many farmers will want to reduce the stocking rate and sell their pigs. If a bad year is forecasted, there will be no buyers and no good price for the pigs, exacerbating the loss.

Livestock and dairy farmers, like in the case of olive growers, currently rely on short term climate predictions - 15 day rainfall and temperature forecasts - to make their decisions. These climate services are provided by the Spanish meteorological services - AEMET - and by the online service tiempo.es. AEMET also provides three-month seasonal predictions for P and T and a drought monitoring service. The COVAP cooperative also provides advice to its members based on AEMET climate services.

Coping and adaptation strategies

Much of the coping strategies adopted by *dehesa* livestock farmers were found to be reactionary in nature. The decisions taken are closely related to the biophysical characteristics of the farm (availability of water, possibility of cultivation, acorn production, ...). As dehesa farmers mentioned; “If there is no water on a farm, then ‘off we go’. You can do without a shed, but not without water”.

During the recent drought, livestock farmers deployed coping strategies like drilling boreholes, rainwater harvesting, relying on water tankers for support, food rationing or looking for alternative sources of feed (such as leftover potatoes, worms for sheep, sunflower meal and bran, almond kernels, tomato pulp, olive branches). Measures such as herd reduction, either through sale or sacrifice, or changes in the composition of the herd (pigs and ruminants) were also employed.

5 Discussion: Synthesis across Living Labs

Developing effective climate services (CS) for anticipating and responding to climate change necessitates leveraging a wide array of knowledge bases, encompassing both SK and LK. Efforts across literature and practice have called for integration of LK within the CS design, development and provision process, however, to date the integration of LK within CS has remained very narrow. This has been attributed to lack of clarity about what is LK or cherry-picking of a certain type LK which is easily integrated within CS (Hadlos et al. 2022; Masinde 2015). In this deliverable, we build on the characterisation of LK provided in Van den Homberg et al. (2022), emphasising that LK encapsulates different types of knowledges generated through a variety of processes ranging from traditions and customs passed down generations, to personal experience, to knowledge resulting from being embedded in an organisational set up. Development of CS requires a negotiation between these different knowledge systems. This deliverable, therefore, aims to understand the LK held by different actors along the CS value chain. Furthermore, we intentionally focused on LK associated with decision making in an effort to better understand LK in the context of use and its current applicability. As mentioned in chapter 2, we use the concept of risk identification, cues and thresholds to ascertain how knowledge and information is triangulated for decision making by different actors.

5.1 Understanding Local Knowledge used within decision making across the I-CISK Living Labs

Developing useful and used CS requires them to be more decision-oriented and provide information that can be interpreted by end users and is actionable (Kirchhoff, Lemos, and Dessai 2013). This study focusses on understanding the role of knowledge and information within decision making. Decision timelines were used as a tool to represent and understand key decisions across a given time period, whereby we use the concepts of risk identification, cue extraction and triangulation. We introduce the concept of 'triangulation of information' as a way to understand the different sources of knowledge and information used by stakeholders for decision making. A first step is that actors identify increased risk that impact their key sectoral activities along the timeline. We used the concept of risk as a sense making step in between the observations and the cue extraction. Cue extraction requires already a quite clear focus of the decision maker as to what is important to act on. The monitoring of cues is sequential to the identification of which changes in the environment can cause potential negative impact. We differentiate between different types of cues i.e., cues that are generated through weather, climate or environmental observations and cues that are based on the socio-economic context of the decision maker. Cues distilled from LK are helpful in discerning how LK is made actionable by individuals and communities. These cues that are derived from LK (and LK more broadly) are not only useful in making sense of the changing environment but also inform the understanding, interpretation and acceptance of information provided from external sources such as CS (Hayden, Mattimoe, and Jack 2021).

Our objective was to create decision timelines in each of the I-CISK LLs with as many diverse stakeholders along the midstream and downstream part of the CS value chain as possible (so not only CS end users but also CS purveyors and providers). Given the differing composition of the MAP and the contexts in each of the LLs, as well as the different stages of the co-creation process, the decision timelines developed in each LL may have focused primarily on the midstream or the downstream part of the CS value chain, rather than both. For example, the LL Lesotho interviewed community members and a selected community focal points (end users), while the Lesotho Red Cross Society (LRCS), Lesotho Meteorological Services (LMS) and Disaster Management Agency (DMA), who can be considered providers (LMS) and purveyors (LRCS, DMA) of CS were not included. In the Rijnland LL, the focus was on the decision timeline of the water authority, who can be considered a CS purveyor,. Given the diversity of stakeholders across I-CISK LLs, an inter-comparison across LLs is difficult. However, across all I-CISK LLs, we find that stakeholders rely on their LK and multiple external sources of information to make decisions. Table 3 provides an overview of LK cues and CS information used by different stakeholders across the I-CISK LL. Given our broad framing of LK, we find cues informing decisions can be derived from weather patterns, socio-economic changes, overarching policy contexts and existing culture of governance. In case of an organisational set up, for example, the Rijnland Water Authority in the Rijnland LL, knowledge associated with protocols and procedures is combined with weather/climate information to inform decision making. Similarly, in the case of Emilia-Romagna in the Italian LL, a combination of information from monitoring stations, existing protocols for management and past experience are critical when making decisions. For individual end users such as farmers, for example, in Georgia and Lesotho, cues derived from long-term observation of local weather conditions, local market conditions and social interactions were used to inform decision-making across different timescales. In some cases, cues can be defined as a clear threshold, where precise information is used to trigger action. Table below provides examples of such thresholds being used by olive growers and dairy farmers in the Spanish LL to plan their actions. It should be noted that the table below provides an overview, without intending to be exhaustive of the LK sources, cues and thresholds that may exist. Gaps in the table may not necessarily mean that a threshold (for example) does not exist.

The information summarised in Table 4 shows that linking key decisions and actions to corresponding knowledge and information sources helps in understanding the context in which climate information as made available in a CS is provided. It also gives insight into what channels of information are already regarded as trustworthy by the intended users, existing competencies of users when it comes to understanding climate information, and their expectation when it comes to using the climate information.

Table 4 Overview of key decisions and knowledge and information underpinning those decisions

Living Lab	LK Holder	Key Decisions	Timescale			Triangulation of information			Climate information needs
						LK Cues	Thresholds	CS used	
			Tactical	Operational	Strategic				
Crete, Greece	Water Manager	Storage or release of water				• Low flows • Past experience based on annual precipitation patterns		Weather forecast (and a pilot EWS)	Seasonal forecasts
		Water allocation and distribution to private clients				• Expected tourism demand • New investments in agriculture • Available funding and strategic planning • Long term strategy of the water management		Climate studies and projections of climate change	

						organisations			
		Water allocation and distribution to public clients				• Monitoring of flows (in Nov-Dec (wet period) and May-June (dry period) • Past experience and knowledge of annual precipitation patterns • Expected tourism demand (May – Sept)		Precipitation measurements (May - June, Sept - Oct)	
		(Excess) Water allocation and distribution to public clients				• Demand due to extended tourism period • Past Experience and knowledge of annual precipitation patterns		Precipitation measurements (May - June, Sept - Oct) A pilot case of EWS	
	Port Manager	Traffic management				• Past Experience		Wind Forecasts Storm Forecasts Sea surging data	Seasonal and decadal forecasting services.
		Ship management				• Past Experience			

		Port defences				• Funding and overarching policies regarding tourism and development plans		Temperature forecasts (during very hot periods Historical data	
	Resort Manager	Maintenance works				• Past experience (identifying periods of favourable weather). • Forecasts			
		Outdoor activities							
Emilia – Romana, Italy	Regione Emilia Romagna	Lower withdrawals during drought				• Weekly meetings with Drought Observatory		Set of drought indicators ARPAE monitoring network	Weekly and seasonal forecast information
		Long term management							Climate projections
		Extraordinary withdrawals authorisation						ARPAE monitoring network	Weekly and seasonal forecast information
	ARPAE	Provision of observed and forecasted meteorologica l and hydrological data							
	Consorzio Burana	Storage and distribution of water for irrigation				• Anticipated demand • Anticipation of reaching low		ARPAE's Demand Forecast	Weekly and seasonal forecast information

						flows • Past experience of weather conditions and learning from previous R&D interventions			
		Maintenance and modernisation of infrastructure				• Past experience of working with R&D interventions			Multi-year forecast information (of extremes)
	Consorzio Emilia Centrale	Distribution of water for irrigation				• Technical expertise and experience • Internal drought situation and emergency management protocols	Minimum Ecological Flow plus fixed thresholds that trigger "Emergency drought management	Information from monitoring stations; ARPAE forecast bulletin; status of snow and lakes; ARPAE monitoring network	Weekly and seasonal forecast information
		Storage or release of water by offline systems						Volume forecasts	
	IRETI	River discharge control						Current and historical data (from ARPAE or Hydrological historical value annals) Bulletin from ARPAE Daily data from ARPAE monitoring network	Forecast information on the discharge (1-2 weeks and 1-month ahead)

	AREN	Maintenance of reservoirs						Daily data from ARPAE monitoring network; Weather forecast	Forecasts of streamflow up 1-month ahead Forecasts of low flows for other seasons (apart from summer)
		Scouting for new Plants							Long term climate change projections
Lesotho	Livestock farmers	Land preparation & Planting				• Observation of the moon • Public gatherings		Climate information provided via radio, social media and phone messages	
		Weeding				• Frequent mist on top of mountains as predictor of cold conditions • Dry wetlands • Public gatherings			
		Harvest							
		Livestock breeding and sale				• Observation of the moon • Public gatherings			
	Non-farmers	Brewing				• Frequent mist on top of mountains as predictor of cold conditions • Dry wetlands • Observation of the moon		Climate information provided via radio, social media	
		Stokvel							
		Firewood selling							
Rijnland, The Netherlands	Rijnland Water	Imminent Drought				• Weekly re-evaluation of		Monitored and predicted hydroclimatic information	

	Authority	management measures (March - Sept)				actions		with uo yo 2-week prediction lead time	
		Long-term drought management				• Evaluation meeting by the drought-event emergency management team of the water authority (November)			
		Investment decisions						Climate scenarios	
Alazani – Iori, Georgia	Winemake rs	Pruning				• Experience of dealing with frost • Availability of human resource		Weekly prediction of temperature & precipitation provided by yr.no and amindi.ge	Reliable precipitation and temperature forecasts (one to 10-days ahead); Information on hail
		Daily operations (for e.g. spraying pesticides, tying up wines etc)				• Advice from other farmers (through cooperatives or Facebook groups) • Daily direction of movement of clouds			
		Harvest				• Demand from wine-making factories • Wine variety (sugar content)			

						• Availability of human resource			
	Wheat farmers	Land preparation and sowing				• Amount of precipitation & temperature • Cessation of autumn rains • Movement of clouds • Past experience • Consultation with other farmers		Weekly prediction of temperature & precipitation provided by yr.no and amindi.ge	Reliable precipitation and temperature forecasts (one to 10-days ahead); Information on hail
		Pesticide operations				• Amount of precipitation & temperature • Cost of pesticides • Consultation with other farmers			
		Harvest				• Availability of labour and machinery			
	Georgian Ameliorati o	Finalisation of the water allocation plan				• Demand information through farmer applications for irrigation		Historical information on water availability (Georgian Amelioration's own records)	Streamflow and volume forecasts (1-month ahead)

						contracts • Past experience of managing demand.			
		Provision of irrigation service (during the season)				• Previous experience of revising irrigation schedules during the season		Precipitation forecasts (2 weeks) & Monitoring streamflow through local stations	
Los Pedroches, Spain	Olive growers	Fertilisation				• Based on previous year's harvest • Economic cost	The autumn rains have to fall between September-October (200 L/m3) and then rain in February-March and April (200 L/m3). Temperature (ideal): 20 – 22^{0}C	15-day rainfall and temperature forecasts provided by Spanish Meteorological Services (AEMET); online service (tiempo.es)	
		Harvest				• Phenological knowledge			
		Pruning				• Experience of dealing with frost			
	Dairy farmers	Sowing of winter fodder crops				• Precipitation • Observing flows in the stream • Recharging of the aquifer	100 L of water in the first 2 weeks of October	15-day rainfall and temperature forecasts provided by Spanish Meteorological Services (AEMET); online service (tiempo.es)	
		Harvest				• Production	A rainy March		

						forecast and number of livestock	is necessary, with at least 200 litres of rainfall between March and April	3-month seasonal predictions for temperature & precipitation and drought monitoring service provided by AEMET	
	Livestock farmers	Choosing the crop variety				• Local weather conditions (dry or wet) • Knowledge of crop resilience			
		Sowing				• Wetness of the soil			
		Buying or selling of pigs				• Acorn harvest (expected)			

5.2 Pathways for Local Knowledge integration within Climate Services

Climate is rarely the sole factor guiding decision making, with end users using climate information primarily when it adds value to their current strategy (Alexander and Block 2022; Goddard 2017; Kumar 2010). The cornerstone of building usable CS, therefore, is to provide decision-oriented information. It requires tailoring of climate information with other types of knowledge and information to match the needs, capacities and socio-political and institutional contexts of the stakeholders (Daniels et al. 2020). As mentioned in the previous sections, the decision timelines as were established within the varying contexts of the LLs can help in articulating user needs and capacities in a manner that is accessible and can contribute to producing CS that are more credible, salient and legitimate. Figure 19 below highlights the ways in which different components of the decision timeline can inform the credibility, salience and legitimacy aspects of climate information. For each LL, the degree to which these three aspects are informed differs. In the case of Alazani-Iori LL, for example, streamflow monitoring data gathered from local stations was used to validate scientific data (see Pechlivandis et al. (2024)), thus contributing to the credibility of the information. In terms of salience, LL actors did use their LK to select which SK to use. For example, in the Los Pedroches LL olive tree growers used 15-day forecasts as this was the most useful for them and also because they had more trust in the 15-day forecasts than they did in longer-term predictions. Not all dimensions of legitimacy were explored in this research, as in most LL not all actors in the midstream and downstream part of the CS value chain were included. However, the knowledge gained from the downstream users can help build trust. For example, the Lesotho LL did not include the Disaster Management Authority (DMA). DMA is responsible for communicating early warning messages and adding LK to the messages they provide may increase the acceptance and legitimacy of the messages to local communities. The timeline exercise can also help in identifying opportunities where LK can inform SK.

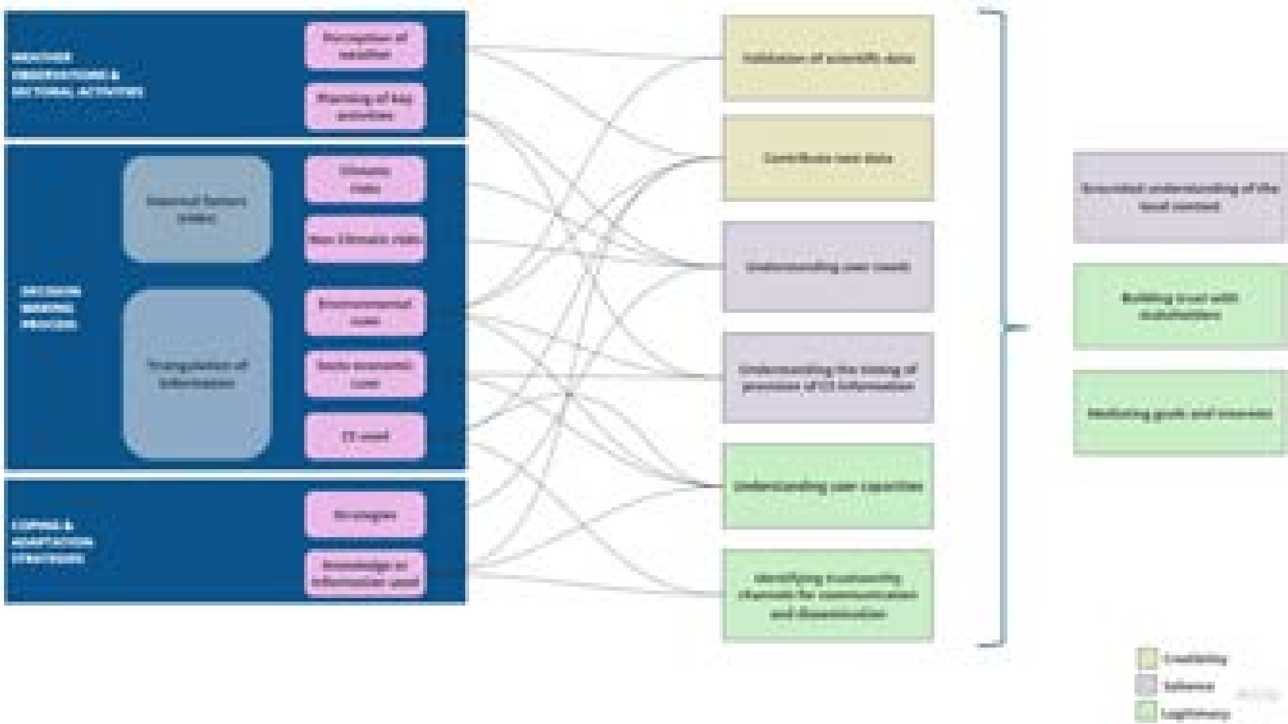

Figure 19 Ways in which decision timelines can contribute to the credibility, salience and legitimacy of climate information

While this deliverable does not go in-depth into how knowledge gathered from the decision timelines can be integrated within CS, it is crucial that a collaborative process is followed in co-designing the CS so that the outcomes are not perceived as imposed (Berkes, Colding, and Folke 2000; Taylor and de Loë 2012). A previous iteration of this deliverable (Van den Homberg et al., (2022)) highlighted integration approaches that can be used to integrate LK within CS. Here, we highlight the aspects of CS that can be informed through LK gathered from decision timelines. Notwithstanding, it is important to understand and validate the reliability of LK with LK holders or through other scientific methods. Impacts of climate change have the potential to alter local weather and biophysical patterns in ways that may not find precedence in LK of stakeholders, thereby necessitating understanding caveats associated with its use.

5.3 Reflection on the use of Decision Timelines

Decision timelines provide a framework to understand the decision-making process in time and local knowledge cues underpinning it. This temporal mapping is crucial for identifying patterns and trends that might not be apparent through other data collection methods, such as surveys or interviews. Additionally, decision timelines facilitate a participatory approach to data collection, engaging community members directly in the process. This participatory aspect ensures that the collected data is grounded in the lived experiences of the community. in the following sections we outline the benefits as well as some limitations of using the decision timelines.

As mentioned above, I-CISK LLs used various approaches to constructing the decision timelines (see Chapter 2). In addition to using the timelines as a way to understand the decision-making process, LLs also used it to understand information gaps and needs, knowledge management and transfer in a multi-stakeholder set up and to ideate the use cases for the planned CS. This highlights the versatility of the tool in being able to be used for multiple objectives, across different phases of the co-creation process (co-exploration and ideation), to develop user stories and personas and to inform co-evaluation of tailored information.

Successful implementation of a participatory approach such as decision timelines relies critically on key enabling factors, including; appropriate amount of time and resources, identifying the right stakeholders, agreement on the goals of the exercise, and suitable skills to conduct the process (Van Meensel et al. 2012). Furthermore, data collection involving local knowledge necessitates that enough space is provided to the participants to share their lived experiences (through anecdotes or other ways of storytelling), and that researchers leading the data collection process are aware of their own biases and are not dismissive of the knowledge of local communities. This is key in moving beyond paying mere lip service to LK inclusion with CS (Troglic et al. 2021). Lastly, while decision timelines are effective in providing a “common language” to CS providers and end users, they tend to be concise thereby forsaking much of the narrative information in favour of conciseness and precise LK based cues. We recommend using complementary approaches (such as semi-structured interviews, storytelling etc.) to better contextualize the timelines.

5.4 Local Knowledge and the co-creation process

The use of the decision timelines for LK was piloted in the context of the I-CISK LL. While the different LLs were at different stages of their co-creation processes, the use of decision-making timelines for LK was primarily in the co-exploration of end user needs stage of the co-creation cycle, to explore decision making processes and information needs. However, there is value in utilising decision timelines for LK at various stages of the co-creation cycle to facilitate the development of salient, credible, and legitimate CS. Drawing from the potential pathways of integrating LK in CS development (Figure 19), Figure 20 below highlights the potential applicability of decision-making timelines at different stages of the co-creation cycle to collect local knowledge:

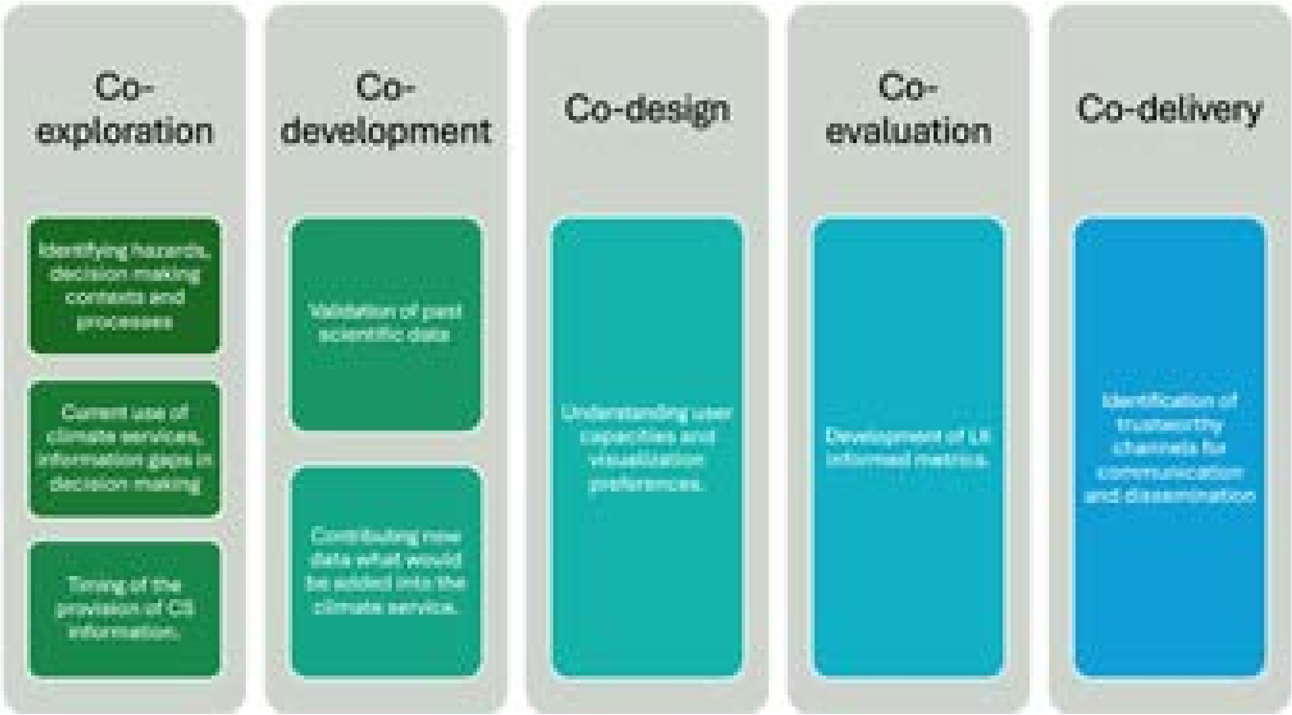

Figure 20 Added value of LK exploration across co-creation phases

6 Conclusions and Recommendations

Climate Services (CS) are produced at the interface of science and society with stakeholders with different backgrounds, experience and knowledge systems. Inclusion of Local Knowledge (LK) within CS has been recommended as a way to address the usability gap by addressing the credibility, salience and legitimacy aspects of climate information. Here, we particularly focus on LK use to inform decision making by different stakeholders on the CS value chain, positing that LK provides a frame of reference informing how stakeholders understand and interpret their surroundings and new information such as from SK. Unpacking the decision-making process in this way helps to understand the context in which LK is used and its applicability in understanding changes in the local context. We use the concept of 'triangulation of information' to emphasize that LK is used as a lens to understand and interpret climate information. Furthermore, focusing on LK use by both end users and upstream agents (CS purveyors and providers) is useful in understanding culture of how knowledge is developed, exchanged, and made actionable across the CS value chain. This is crucial in ensuring that whatever CS gets developed is properly embedded in the local reality and is informed by the dynamics of the enabling environment.

Decision timelines were used as a tool to unpack and understand, in practice, the role of LK (and LK based cues) on decision-making. As a tool, it offers flexibility and a framework for grounding the interactions that happen as part of different phases of the co-creation process. However, as mentioned above, developing rich decision timelines depends on quality of participation and interaction process. We presented examples from I-CISK LLs where this tool has been piloted to elicit LK from CS providers, purveyors and end users. In this exercise, timelines were constructed individually with an end user group or a service purveyor to understand the decision-making process of each, though clearly the intention is not to have siloed discussions. We recommend that these timelines are used to identify complementary information needs, facilitate cross discipline learning, and inform trust and consensus building processes. Creation of these decision timelines provided a unifying framework combining discussions related with identifying information needs, key decisions supported by CS and existing capacities and preferences of stakeholders. Moving beyond this pilot phase requires that these decision timelines are not constructed as a one off, but are systematically used as a discussion tool and appraised across the co-exploration, co-design, co-evaluation and co-delivery phases.

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Appendix 1 Guidance for the decision timelines workshop

Tips for the Decision timeline workshop

- Encourage participants to be as specific as possible especially when describing local weather conditions around the year, how climate and other risks are identified etc.
- In order to stimulate discussion, use examples of extreme events or other local events (like construction of a new irrigation channel, other infrastructure development etc) to trigger people's memory.
- When discussing LK, it is important to avoid the term 'LK' as much as possible. Instead frame the discussion around how risks are recognised and if any local observations are used, what triggers decisions etc.
- Keep the decision timelines as detailed as possible, don't disregard any input at this stage.

Workshop setting: Online or offline

Materials needed: If the workshop is online then use the miro board template. In case of an offline workshop, flipchart paper, coloured pens, icons, tape etc can be used to facilitate an interactive session.

Group size: This activity should be carried out in a focus group setting with at most 3 to 4 persons. If possible, and if the LL MAP comprises stakeholders from diverse livelihoods then the workshop leads should try to form these focus groups per livelihood.

Time: 45 - 60 mins

Timescale considered: Prior to starting the decision timeline workshop, it is important to identify with the members of the focus group the decision timescale that is relevant to them. For instance, in case of farming and agriculture based livelihoods a 12 or 18-month decision timeline can be considered while for tourism-related businesses or other types of businesses longer timescale (those corresponding to business development timescale) may be chosen. In the case of urban dwellers like those represented in the Hungarian LL, a longer time scale (5 years or decadal) might be more useful in understanding how lifestyle and decisions may have changed in response to heat stress.

Activity

Each participant will be given a sheet of paper with a row and columns (or corresponding Miro board template) to record the input. Each step of the activity entails questions that will be asked to all the participants prompting them to think, discuss and record their answers on their sheet. After each step the answers will be discussed as a group, participants are free to add or edit their response as they see fit. The questions mentioned below are only meant as a guidance and should be adapted to suit the local context. Furthermore, questions mentioned below are mostly directed towards CS end users (for e.g.,individual farmers, hoteliers etc).

Part 1 - Knowledge of local climatic conditions and climate hazards that impact livelihood and business processes. [In this first part, participants are primarily asked to record their perception of weather patterns across the year, which key livelihood activities happen and when.]
• What weather changes (temperature, precipitation etc) do people observe across a year in the region? • What key decisions are taken across livelihoods (both farming and non-farming, if applicable) and when?   ▪ Ask them to assign different livelihood activities to the seasonal calendar • What are the seasonal changes or external drivers that affect their decision making? (For e.g., changes in weather, income, availability of labour etc) • · How does weather or climate variability impact the decisions that they take?
Part 2 - Knowledge on climate risks, information triangulation and use [Participants are encouraged to discuss and elaborate on the ways through which they identify risks ahead of time, how they obtain and triangulate among different sources of information.]
• What are the ways in which participants identify the risks faced by them?   o If there are any environmental cues they use, learning from their social relations or past experiences etc? • How do they use their understanding of the local environment to understand the risks? • What other sources and types of information are used by them?
Part 3 - Knowledge of coping strategies, adaptation options or anticipatory actions [In this part, participants are asked to elaborate on the coping and adaptation strategies adopted by them, why those strategies and when these are implemented.]

• What types of coping or adaptation strategies do participants implement to manage risks and when?
• What gains or losses do these strategies provide them?
• What impacts the choice of these adaptation strategies?
    o What are these choices based on?
    o What knowledge or information do participants use when deciding on these adaptation strategies?

Part 4 - Reflection [in this concluding section, the purpose is to understand how above mentioned local conditions, livelihood activities, coping measures and information sources have changed over time]

- Can you describe how weather/seasons have changed in the last x years?
- Can you describe for us how your occupation/livelihood has changed in the last x years?
- How have the risks changed over the past years? Change in timing? Emergence of new types of risks?
- How has the participant's own capacity (in terms of new technologies, resources etc) changed over the past few years?

Decision Timeline Workshop with CS upstream agents

In case the MAP involves CS upstream agents then the above list of questions can be adapted to suit their decision making process.

- What weather changes (temperature, precipitation etc) do people observe across a year in the region?
- Focussing on a key service provided, what protocol is followed across the year?
- What are the external drivers (climatic) that impact the continuous supply of the service?

Table A1 Interview matrix used in individual meetings for identifying information gaps and adaptation needs - Example from the meeting with the Water Management MAP member. (Source: De Stefano et al. 2024)

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 availability.	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) at the end of summer and put political pressure to the water manager*)	Maybe some monthly predictions of precipitation and temperature, assessments of expected needs, previous experience (Statistics of meteorological forecasting regarding precipitation amount) Question: are there any specific thresholds which are used?	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 over allocation)
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?	

Colophon:

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