I-CISK

HUMAN CENTRED CLIMATE SERVICES

Deliverable D4.4

Participatory modelling for allowing citizens, stakeholders and decision-makers to become active players in climate action

May 2025

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037293

I-CISK

Innovating CS through Integrating Scientific and LK

Deliverable Title:	Participatory modelling for allowing citizens, stakeholders and decision-makers to become active players in climate action
Author(s):	Sumiran Rastogi, Nora van Cauwenbergh
Contributing Authors(s):	Alexandros Ziogas, Paolo Mazzoli, Daniele Castellana, Nikoletta Ropero Szymañska, Nuria Hernández-Mora, Schalk Jan van Andel, Györgyi Bela Balbina Nyamakura, Riccardo Biella, Charles Wamucii, Lotte Muller
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Executive Summary

Participatory methods are critical in ensuring that CSs (CS) are not only technically sound but also salient and legitimate in the eyes of the users. This deliverable demonstrates the pivotal role of participatory methods in the co-creation, learning, and innovation processes required to develop inclusive and actionable CS. Spanning multiple LLs (LLs) across diverse contexts, the project applied a wide range of participatory tools—such as decision timelines, citizen science, and serious games—to involve stakeholders in meaningful ways.

Participation in I-CISK extended far beyond consultation, supporting both product- and process-oriented outcomes. Product outcomes included the development of better-aligned, user-tested services, while process outcomes involved capacity building, fostering legitimacy, enhancing sustainability, and informing policy. Importantly, participatory approaches facilitated social learning—transforming how climate knowledge is shared, interpreted, and used. Stakeholders evolved from passive recipients of climate information to active co-creators, helping to shape more context-sensitive and enduring responses to climate risks. These participatory engagements proved essential in building trust, strengthening local agency, and embedding resilience thinking into broader governance and decision-making structures.

Despite these successes, the project also highlighted persistent challenges. Much of the engagement remained in the consultation space unless deliberate co-design methods were applied. This reflects wider structural and practical barriers—such as time, resources, and capacity gaps—that can limit deeper collaboration. Going forward, the I-CISK experience underscores the need for more intentional planning around participatory design, with a focus on building long-term engagement strategies that are context-aware and inclusive. When participatory methods are thoughtfully applied, they are not just facilitators of better CS—they are catalysts for systemic, inclusive, and transformative climate action.

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List of Acronyms

ARPAE: Regional agency for Prevention, Environment and Energy of Emilia-Romagna (Italy)

CS: Climate Services

DMA: Disaster Management Authority (Lesotho)

ECMWF: European Centre for Medium-Range Weather Forecasts

LK: Local Knowledge

LL: Living Lab

LMS: Lesotho Meteorological Services

LRCS: Lesotho Red Cross Society

MAP: Multi-actor Platform

NEA: National Environment Agency (Georgia)

SMHI: Swedish Meteorological and Hydrological Institute

UHI: Urban Heat Island

UNDP: United Nations Development Programme

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1. Introduction

Climate Services (CS) provide stakeholders resources to cope and adapt to climate change. CS are developed through the concerted effort of stakeholders on the CS value chain (Figure 1). The CS value chain comprises a network of organisations with each link of the chain adding value (Hewitt & Stone, 2021). Stakeholders situated "upstream" on the CS value chain, which includes data providers and integrators and typically research institutions and national hydrometeorological services, possess scientific and technical capacities and are responsible for generating and curating datasets. Service providers and purveyors located in the middle provide a brokerage function, converting climate data into information products that service user needs. Finally, the final recipient of the information ("users") are the stakeholders who deploy the information for their decision-making. A growing body of literature has underscored the importance of embedding participation in CS processes—not merely as a mechanism for engagement, but as a way to ensure relevance, usability, and legitimacy of services in diverse social and ecological contexts (Lemos et al., 2012; Vincent et al., 2018; Bremer & Meisch, 2017).

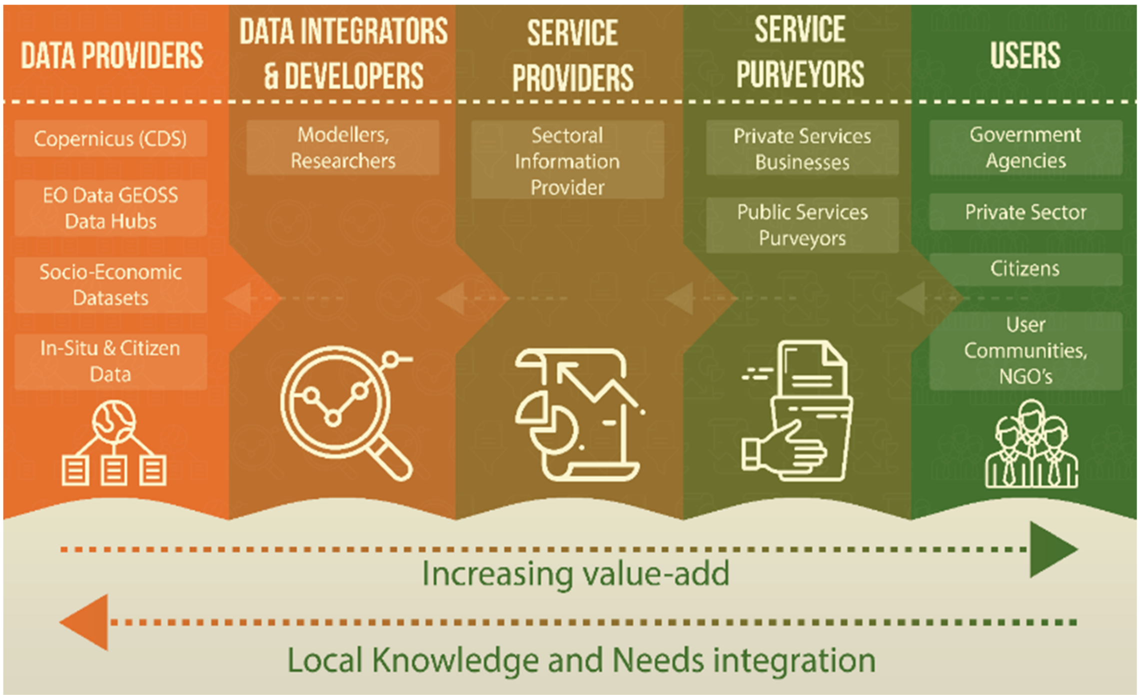


Figure 1 CSs Value Chain (Source: icisk.eu)

The I-CISK project follows a co-creation process to produce CS across its seven Living labs (LLs). The co-creation process follows iterative steps (Figure 2), leading to the co-evolution of knowledge and service (I-CISK, 2022). Each step in the co-creation process requires engagement and appraisal to contextualise CS better to produce credible, salient, and legitimate information. Co-creation within each LL is operationalised through a Multi-Actor Platform (MAP) comprising research institutions and local partners working in collaboration with stakeholders from multiple sectors, including citizens, public authorities, enabling institutions and the private sector. The MAP established in each of the seven LLs has been described in Masih et al., (2022). Maintaining the quality of engagement and participation of stakeholders in the CS development process is critical to the success of the co-creation process. Participatory research methods (participatory methods) provide an avenue for running processes that encourage stakeholder participation as an outcome as well as a means to ensure meaningful participation, thereby strengthening stakeholder ownership, increasing transparency and democratising the process (Hare et al., 2003). The co-creation framework followed within I-CISK project provides recommendations regarding the use of different participatory methods across the stages of co-creation.

Figure 2 Co-creation of user-centred CSs: building blocks of the process that take place in a LL context (I-CISK, 2022)

This deliverable corresponds to task T4.3, which focuses on the use of participatory methods to engage and inform end-users and encourage them to become active players in climate action.
We discuss the participatory methods used across the I-CISK project to facilitate the different stages of the co-creation process. We also discuss the relevance of these methods in supporting research and innovation carried out as part of the I-CISK project. This includes using participatory techniques to design and create awareness about CS, characterise and understand adaptation strategies, evaluating the role of co-creation processes in affecting adoption of CS, and understanding the impact of CS use. The deliverable is structured as follows: in chapter 2, we provide background on participatory methods and their use; Chapter 3 provides an overview of participatory methods used across the I-CISK LLs; Chapter 3 is a deep dive into specific participatory research, methods and tools developed as part of the I-CISK project. Finally, Chapter 4 provides a synthesis and discussion of the findings.

2. Background on participatory methods

Participatory Methods have been defined as "a purposeful learning process for action that engages the implicit and explicit knowledge of stakeholders to create formalised and shared representations of reality" (Voinov et al., 2018). Therefore, the use of participatory methods also enhances individuals' capacity, making citizens active players in climate action and leading to societal change. When talking about learning resulting from participatory methods, they highlight social learning as a process through which individuals acquire new knowledge, skills, or behaviours through interaction with others in a community or network. This emphasises the role of dialogue, observation, and shared experiences in shaping understanding and decision-making (Basco-Carrera et al., 2017).

The effectiveness of any participatory method depends on several factors, such as the stakeholders' goals, needs, concerns, and interests. Different participatory methods may be used depending on the level of stakeholder participation, leading to different ways in which stakeholders contribute to a process. The level of engagement with regard to influencing the process may range from (Basco-Carrera et al., 2017):

- **Ignorance** – stakeholders are disengaged with what is happening
- **Awareness** – stakeholders have a basic understanding of what is happening in a process
- **Information** – one-directional flow of information (in this case, from CS providers to downstream actors in the CS value chain)
- **Consultation** – stakeholders are consulted (flow of information from CS users and purveyors to upstream agents on the CS value chain)
- **Discussion** – bi-directional relationship between stakeholders
- **Co-design** - sense of ownership fostered among stakeholders
- **Co-decision-making** – stakeholders share the onus to act

Based on this ladder of participation, different participatory methods may be selected for different objectives. Voinov et al. (2018) describes a typology of participatory methods and their role across different stages of a participatory process. This includes participatory methods supporting fact-finding, process orchestration, and modelling (qualitative, semi-quantitative, and quantitative modelling) (see Figure 3). Participatory methods have been used across CS and related fields to facilitate stakeholder participation. Table 1 provides examples of relevant participatory methods, their description and use cases from the literature. This table is not exhaustive, but does provide an overview of the broad range of participatory methods.

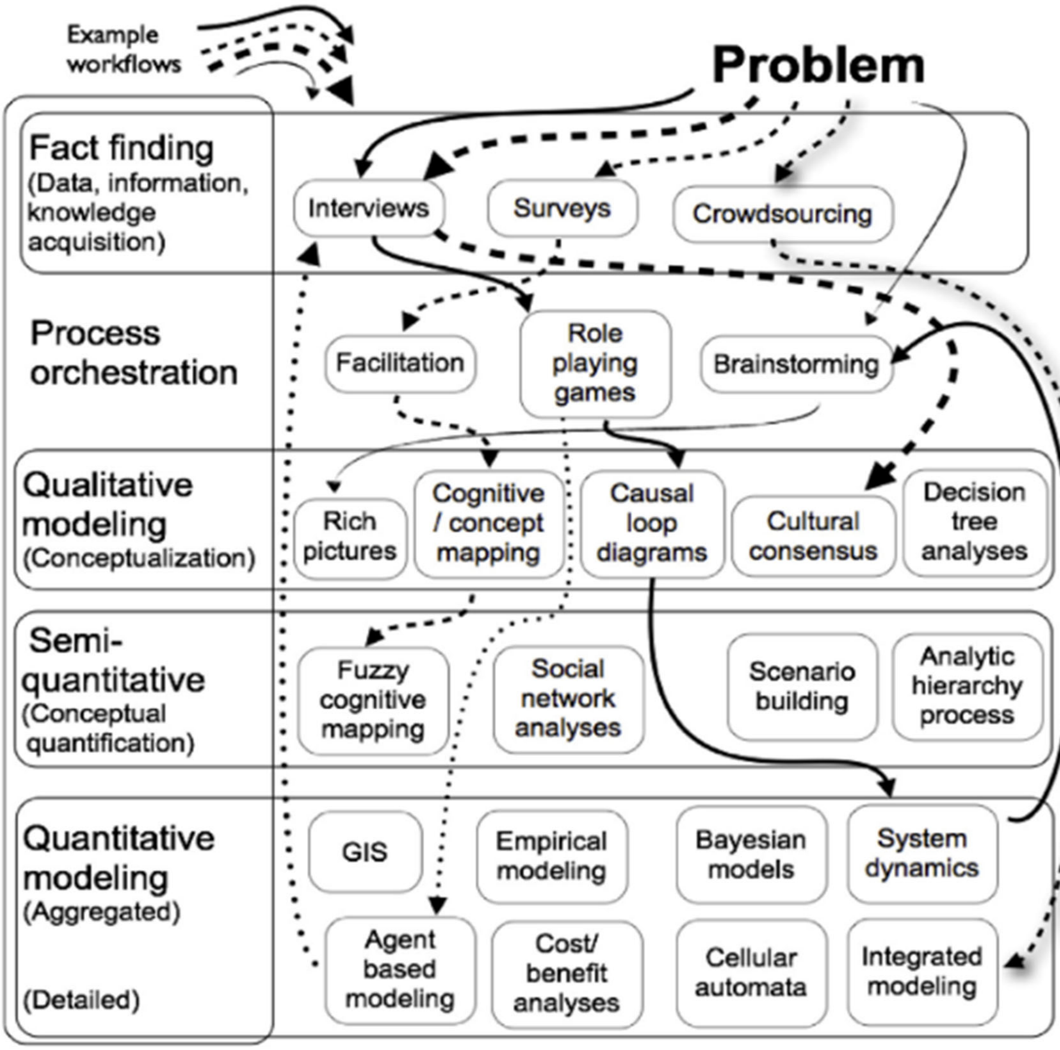


Figure 3 Typology of participatory methods with example workflows (Voinov et al., 2018)

Table 1 Overview of participatory methods (Homberg et al., 2023; adapted from Voinov et al., 2018; IFRC, 2023)

Participatory method	Description	Relevance	Example of use
Surveys	Surveys comprise of a suite of questions that are aimed at trying to study an issue.	Fact finding	Understanding climate change perception of end users of CS (Clifford et al., 2020)
Interviews (structured and semi-structured)	Interviews comprise of a series of questions that are meant to support a face-to-face consultation when exploring an issue.	Fact finding	People centred dissemination and communication of drought warning (Calvel et al., 2020)
Serious games or Role-playing games (RPG)	RPGs involve the creation of a virtual world, with simplified real-world conditions and rules. It aids in exploring and understanding the context and develop possible solutions through dialogue and collective exploration by the stakeholders.	Process orchest-ration; Qualitative modelling	Building cross cultural knowledge on climate change to enable social learning and support adaptation decision making (Blackett et al., 2022)
Focus Group Discussions (FGD)	FGD are a qualitative research method and data collection technique in which a group of people participate in moderated discussion regarding a given topic or issue.	Fact finding; Process orchest-ration	Exploring risk perception and adaptation decision making among farmers (Singh et al., 2022)
Rich pictures	This is a diagramming tool which makes use of visual media (like symbols, texts, clipart) to represent how a group of people think about a particular issue.	Qualitative modelling	Stakeholders' understanding of sustainable development (Bell et al., 2016)
Cognitive mapping	Cognitive maps or concept maps are graphical representations of organized knowledge that are used illustrate relationships or individual's knowledge or belief about an issue of interest or a system.	Qualitative modelling	Understand and analyse stakeholders' perception of drought impacts (Giordano et al., 2013)
Decision tree analyses or problem tree	Decision trees are used to depict the sequence of decisions and system changes that occur over time and its consequence on outcomes	Qualitative modelling	Adaptive management (Haasnoot et al., 2013)

	viewed as relevant by the stakeholders		
Social Network Analysis	This method is used to study social relations among actors, and how these relations and their patterns can impact or be impacted by actors' views, behaviour, perceptions, and learning.	Semi-quantitative mapping	Understanding the role of actors involved in the provision of agricultural CS (Tesfaye et al., 2020)
Cultural consensus	These are a suit of analytical techniques and models that are used to estimate cultural beliefs and the degree to which individuals know or report those beliefs.	Qualitative modelling	Comparing socio-ecological knowledge among different stakeholder groups (Hesed et al., 2022)
Participatory geographic information systems	These are computer-based mapping frameworks that can aid stakeholders in visualizing and understanding their problems spatially.	Quantitative modelling	Participatory mapping to pinpoint areas susceptible to floods and measures taken to reduce vulnerability (Cruz-Bello et al., 2018)
Agent based modelling (ABM)	ABM is a simulation method used to depict system behaviour and changes over time. An ABM consists of agents which are represented by attributes, behaviour rules, and interactions with other agents with the environment.	Quantitative modelling	ABM used to understand factors that promote adoption of seasonal forecasts (Alexander & Block 2022)
Seasonal Calendar/Decision timelines	This method helps in exploring the seasonality of events in community over a one-year period. A seasonal calendar can be used to explore the farming activities of communities in a year.	Fact-finding; Qualitative modelling	Seasonal calendars of weather patterns, livelihood activities, local indicators of flooding, rainfall and drought (Pauli et al., 2021)
Transect walk	This method involves walking through the community to observe and discuss the daily activities, surroundings, resources, and risks face by the community.	Fact-finding; Process orchestration	Documenting micro-level adaptation practices in data poor environments (Haque, 2021)
Historical profile and visualisation	These techniques help in engaging in discussion by building a picture of past disaster events and their effect on the community. Community members create a	Fact-finding; Process orchestration	Study produced a flood disaster risk reduction timeline (Bwambale et al., 2022)

	timeline of significant events and developments over the past decades.		
Storytelling	Storytelling and other narrative inquiry techniques are a qualitative research and data collection method that use the medium of stories as a way to gain insight into human lives, cultures, and behaviours of individuals.	Fact-finding	Study uses narrative approach to elicit perceptions about historical and current weather, water and climate patterns to understand how climate change is perceived (Marschütz et al., 2020)
Discrete choice experiment	Method used to estimate and forecast the behaviour of an individuals' choice. Participants choose between a finite number of options with different attributes, helping researchers analyze preferences and trade-offs without asking participants directly.	Quantitative modelling	Assessing the preferences for different modalities of agricultural services and their economic value for smallholder farmers in Ethiopia (Tesfaye et al., 2019)
Citizen Science	It refers to the involvement of general public in the scientific research process. Participation may be to	Fact finding	Using citizen science for urban climate resilience across European cities (Neset et al., 2021)
Participatory evaluation	An approach to assessing programs or projects that actively involves stakeholders—such as community members, service users, or project partners—in the evaluation process. Rather than being solely led by external evaluators, this method emphasizes shared decision-making, co-definition of evaluation questions, data collection, analysis, and interpretation.	Qualitative/ Quantitative modelling	Developing participatory models to protect and improve water resources while considering economic and social concerns in the community. (Voinov et al., 2008)
Contribution Analysis	A participatory evaluation approach to systematically understand an intervention's contribution to observed outcomes and impacts.	Qualitative modelling	Contribution analysis to assess different programs and assess learning (Apgar et al., 2020)

3. Participatory methods to support co-creation across LLs

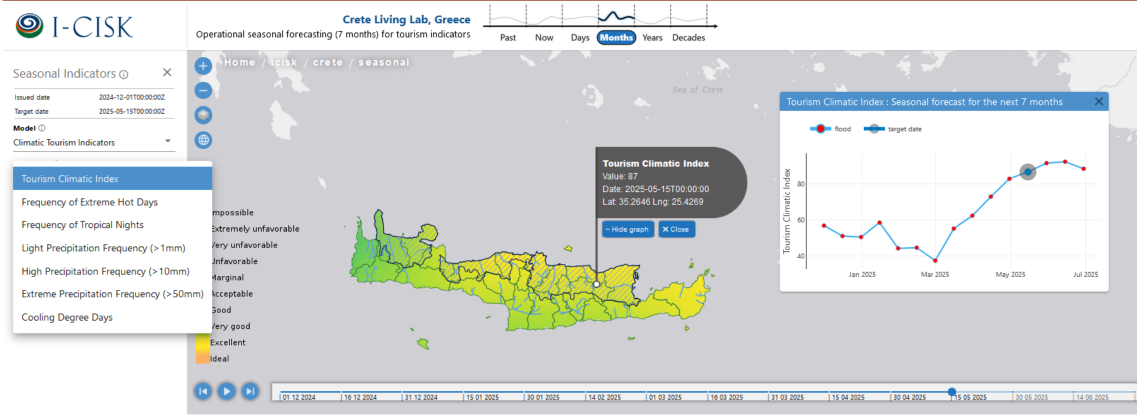
This chapter provides an overview of different participatory techniques used to facilitate co-creation process across the seven I-CISK LLs.

3.1 LL in Crete, Greece

The island of Crete LL, in southern Greece, is characterised by a variable landscape with extensive mountainous regions in the central part, and flat areas close to the coast. Crete is among the flagships of the country's tourism industry, with a thriving tourism sector. Being a large island, it concentrates on significant and varied economic activities and plays an important economic role for the country. Crete is among the regions of Greece most vulnerable to climate change, presenting high vulnerability in the tourism and transportation sectors, followed by health, agriculture and water resources. This LL focuses on the tourism sector using a multi-sectoral approach. Water availability can impede tourism as an economic activity since it is directly associated with the guest experience. Further, energy demand, especially for cooling during hot summer days and nights, is an important consideration for the tourism industry. High intensity events (precipitation, winds, heat) are primarily related to transportation infrastructure (mainly ports and roads), which support the economic industry and tourism-related infrastructure.

The CS, which is co-developed in Crete LL (Greece), addresses climatic challenges in the Tourism sector beyond the approach of the accommodation and tourism services sector. Under the frame of a multi-sectoral approach, the LL has been formed by a combination of stakeholders who represent needs and challenges from cross-cutting sectors, including the tourism sector, water management, transportation infrastructure (roads, ports) and energy sector, ensuring that synergies and trade-offs are appropriately considered in the development of the CS.

To address tourist services' needs, seasonal forecasting of extreme heat and precipitation, aesthetic indicators for outdoor activities, and energy needs have been integrated into a comprehensive web-GIS tool that provides the necessary information on spatial distribution (maps) and time-evolution graphs Figure 4.

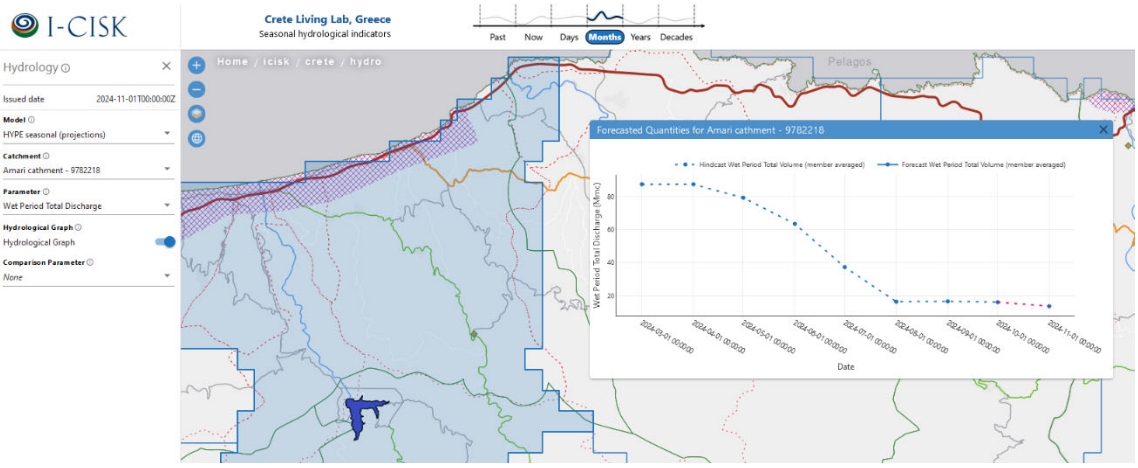


Issued date 2024-12-01T00:00:00Z
Target date 2025-05-15T00:00:00Z
Model: Climatic Tourism Indicators

Tourism Climatic Index
Value: 87
Date: 2025-05-15T00:00:00
Lat: 35.2646 Lng: 25.4269

Figure 4 Screenshot of the I-CISK CS developed for the Water Managers in the island of Crete under a multisectoral approach towards supporting the tourism sector – Wet period total volume: current forecast and history of forecasting.

To address water allocation needs, seasonal forecasting of river discharge and a tailored wet-season indicator (wet season: a 4-month period, from November to February) were integrated. The service is based on providing a forecast for the coming (next year) wet period, from as early as March or April (8 months ahead). The CS addresses the needs of the water managers for yearly decisions on water allocation, which are taken around April and are reassessed in September. A screenshot of the service is given in **Error! Reference source not found.**.



Issued date 2024-11-01T00:00:00Z

Model: HYPE seasonal (projections)

Catchment: Amari cathment - 9782218

Parameter: Wet Period Total Discharge

Hydrological Graph: Hydrological Graph

Comparison Parameter: None

Forecasted Quantities for Amari cathment - 9782218

Figure 5 Screenshot of the I-CISK CS developed for the Water Managers in the island of Crete under a multisectoral approach towards supporting the tourism sector – Wet period total volume: current forecast and history of forecasting.

Similar to the above, a landslide dynamic instability index was developed to support transportation infrastructure, and port management-related wind indicators were produced and integrated at the seasonal forecasting timescale.

Further, the majority of the information above was also provided at the end-of-century scale through climate projection scenarios.

The core for the development of the above services has been the Multi-Actor Platform (MAP), which have been established on the island and comprises stakeholders from key sectors (tourism, water management, transportation—ports and road network, academia), both from the public sector (policymakers, institutions) and the private sector (business, development).

Co-exploring the needs for information and services was based on one-to-one interviews and a structured interview approach, supported by full-MAP workshops. The procedure provided important insights into the variety and maturity among MAP members regarding CS. The awareness about CS and their potential in decision making differs significantly, from very high to rather low, which also affects the level at which specific CS needs are articulated. This understanding was used: (a) to focus efforts with more discussions and examples on less mature stakeholders, and (b) to re-think and re-plan the CS development time-schedule with tiered development of CS components (components referring to more mature stakeholders were developed earlier to be also used as examples to other MAP members). The same techniques were used for the identification of adaptation plans and strategies, which supported forming a coherent perception of the CS needs for the targeted LL. It is important to note that, due to the multi-sectoral approach of the developed CS, the multitude of needs which have been identified would require disproportionate effort, given the project boundaries, to be developed and incorporated into the service. In combination with the development of the CS maturity of the stakeholders, those needs were prioritised in order to refine the components of the CS, which were developed. Although not all of the needs were covered, this procedure significantly raised the awareness of the MAP members of the potential of CS for operational decision making as well as long-term adaptation planning. The co-development approach was also based on the exchange of knowledge with scientific organisations within I-CISK (ECMWF gained insights into data gaps and needs, SMHI used the information for impact modelling).

The pre-operational version of the CS has been available to the end-users since September 2024, providing valuable time for hands-on experimenting and actual testing of the service. This procedure (co-delivering phase of development) contributed to the awareness raising of the MAP, building a stronger foundation through service application, but also provided valuable input for the CS development. Suggestions by the end-users led to refining of visualizations (identify information of importance for the user or avoiding misleading visualizations), the inclusion of added information (e.g. wave height info for the port-service) which had initially not been prioritized, and the inclusion of new futures in the service (potential for user interaction with information graphs) but also highlighted the value and end-user interest for operational, seasonal forecast-based services, which support everyday operation and decision making aspects which are affected by climatic threats.

Table 2 Overview of participatory methods used across the LL in Crete, Greece

Problem investigated	Phase or phases of co-creation	Methods used	Purpose of the methods used	Who was involved?	How were the findings integrated?
CSs currently in use, information gaps and needs	**Co-explore** climate information needs and CS desires	- One-to-one interviews via e-meetings and telephone calls - Structured interview approach addressing specific topics: critical climate threats and potential impact, opportunities, CS use, and CS needs - Full MAP workshop	- Fact finding - Understand the CS level of use - Increase awareness of stakeholders of CS potential - Identify data needs - create a common understanding among MAP members of the co-creation process and goals	EMVIS I-CISK team, representatives of the MAP member organisations. In the Workshop also IHE and SMHI members of the I-CISK team were also involved	- understanding the various levels among MAP members regarding: awareness about existing CS, understanding of what a CS can offer and readiness to specifically express their CS needs - Inform relevant project needs (e.g. LL Characterisation report and Deliverables) - Plan the structure of future meetings
Operational needs as well as long-term planning needs	**Co-identify** adaptation plans and disaster risk reduction strategies to be supported	- One-to-One interviews via e-meetings and telephone calls - Structured interview approach addressing specific topics: decision timeline exercises	- Fact finding - Identify CS needs from individual MAP members, unaffected by other members of the LL	EMVIS I-CISK team, representatives of the MAP member organisations.	- Inform relevant project needs (e.g. Deliverables), work done in the fields of Co-developing of CS - Plan the structure of future meetings - Convey needs to climate data producers (I-CISK partners) and start planning the new CS

Problem investigated	Phase or phases of co-creation	Methods used	Purpose of the methods used	Who was involved?	How were the findings integrated?
Climate product – new CS	**Co-develop** climate (impact) data and knowledge into a climate product	- One-to-One interviews via e-meetings and telephone calls - Decision timeline exercises	- Fact finding - Process orchestration - Inform MAP members on potential options for new climate products - Identify the characteristics of the new CS	EMVIS I-CISK team, representatives of the MAP member organisations.	- Inform relevant project needs (e.g. Deliverables), work done in the fields of Co-developing of CS - Suitable indicators have been identified - Shape the form of the new CS - Inform development teams
The design of the new CS	**Co-design** the user-centred CS providing climate information	- One to one e-meetings - Presentation of mock-ups - workshop	Identify the desired characteristics of the CS: information setup, visualization aspects	EMVIS I-CISK team, representatives of the MAP member organisations. In the Workshop also SMHI members of the I-CISK team were also involved	- Evaluate progress - Inform development teams - Develop the new service
Evaluation of the developed service	**Co-evaluate** the co-created CS	- One-to-one e-meetings Presentation of the service – hands-on experience	Understand if the CS is meeting the expectations of the MAP members in terms of: (a) information provided, (b) suitability for the purpose, (c) pleasant and clear visual result	EMVIS I-CISK team, representatives of the MAP member organisations.	- Evaluate progress - Inform development teams - develop the service - Identify the value chain - Inform the business plan
Evaluation of the service	**Co-deliver** pre-operational CS information system	Hands-on with the newly developed service. Links distribution and support for test use by the MAP members	Identify any issues regarding: (a) usability of the service, (b) bags, (c) refining the final result	EMVIS I-CISK team, representatives of the MAP member organisations.	- Evaluate service - Refine the service - Identify the value chain - Inform the business plan

3.2 LL Emilia-Romagna, Italy

The Emilia-Romagna LL focuses on the co-development of CSs (CS) for drought management in the Secchia River Basin, specifically in the upper part of the basin around the Castellarano Weir, which provides serves a key irrigation canal diversion. The Multi Actor Platform (MAP), coordinated by GECOsistema (a partner of the I-CISK project), includes;

- regional authorities (Regional Government and authorities responsible for climate monitoring and early warning systems
- Irrigation consortia (Emilia Centrale and Burana), managing agricultural water distribution and optimizing irrigation strategies in response to drought conditions
- Hydropower companies (Aren) that depend on river discharge for operational planning.
- The local environmental agency (ARPAE)
- Municipalities (IRETI) ensuring compliance with water regulations and overseeing emergency response plans.
- academic and research institutions from the project supporting the scientific development of CSs and integrating hydrological and meteorological models.

The LL addresses the critical challenge of integrating LK with scientific climate projections to improve water resource management during periods of drought. This region experiences increasing variability in precipitation patterns, prolonged dry spells, and competing demands for water resources across the agricultural, energy, and municipal sectors. Stakeholders have highlighted the need for more localized and reliable climate forecasts that incorporate downscaled hydrological data tailored to specific river sections, leveraging also on local real-time observations and specific environment relevant thresholds (Environmental Flow Requirements) to compare to the forecasts. Additionally, there is a strong demand for improved visualization and accessibility of climate data through user-friendly interfaces that facilitate decision-making. Another key requirement is the better integration of existing hydrological monitoring networks, particularly linking ARPAE's observational data with Copernicus and other European forecasting services. Finally, stakeholders require decision-support tools capable of supporting water management scenarios under different upcoming drought conditions, enabling proactive adaptation measures.

The table below summarizes the participatory approaches used in the Emilia-Romagna LL to facilitate stakeholder engagement and co-develop tailored CS.

The participatory approaches adopted in the Emilia-Romagna LL facilitated the exchange between local stakeholders and Project experts. The integration of LK, including current water management practices and operational thresholds, into both the CS and the underlying forecasts has strengthened the local relevance of the CS. Scientific expertise contributed to improving the technical robustness of the CS, particularly in integrating with relevant upstream services like Copernicus and local data such as from the ARPAE network. The iterative engagement supported on one side the progressive refinements of the service, aligning it with stakeholder needs and decision-making processes, while on the other side increasing trust among stakeholders, increasing feasible usability of the service and laying the groundwork for long-term adoption.

Table 3 Overview of participatory methods used across the LL in Emilia-Romagna, Italy

Problem investigated	Phase or phases of co-creation	Method used	Purpose of the method	Who was involved?	How were the findings integrated?
Understanding stakeholder needs for CSs	**Co-explore** climate information needs and CS desires	Workshops & Question-naires	Identify key information gaps and LK needs	GECO +MAP stakeholders (regional authorities, irrigation consortia, hydropower companies, ARPAE)	Findings informed the initial service design and data requirements
Defining adaptation and disaster risk reduction strategies	**Co-identify** adaptation plans and disaster risk reduction strategies to be supported	Miro Board exercises, workshops, stakeholder consultation	Define strategic measures for climate adaptation and risk reduction	GECO +MAP stakeholders	Shaping structured adaptation pathways to support and informing policy recommendations while guiding CS development
Incorporating local data and knowledge into climate forecasts	**Co-develop** climate (impact) data and knowledge into a climate product	Stakeholder consultation	Adapt forecasts to reflect local hydrological conditions	GECO Hydrological experts, ARPAE,	Local data were passed to WP3 so that adjustments can be made to downscaling techniques and bias correction methods
Evaluating usability and visualization of the CS	**Co-design** the user-centred CS providing climate information	One-on-one interviews, User testing	Refine interface, visualization tools, and data interpretation	GECO + single institutions member of the MAP	Stakeholder feedback was used to improve graphical displays and user interaction options
Testing the initial deployment of the service	**Co-evaluate** the co-created CS	One-on-one interviews, User testing	Assess the usage of CS in real-world- like decision-making scenarios	GECO + single institutions member of the MAP	User responses led to further iterations and feature refinement for second version of the CS
Identifying pathways for long-term sustainability	**Co-deliver** pre-operational CS information system	One-on-one interviews, and stakeholder consultation	Explore financial and institutional sustainability options	GECO + institutional MAP Members (Regional Consortia)	Exploring value and drafting business model of the service

3.3 LL in Southern and Senqu Valley regions, Lesotho

The LL in Lesotho, co-led by the Lesotho Red Cross Society (LRCS) and RC510 (partner to the I-ICSK project), focuses on droughts and cold waves in Lesotho's Southern and Senqu Valley regions, where rain-fed agriculture and livestock farming dominate. These areas are most vulnerable to climate-induced disasters like droughts, hailstorms, snowstorms, and early frost, which severely affect lives and livelihoods. The LL brings together LRCS, Lesotho Meteorological Services (LMS), and the Disaster Management Authority (DMA) to co-create adaptive strategies and empower communities.

Lesotho's increasing climate disasters highlight gaps in early warning systems, coordination, and user-friendly CSs. Priorities include:

- Improved forecast accuracy for the prediction of droughts and cold waves.
- Inclusion of LK in CS.
- Accessible CS information systems for early action.

Participatory methods enabled two-way learning. LMS shared technical expertise and provided local data, while LRCS contributed insights into community needs. Indigenous knowledge, such as local drought indicators, complemented scientific data. This exchange improved trust, relevance, and usability of CSs.

Within the phases of co-creation, workshops were conducted to define the requirements for CS based on the priorities of LRCS and LMS. These services integrated both local and global data to enhance preparedness. LRCS actively tested and refined prototypes of the drought information system, ensuring usability and relevance. The development of the CS has been closely aligned with Early Action Protocols for droughts and cold waves, ensuring effective early action planning and promoting long-term sustainability.

Throughout this process, social learning within the MAP has played a crucial role in shaping the final CSs. One key insight emerged from initial assumptions about the maturity of LMS's drought forecasting system, which is highly advanced and integrates both global and local data. As a result, there was no need to improve the forecast itself. Instead, the focus of the CS for drought shifted to addressing other needs, such as ensuring easy consumption of forecasting information for non-technical users and facilitating the sharing of information among stakeholders. Additionally, the maturity of adaptation strategies, particularly Early Action Protocols, influenced the decision on the types of CSs needed for the two hazards. Engagement with LRCS also reinforced the importance of impact-driven decision-making, ensuring that the IBF system remains practical for humanitarian response. Notably, ECMWF gained valuable insights from LMS, especially regarding how local expertise and historical knowledge contribute to climate forecasting and decision-making in Lesotho. This exchange of knowledge has strengthened the CSs, making them both technically sound and operationally relevant.

Table 4 Overview of participatory methods used in the Lesotho LL

Problem investigated	Phase or phases of co-creation	Method used	Purpose of the method	Who was involved?	How were the findings integrated?
What are the needs of the users when monitoring and implementing the Early Action Protocol?	**Co-explore** climate information needs and CS desires	Direct engagement with users (e.g., one-on-one interviews, focus groups, and workshops)	To gather insights on specific needs, preferences, and challenges of users when implementing Early Action Protocols for droughts and cold waves.	LRCS LMS DMA	The findings informed the development of problem statements and user stories, which served as a foundation for designing the CSs.
What are the current adaptation plans in place?	**Co-identify** adaptation plans and disaster risk reduction strategies to be supported	Desk research, direct engagement with users (e.g., interviews and consultations)	To understand the existing adaptation and disaster risk reduction plans and assess how CSs can support these efforts.	LRCS	Based on the findings, the team differentiated the CSs needed: technical support for forecast improvement for cold waves and an information system for drought risk management. These decisions aligned with the maturity levels of the Early Action Protocols.
What data sources should be used when creating CSs? How does the availability of data influence the timeline in the decision-making process? How can indigenous knowledge contribute to the development of CSs?	**Co-develop** climate (impact) data and knowledge into a climate product	Desk research, direct engagement with users (e.g., consultations and knowledge-sharing sessions)	To evaluate data accuracy, identify the most suitable global and local datasets, and explore the role of indigenous knowledge in enhancing CSs.	LRCS, LMS	It was established that global data is valuable for early preparedness, as it is produced in advance and would enable LRCS to plan their activities proactively. Meanwhile, local data, produced by LMS and national institutions, is more accurate and forms the basis for actionable alerts. This is particularly important because MAP stakeholders are mandated to act based on local data, as defined by current adaptation strategies such as the Early Action Protocol. Additionally, since local data is released closer to the start of the rainy season and benefits from downscaled forecasts, it is expected to provide greater accuracy. These insights guided data selection and integration strategies for CSs.

What are the users missing from the cold-wave forecast? Can global datasets complement local datasets for the CSs? How do we integrate local data into the CS information system?	**Co-design** the user-centred CS providing climate information	Direct engagement with users (e.g., iterative feedback sessions and collaborative workshops).	To identify gaps in the current cold-wave forecasts, explore the complementarity of global and local datasets, and define integration methods for user-centric CSs.	LRCS LMS	For cold waves, findings guided the forecast skill assessment and recommendations on optimal products. For droughts, insights shaped the design of the CS information system, ensuring it addressed user needs effectively.
How does the prototype of the drought CS information system perform? Does it meet user needs and expectations? How can it be improved to enhance usability and effectiveness?	**Co-evaluate** the co-created CS	Validation workshop with users, including prototype testing and structured feedback session	To assess the functionality, usability, and relevance of the prototype from the users' perspective, ensuring the final product meets operational requirements and supports decision-making processes effectively.	LRCS	Feedback from the validation session was analyzed and prioritized to refine the prototype. Key insights informed adjustments to features, data presentation, and overall design to better align with user needs and decision-making workflows. Updated versions of the prototype incorporated these refinements before moving into development.
How will the CS information system for drought be tested and finalized? How will key stakeholders be engaged with the system?	**Co-deliver** pre-operational CS information system	User test and demo	Finalize the Impact-Based Forecasting (IBF) system for drought.	LRCS	LRCS will lead a discussion and dissemination session to introduce the IBF system to key stakeholders. To ensure practical engagement and feedback, an IBF simulation exercise will be organized, allowing stakeholders to test the system and refine its application in decision-making.

3.4 Rijnland LL, the Netherlands

The Rijnland LL in the Netherlands focuses on the impact of hydrological drought in the Rhine basin and meteorological drought over the Rijnland area, which is managed by the Rijnland water authority in the western part of the Netherlands. This area is mainly a land-reclamation area, managed as an irrigation and drainage system at the downstream end of the Rhine delta. The sectors that the CSs co-created in the Rijnland LL focus on include water management, agriculture, and (inland) navigation. The MAP consists of representatives of the water authority of Rijnland, water tourism boating clubs, and horticultural and crop grower organisations, as these are the first sectors to be affected in case of a drought.

Currently, knowledge and use of long-term climate change information and the impact of droughts is limited, and operational use of hydrometeorological forecasts for mitigating the impact of an upcoming drought is limited to a forecast horizon of two weeks.

The table below presents participatory methods used to identify the challenges MAP members face during droughts, and information needs to mitigate these challenges in upcoming droughts and strategise adaptation to climate change and potential impact on the frequency and severity of droughts in the future. These findings have been integrated in a pre-operational I-CISK Rijnland drought information app. This app is designed with four CS components; (i) a User-specific drought situation calendar, (ii) a seasonal forecast of cumulative precipitation deficit, which is the formal indicator used to monitor drought, (ii) a seasonal streamflow forecast for the River Rhine at Lobith on the Dutch/German Border and the primary forecasting location, and (iv) information on the projected impact of climate change on frequency and magnitude of droughts. The design of the App is such that additional components can easily be added.

The interactive joint MAP workshops also brought about joint learning across the participating sectors, e.g.: the boat owners (water tourism) expressed to now be more aware of the strong impact of droughts on the agricultural sector, the agricultural sector increased their understanding of the water authorities decision process and variables and thresholds that inform the water authorities drought mitigation actions (local cumulative precipitation deficit, and Rhine discharge at Lobith). The water authority and the I-CISK consortium members learned that the water tourism and agriculture have an interest in seasonal lead times (beyond 1-month) and are especially interested in five-year climate change outlooks. The interest in such shorter-range climate outlooks was of particular interest as the common horizon of publicly available climate change information in the Netherlands is typically 25 to 75 years from present day.

Table 5 Overview of participatory methods used in Rijnland LL

Problem investigated	Phase or phases of co-creation	Method used	Purpose of the method	Who was involved?	How were the findings integrated?
Find out what climate information is presently used and what information needed	Co-explore	Group meeting	Process-orchestration Fact-finding	Map members per sector	The results fed into the set-up of the User Stories workshop, directed the search for available climate data, and resulted in a complete wish-list for climate information
Find out what information needs and what the MAP intends to use the climate information for	Co-explore and co-identify	Workshop	Fact-finding	Map members, all sectors together	The workshop resulted in detailed information needs (variables, time horizon, spatial and temporal resolution), and User Stories defining short- and long-term DRR and Climate adaptation decisions, actions and strategies
Find out the drought indicators used	Co-develop	Group meetings	Fact-finding and quantitative modelling	MAP members, per sector and joint	Drought indicator variables and alert thresholds were brought together to define procedures for forecasting and alerting
Design a drought information service	Co-design	One-on-One meetings	Fact-finding and conceptualisation	MAP members individually	The previous steps were used to develop mock-ups of components of the drought information app to be developed. Feedback collected was analysed to result in a first design of the drought app
Co-evaluate and co-develop a pilot drought app	Co-develop and co-evaluate	Bilateral meetings and one final group meeting	Demo the co-developed application, and with feedback, implement small updates	MAP members per sector, and MAP as a group	The pilot application will be presented to MAP members per sector in April-May 2025 for feedback. A joint MAP final event in September 2025 will be used to demo the updated app and set out plans beyond the project

3.5 Alazani-Iori LL, Georgia

CSs, including hydrometeorological and meteorological services, are as yet at an early stage of development in Georgia. At present, tailored services are available only to a limited number of sectors and stakeholders, such as government agencies and energy companies. Recognizing the need for a more inclusive and structured approach, a MAP was established to bring together key national organizations responsible for providing weather and climate information. These include the National Environment Agency, operating under the Ministry of Environment and Protected Areas, which holds the primary mandate for delivering climate-related data in Georgia. In addition to government agencies, the MAP also incorporates service providers such as the Georgian Amelioration (the national irrigation authority) and the Rural Development Agency. Local representatives, including the Kakheti Regional Administration, the Information Consultation Center, the Kakheti Regional Development Foundation, the Georgian Farmers Association, and various local NGOs, are also engaged. Collectively, these stakeholders represent key sectors such as agriculture, water management, and environmental conservation (Masih et al., 2022).

The primary objective of the participatory process in the Alazani-Iori LL (LL) was to foster collaboration among MAP members, enhance understanding of climate change impacts in the region, assess the CS needs of end-users, and build the capacity of MAP participants. To achieve this, a problem tree exercise was conducted in collaboration with MAP members to identify and analyse the key challenges facing the region (see **Error! Reference source not found.**). The findings from this exercise were subsequently validated through feedback from local community members who were not directly involved in the MAP, ensuring a more comprehensive understanding of the issues at hand. Additionally, decision timelines (further explained in Section 3.4) were employed to examine decision-making processes across different livelihoods, shedding light on the types of climate information and knowledge used to support these decisions (see example of the decision timeline for wine-makers **Error! Reference source not found.**).

Furthermore, participatory methods such as key informant interviews and decision timeline analysis were used to assess CS needs at the national level. The MAP discussions highlighted a critical need for climate information related to water availability and drought conditions for effective water allocation and agricultural planning, particularly in the face of increasing climate variability. In response, the CS developed within the Alazani-Iori LL includes tailored information products focused on drought monitoring and forecasting. These products provide critical data, including streamflow forecasts, precipitation levels, temperature trends, and drought indices (SPI and SPEI).

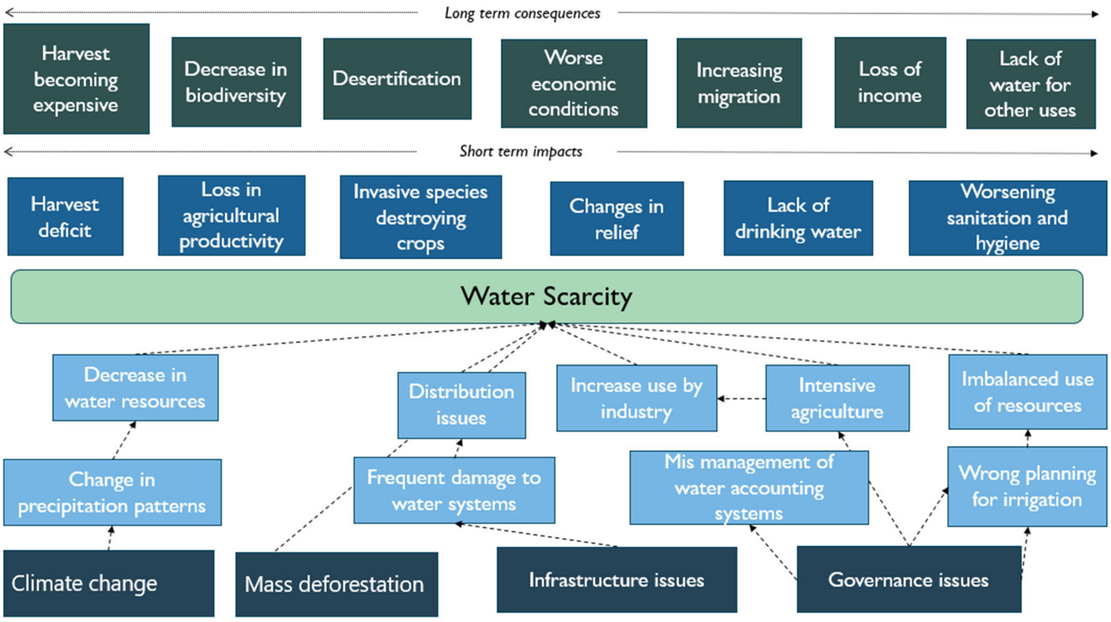


Figure 6 Problem tree constructed with the MAP members in the Alazani-Iori LL in Georgia

The participatory process within the Alazani-Iori LL played a crucial role in building trust in the MAP and fostering collaboration in the co-creation of CSs. By employing participatory methods such as decision timelines, the process deepened the understanding of end-user needs while also facilitating learning about the local context. For example, discussions with farmers revealed a key insight—while only a small fraction rely on irrigation, most downstream farmers depend primarily on rainfall for agriculture. This distinction underscored the need for CS tailored to different user groups. Participatory methods also helped negotiate and reconcile differing CS needs among various stakeholders. At the national level, policymakers required tools for managing competing water demands, such as irrigation and hydropower, leading to the development of a streamflow forecasting system. In contrast, local farmers, who depend more on rainfall, had a greater need for temperature and precipitation forecasts. While these needs varied, they were ultimately complementary. Another key takeaway was the existing use of climate information by local farmers. Despite the absence of a comprehensive national CS system, many farmers already rely on weather apps on their phones to guide their farming decisions. This finding presents an opportunity to expand and integrate digital CS to better support agricultural planning. The participatory process within the Alazani-Iori LL demonstrated the value of inclusive, user-driven CS development. By directly engaging diverse stakeholders, the process strengthened capacity-building among MAP members, fostered a shared understanding of climate risks, and encouraged cross-sector knowledge exchange.

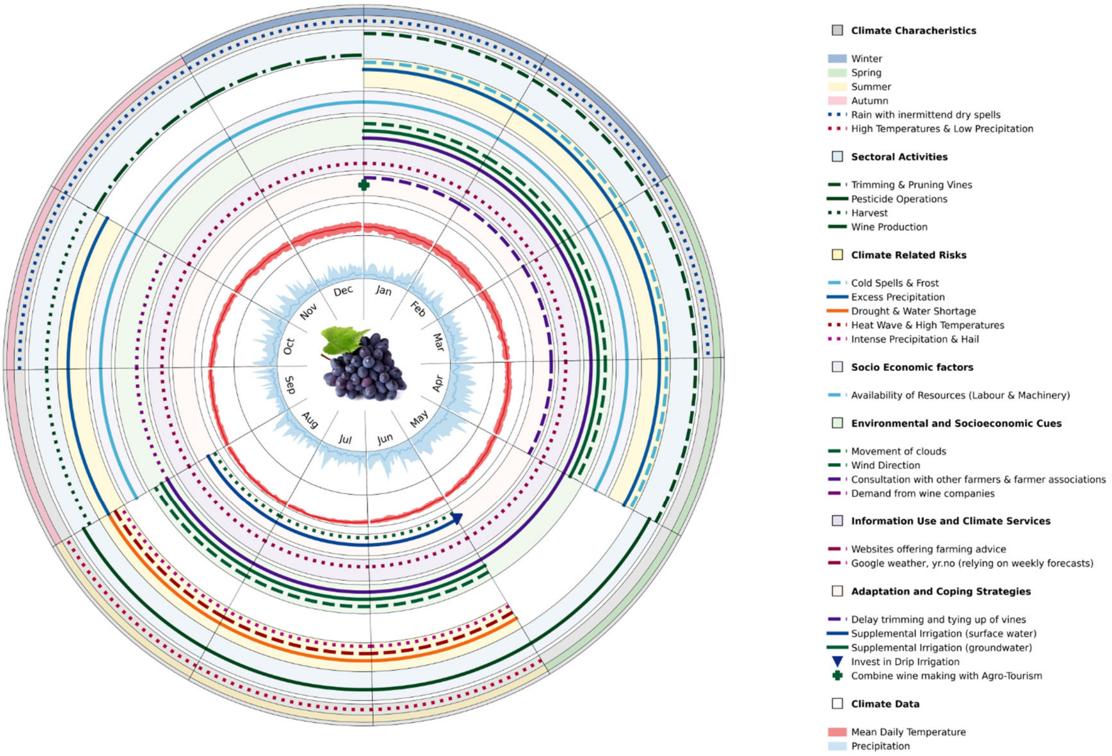


Figure 7 Decision Timeline for winemakers in the Alazani-Iori LL

Table 6 Overview of participatory methods used in the Alazani-Iori LL

Problem investigated	Phase or phases of co-creation	Method used	Purpose of the method	Who was involved?	How were the findings integrated?
Challenges posed by climate change and needs at the local level	Co-exploration	Online meeting and discussion	• Introduction to the I-CISK project and its goals • Introduction of MAP member and consolidation of the MAP • Discussions on climate-related challenges and needs at local level. • Discussions around water stress caused by demand from irrigation, energy, water supply and tourism.	MAP members, CENN	• Results from this meeting were integrated in Deliverable 1.1 and 1.2 • Discussion provided basis for more in-depth exploration of expressed CS
	Co-exploration	In person meeting, Presentation and discussion	• Exploration of data and information needs. • Understanding the historical background of CS production and use in Georgia, and current capacity of the NEA • Exploring synergies and complementarities • Understanding CS users from NEA's perspective	NEA, IHE Delft, SMHI and CENN	• Strengthening collaboration • Meeting resulted in sharing of local data which was then integrated in D3.1, D3.2
Challenges posed by climate change and needs at the local level	Co-exploration	In person meeting, presentation and discussion	• Understanding livelihood challenges and water stress at the local level • Contextualise the need for CS • Introduction to CS and opportunities offered by it	MAP members, CENN, SMHI, IHE Delft	• The results from this meeting were integrated in Deliverable 1.1 and 1.2 • The discussion provided basis for more in-depth exploration of expressed CS • Build capacity of the MAP members.
	Co-exploration	Capacity building session	• Capacity building session around the issue of climate change. • The training covered the issues of Climate change - challenges and tools to fight, Food systems and	MAP members, CENN	• The training was meant to improve the capacity of the MAP members to be better engaged in the I-CISK co-creation process.

			climate change, Impact of climate change on forest resources.		
Understanding the decision-making process at the local level	Co-exploration & Co-identification	Participatory workshop (using problem tree and decision timelines) and one on one interviews	• Understand local perceptions of changing climate and weather patterns, the impact of climate change on livelihoods in the region, and identify coping and adaptation strategies implemented by local communities	MAP members, members of the local community (outside the MAP) CENN, IHE Delft	• Results from the workshop and interviews were integrated in D2.2, D2.5 and D2.6 • Decision timelines were used as a basis to further understand and discuss user needs. • LK and decision timelines information is also used to set up the Serious Game. • Data from the interviews used for case study for scientific paper.
Understanding the enabling environment in which the CSs will be embedded	Co-exploration and co-identification	Key informant interviews	• The purpose of the meeting was to understand the challenges and needs of other actors along the CS value chain in Georgia (within and outside of MAP) • Explore the tacit knowledge and decision-making processes of upstream agents	NEA, RDA, Georgian Amelioration, Scientific Research Center, Information Consultation Center	• Establishing collaboration with the key stakeholders. • Data from the interviews used for case study for scientific paper.
Co-development of the CS	Co-exploration and Co-develop	Discussion	• Presentation of the findings of the field work • Sharing of the pilot mockup and obtaining feedback • Exploring additional information with the MAP to make CS salient to their needs	MAP members, IHE Delft, CENN	• Based on feedback additional information on drought indicators was added to the CS.
	Co-development and Co-design	Bilateral meetings	• Designing the streamflow prediction – discussion on its specifications and requirements	NEA, GECO Sistema, 52N, SMHI	• Feedback during the meeting guided the development of the streamflow prediction system and its delivery to NEA.
Understanding the enabling environment for CS	Co-exploration	Discussion		Georgian Amelioration, IHE Delft, CENN	• Establishing collaboration with the key stakeholders.

in Georgia and the key service providers	and co-identification		• Understand the needs and decision-making process of Georgian Amelioration • Introducing them to I-CISK and the CS being developed as part of the project • Explore synergies and complementarities • Exploring options for sustainability of the CS		• Understanding of the decision-making process was used to make the CS salient.
	Co-exploration and co-identification	Discussion		Rural Development Agency, UNDP	• Establishing collaboration with the key stakeholders. • Inform the development of CS to match the needs of key stakeholders.
User testing of CS and creating awareness about its use	Co-evaluation	Participatory workshop (online) Semi- structured interviews	• Collect user feedback on the performance, interpretation, and applicability of the CS (seasonal streamflow forecasts) and verification metrics. • Refine drought thresholds.	NEA, CENN, IHE	• Establishing collaboration with the key stakeholders. • Refinement of the CS, co-evaluation framework, drought thresholds and visualization methods. • Refinement of the next rounds of co-evaluation and verification methods.
	Co-evaluation	Participatory workshop	• Use serious game to co-evaluate the CS • Capacity building session	MAP, CENN, IHE	• Test the CS with intended end users • Explore the potential of the CS with end users

3.6 Los Pedroches LL, Spain

The Andalucía-Los Pedroches LL focuses on the region of Los Pedroches, a primarily agricultural area located in the north of the province of Córdoba, in the autonomous region of Andalucía, Spain. It also includes the Sierra de Cazorla, Segura and Las Villas Natural Park in the upper Guadalquivir RBD as a complementary site for testing the CS developed for forest landscapes with different habitats than the Cardeña and Montoro Natural Park, located in los Pedroches. Spain is located within the Mediterranean region, where droughts are a recurring feature. The country experiences significant climatic and rainfall variability, both seasonally—with dry, hot summers and colder, more humid winters—and interannually—with periodic drought cycles of varying intensity and duration. Climate change processes will affect the Mediterranean region. Predicted adverse impacts include more severe droughts, decrease in runoff due to increased temperature and evapotranspiration, and seasonal shift of rainfall patterns.

The agricultural sector is particularly vulnerable to drought. This is the case for both rainfed and irrigated agriculture, since climate change processes will affect the availability of both blue and green water. However, rainfed agriculture and extensive livestock farming have a limited range of adaptation options available in the short term. Los Pedroches is a primarily rainfed agricultural region, where different land use systems and landscapes coexist. The high ecological and socio-cultural value of the *dehesa* agroforestry system and the *olivar de sierra* (mountain olive groves) agroecosystem, both of which are predominant in Los Pedroches, and their vulnerability to climate change and hydroclimatic risks, make the region a particularly relevant site for the I-CISK project.

The Andalucía-Los Pedroches MAP is composed of water and protected area managers, research and outreach organizations, agricultural and livestock cooperatives, and civil society organizations, from the agricultural, animal husbandry and natural area management sectors (Masih et al., 2022).

In the Spanish LL participatory methods were (or will be) used to co-identify CS needs. Based on the interactions with members of the multiactor platform and other stakeholders through interviews and workshops, the following CSs were identified to co-develop in the framework of the ICISK project:

- CS1: Medium term monthly weather forecasts (6 months at 250 m scale)
- CS 2: Ten-year climate change projections
- CS 3: Historical climate data
- CS 4: Relationship between climate, phenology and plant production
- CS 5: Characterization of groundwater dynamics

In addition to the above CS, the LL also focused on improving understanding of hydro-geological dynamics at the local scale; explore the relationship between agricultural production and climate projections and predictions (see section 2.3.1) and; characterize adaptation strategies: Understand and characterize adaptation strategies placing adaptation options along a coping-adaptation spectrum (see section 2.3.2).

The co-creation experience in the Andalucia Los Pedroches LL has proven extremely useful as a space for scientific collaboration and co-creation, allowing for improved scientific approaches and research design by identifying common needs among stakeholders, based on the exchange of experiences and strategies, and generating beneficial long-term relationships of trust.

Complete overview of the participatory methods used within the Spanish LL are presented in **Error! Reference source not found.**.

The LK provided by some of the stakeholders has been crucial in improving the CSs developed. Thanks to this integration, these services are of higher quality and useful for the LL and for decision-making in a multitude of sectors. This has been particularly evident in the case of the hydrogeological characterization where LK and experience has been critical for model development in a context of limited data series. Another clear example is the collaboration with local cooperatives that allowed for developing preliminary indicators and correlations that will hopefully allow local cooperatives to use historical data incorporated into the CS to project future expected production volumes.

Our experience shows that it is advisable to formalize participation in the LL through a collaboration document or protocol and seek opportunities for "secondary" benefits for local stakeholders, that is opportunities for continuing collaborations outside of the initial project that created the LL. This is achieved by understanding the LL as a space of creation and collaboration to address a variety of issues, and not only those that are the focus of the original project. In the case of the Andalucia LL, members of the MAP are participating in new EU funded projects – for instance the recently launched Monalissa project that also will be focusing in Los Pedroches –; others have started collaborating on the study of groundwater quality; and others have collaborated on the study of social impacts of drought-induced water shortages. Furthermore, in interactions with participants, it is important to be flexible and respect each participant's time, as well as keep them informed and offer opportunities for participation and interaction.

Table 7 Overview of participatory methods used in the Los Pedroches LL

Problem investigated	Phase or phases of co-creation	Method used	Purpose of the method	Who was involved?	How were the findings integrated?
CSs used and needs	Co-explore	Interviews	• Present the I-CISK project and goals. • Create and consolidate the MAP • Understand the case study region, existing (past and present) climate-related risks, decision-making processes, and information used • Preliminary identification of adaptation measures implemented • Identify the CS needs to be developed in the context of I-CISK	CREAF and UCM ICISK staff Contact people in MAP member organizations	The results from the interviews served to inform the LL Characterization report and prepare the materials for the initial workshop and the following deliverables: Deliverable 1.1. Deliverable 2.1
		Workshop	• Consolidate the MAP, generating a common vision and objectives. • Provide information on currently available CS generated by different administrations and actors in the region. • Advance in the characterization of the 5 CS to be developed in the LL to adjust them to the needs of the agricultural, forestry and livestock sectors. • Agree on the work methodology and next steps for the LL.	CREAF and UCM ICISK staff Representatives of the MAP member organizations and other regional stakeholders (23 people from 15 organizations)	The workshop served to co-define needs and expectations specifically: that data and information exists but is not easily accessible by the end user; that intermediary actors are needed to “translate” existing climate data and make it accessible and adapted to local needs; that I-CISK could help in that translation; and that uncertainty in climate information needs to be clearly communicated and local data can help reduce / inform uncertainty. The results from the workshop were included in a workshop report that was shared with WK participants. Results also served to inform the following deliverables: Deliverables 2.2 and 2.3

					Deliverable 3.3 Deliverable 4.1
Adaptation measures implemented and potential with improved CS	Co-identify	Workshop	• Advance in the characterization of climate adaptation (drought management measures) currently implemented and possible adaptation measures linked to improved CS. • Identification of barriers and levers for implementation of improved adaptation options	See above	The workshop served to identify common typologies of measures – directed to ensure availability of water resources, manage climate-induced phenological changes, ensure the economic sustainability of farming practices; and ensure the sustainability of the resource base – and common barriers to implementing improved adaptation measures in all sectors – financial restrictions, institutional barriers, lack of knowledge and information, or inadequate scale or accessibility of existing climate data. These findings served to inform the CSs to be developed during the co-creation phase. Characterization of the decision-making space in the Andalucía-Los Pedroches LL – included in Deliverable 2.3
Adaptation measures implemented and potential with improved CS	Co-identify	Focus Groups	• Characterize the temporal and spatial dimension of adaptation measures - decision making timelines. • Understand the nature of adaptation strategies in terms of their effectiveness and long-term durability. • Understand how barriers and levers (institutional, economic, technical, knowledge, etc.) prevent or favor the adoption of adaptation measures that reduce long-term vulnerability.	CREAF and UCM ICISK staff Technical staff of the OLIPE and COVAP cooperatives Olive growers Dehesa livestock farmers Milk livestock farmers	The findings for the focus groups were used to develop adaptation pathways and decision-making timelines. Results have been used to inform: Deliverables 2.5 and 2.6 Deliverable 3.3 Deliverable 4.2 Theory of change
Adaptation measures implemented and	Co-identify	Interviews during groundwate		Olive growers Dehesa livestock farmers	Interviews with farmers during each of the field work campaigns – April 2023; November 2023, April 2024 November 2024, and April 2025 –

potential with improved CS		r measuring field campaigns		Milk livestock farmers	served to obtain detailed information on past and present adaptation measures, barriers for implementation, information needs, and local information to inform CSs. This information was used to inform each stage of the co-creation process and fine-tune and triangulate the information obtained from the MAP.
Co-develop climate (impact) data and knowledge into a climate product Co-design CSs	Co-develop & Co- design	Online bilateral meetings with representatives from each MAP member organization	• Update members of the MAP on the status of development of CSs, obtain feedback and suggestions, and request additional information • Validate the list of climatic information available in the region and identify potential new information. • Agree on next steps in the development of the CS	CREAF and UCM ICISK staff Representatives of the MAP member organizations	Input for the development of the CS
	Co-develop & Co- design	Workshop	• Present and discuss progress in the development of CS for the Region adjusted to the needs of the agricultural, forestry and livestock sectors. • Advance in the exploration of visualization options for the information generated and the associated uncertainty. • Agree on next steps and communication activities.	CREAF and UCM ICISK staff Representatives of the MAP member organizations (20 people from 11 organizations)	Input for the development of the CS and the visualization options. Validation of results (adaptation pathways) to be included in Deliverable 2.6 Expected (M42) contribution to deliverable 3.5
		Online bilateral meetings	• Presentation and detailed discussion of visualization of 3 of the 5 CS that had been developed – historical climate information, climate forecasts, and agroclimatic	CREAF and UCM ICISK staff Representatives of the MAP member organizations	Input for the development of the CS and the visualization options.

			indicators – and alternative options for visualization of uncertainty.		
	Co-develop & Co- design	Interviews during groundwater measuring field campaigns	- Obtain LK to inform the development of CS 5 – hydro-geological characterization	Olive growers Dehesa livestock farmers Milk livestock farmers	This information was used to inform the development of the hydro-geological model.
Co-evaluate co-created CS	Co-evaluate	Online multilateral meetings	Two online meetings were organized in early April 2025 where all MAP members were invited to attend to: - Present and discuss the pre-operational CS (a link to the platform was provided before the meeting) - Inform participants of scientific outputs of the project – papers, information factsheets, new research projects. - Discuss post-I-CISK sustainability of the CS - Collaboratively decide on closing events – public presentations, training seminars, etc.	CREAF and UCM ICISK staff Representatives of the MAP member organizations	The results of the meetings were used to review and adjust the pre-operational CS and co-design and plan the final outreach and communication activities and events.
Co-deliver pre-operational CS information system	Co-deliver	Public seminar Training workshop (TBC)	Present the results of the ICISK project and the collaborative work of the Andalucía-Los Pedroches LL, including post- project initiatives such as new projects and initiatives resulting from ICISK, links to other ongoing projects, etc.	Activities will take place in October 2025	Activities will take place in October 2025

3.7 LL in Budapest, Hungary

The CS developed in the Budapest LL is designed to monitor local heat hotspots and microclimate conditions across Budapest. It combines data from drone-based thermal imaging, manual temperature measurements, and citizen science contributions, integrating high-resolution remote sensing data with satellite imagery to create detailed urban heat maps. Advanced AI techniques, including convolutional neural networks and image segmentation, enhance the accuracy of its heat analysis models. It provides localised, street- and block-level climate/heat information, which is crucial for targeted urban planning. This actionable data helps stakeholders, such as local residents, municipal authorities, and businesses, to make informed decisions. The service supports efforts to mitigate the urban heat island effect and improve public health by identifying heat-stressed areas. It is a core component of the Budapest LL initiative, which aims to increase urban resilience and sustainability. The system's user-friendly interface ensures that its data is accessible and practical for everyday decision-making, contributing to enhanced quality of life in Budapest by reducing heat-related risks and promoting sustainable urban development.

The Budapest LL engaged with various groups (experts, NGOs, municipal representatives, students, and local residents) across several phases of the co-creation process to refine and implement its heat mapping service. **Error! Reference source not found.** provides an overview of participatory methods that were used to facilitate CS co-creation within the LL in Budapest.

Early consultations focused on identifying climate information needs, aligning with municipal goals, and establishing the groundwork for citizen participation. As the initiative evolved, comprehensive online surveys and community workshops helped to uncover public concerns, define key hotspots, and shape technical aspects of data collection. Multiple measurement campaigns mobilised students and citizen volunteers to gather real-time temperature data, creating a more detailed view of urban heat distribution. In parallel, ongoing discussions with government representatives facilitated the integration of UHI data into local policies and adaptation strategies.

The CS developed within the Budapest LL significantly enhances various green initiatives and climate action programmes across the city. By providing essential data and projections, it supports community engagement and budgeting, enabling both citizens and city planners to identify the most impactful areas for green initiatives. The service provides analysis tools to e.g. the Green Panel programme to track the effectiveness of upgrades and interventions. In addition, by making climate and environmental data accessible and understandable, the service empowers residents to participate in decision-making processes, thereby strengthening community participation. These contributions ensure that Budapest's approach to climate adaptation is data-driven, community-focused and aligned with sustainable development goals, which is particularly important as Budapest joins the EU Mission on Climate Neutral and Smart Cities, aiming for carbon neutrality by 2030.

University outreach sessions provided additional opportunities for research collaboration, tool development, and capacity-building among young scholars. Finally, follow-up workshops have been planned or conducted to evaluate the co-created CS and present findings to both policymakers and the general public, ensuring that feedback loops remain open, the data stay up to date, and the service remains responsive to user needs.

Table 8 Overview of participatory methods used in the Budapest LL

Problem investigated	Phase or phases of co-creation	Method used	Purpose of the method	Who was involved?	How were the findings integrated?
Climate information needs and CS desires	Co-explore	Discussions	• Establishing the framework for UHI mapping service. Engaging with experts and NGOs to define objectives and gather insights. Identifying and assessing available urban heat data.	Experts, NGOs, MAP members	Helped define the key parameters for urban heat mapping. Provided insights into data availability and stakeholder needs.
Adaptation plans and disaster risk reduction strategies to be supported	Co-identify	Discussion	• Aligning project goals with local governance, reviewing past and current urban heat mitigation measures, and integrating CSs into urban planning.	Climate Cabinet of the Municipality (Erzsébetváros and Terézváros municipalities)	Ensured alignment of UHI mapping with local policy and adaptation planning. Identified barriers to implementation.
Climate information needs and CS desires	Co-explore	Comprehensive online survey	• Gathering data from residents and workers on experiences with urban heatwaves and heat islands. Refining the approach for collecting and analyzing urban heat data.	Local residents	Revealed key hotspots and public concerns about urban heat, shaping data collection priorities.
Understanding CS needs and designing a user-centered service	Co-explore, Co-design	Community engagement workshop	• Educating residents about urban heat risks and engaging them in co-creating solutions. Collecting feedback to improve the mapping methodology.	Local residents and NGOs	Provided direct community input on urban heat challenges. Helped validate and refine mapping techniques.
Climate (impact) data and knowledge into a climate product	Co-develop	Discussion	• Strengthening partnerships to expand citizen science initiatives. Identifying data, tools, and models required for effective UHI mapping.	NGOs	Expanded network of citizen scientists contributing data. Helped integrate community-driven adaptation measures.
Climate information needs and CS desires, Co-develop climate	Co-explore	Citizen Science	• Engaging citizens in mapping urban heat distribution in Erzsébetváros and collecting initial climate data.	Students and experts	Provided baseline data for identifying high-risk areas. Increased citizen involvement in data collection.

(impact) data and knowledge into a climate product		measurement campaign			
Designing user-centered CS	Co-design	Workshop	• Aligning objectives and methodologies with stakeholders to ensure the effectiveness of the UHI mapping service. Discussing preliminary findings.	NGOs	Allowed refinement of data collection strategies and improved outreach methods.
Adaptation plans and disaster risk reduction strategies to be supported	Co-identify	Discussion	• Presenting findings to city officials and discussing how urban heat data can inform broader climate adaptation strategies.	Mayor's Office	Enabled policy integration of urban heat mapping results. Provided feedback on data usability for decision-making.
Climate (impact) data and knowledge into a climate product	Co-develop, co-deliver	Discussion	• Engaging university students in urban heat research through presentations and discussions.	Students and experts	Enhanced technical aspects of data visualization and analysis through student engagement
Climate (impact) data and knowledge into a climate product, and evaluate the co-created CS	Co-develop, co-evaluate	Citizen science	• Expanding data collection efforts with drone-assisted measurements. Testing tools for presenting urban heat data effectively.	Students and experts	Tested and validated drone-assisted data collection, improving spatial resolution of heat maps
Delivering pre-operational CS	Co-deliver	Discussion	Presenting the project findings to policymakers and residents fostered effective cross-learning, revealing strengths and gaps in current heat mitigation measures. Stakeholders learned that while existing initiatives help, integrating green infrastructure and reflective surfaces could further reduce urban heat. Local residents gained practical insights into improving their environments, and policymakers	Local residents and policymakers	Informed recommendations on policy and behavioral adaptation measures.

			saw the urgency for localized, evidence-based solutions. This feedback directly informed our recommendation to pilot community-led green projects alongside updated energy-efficient building codes. Ultimately, our intervention refined strategies and built broad support for enhanced, data-driven heat mitigation efforts.		
Climate (impact) data and knowledge into a climate product and evaluate the co-created CS	Co-design, co-evaluate	Citizen Science	Increasing community participation in mapping heat exposure. Refining data visualization techniques.	Students and experts	Increased data granularity and improved prediction models.
	Co-evaluate, Co-deliver	Workshop	Gathering feedback from policymakers, scientists, and residents to improve the UHI mapping service.	Experts and residents	Refined visualization methods, ensuring usability of heat maps for policymakers and the public.
	Co-design	Workshop	Involving university students in data analysis and tool development for urban heat mapping	Students and experts	Contributed to developing more user-friendly interfaces for heat mapping tools.
	Co-evaluate	Citizen Science	Expanding urban heat data collection with citizen participation and advanced analysis tools.	Students, experts, and residents	Finalized best practices for urban heat data collection, visualization, and policy applications.
	Co-deliver, Co-evaluation	Serious Game	Use the serious game (board and digital version) to create awareness about UHI and urban adaptation.	TBC	Use embedded analytics in the digital version of the game to assess its learning outcomes.

4. Deep dive into participatory research with I-CISK

In addition to facilitating the co-creation of CS, participatory research methods were also used to develop innovative research within I-CISK project. Several key themes were studied across the LLs. The sections below highlight the different thematic areas across which new research has been developed and the LLs in which these have been applied.

4.1 Impact of co-creation on CS users

The concept of co-creation has gained popularity in literature and practice as a way to bridge the gap between CSs production and their use in decision-making (Vincent *et al.,* 2018; Hirons *et al.,* 2021; Chiputwa *et al.,* 2022). The process includes users in co-initiating the process, co-exploring their needs, co-developing the climate information, co-designing the service, co-evaluating the CS, and co-delivering the CS. As such, through interactions between end-users and producers the needs of the users are incorporated in the CS, thereby increasing the likelihood that the CS will be used to support decisions (Vincent *et al.,* 2018; Vogel *et al.,* 2019; Bojovic *et al.,* 2021; Grossi and Dinku, 2022). However, despite co-creation being credited for improving the use of CSs, there is little evidence directly linking co-creation to actual use of the co-created CSs. In this study we unpack this long-held but insufficiently investigated assumption that co-creation will lead to use of CSs in decision-making.

We drew inspiration from the Contribution Analysis approach, which is an evaluation approach that examines how and in what manner an intervention has contributed to an observed outcome (Mayne, 2008). The approach consists of six key steps that require frequent engagement with stakeholders. These stages include i) setting out the attribution problem, ii) developing a Theory of Change and identify risks, iii) gathering evidence on the Theory of Change, iv) assembling and assessing the contribution claim, and the challenges to it, v) seeking out additional evidence, and vi) revising and strengthening the contribution story (Mayne, 2008). Applying the contribution analysis method is beneficial in this context because it enables the identification of factors within the co-creation process and other contextual factors that would have contributed to the use of the CS.

We aimed to assess how and in what manner the co-creation process occurring under the I-CISK process would contribute to its use in decision-making through a longitudinal study. We employed accompanying qualitative methods such as post interaction surveys, interviews, and workshops with members of the Multi-Actor Platform in the Lesotho LL to carry out each step of the process. Specifically, we engaged the end-users of the CS that was co-created i.e. Lesotho National Red Cross Society using the steps in Figure 8. At present, the preliminary findings show that embedding the co-created CS in an already functional decision-making system may help with its uptake and use.

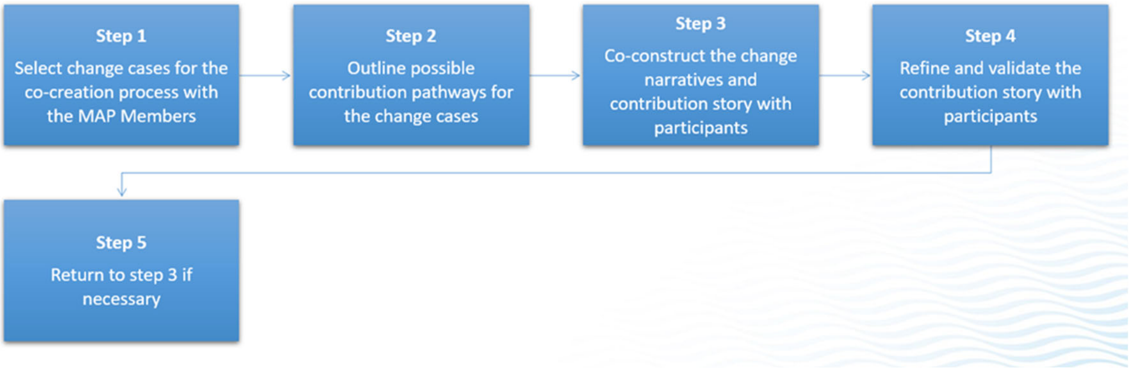


Figure 8 Contribution Analysis method applied in the project with stakeholders

3.2 Using participatory methods to develop local groundwater model

Participatory methods were also used to elicit LK to develop a local groundwater model in Los Pedroches LL. In-depth semi-structured interviews, questionnaires and group discussions were used to first identify and then validate CS needs to inform adaptation options. Once identified, LK and information was used to develop the different CSs more directly related to the local context such as the relationship between agricultural production and climate predictions and the hydrogeological characterization of the region’s groundwater resources.

Global datasets available for climate forecasts, environmental information or hydrological modelling are powerful tools to address limited information in scarce data regions. However, challenges persist as many methods struggle with representing complex groundwater systems such as karst and hard rock aquifers or capturing local-scale heterogeneities (Borzì, 2025). Generating robust estimation of water resources in data scarce regions often requires innovative and combined methodological approaches (Borzi, 2025). In this sense, LK offers the possibility of understanding the physical environment and evolution of water uses and of the status of water resources. This is particularly relevant to study heterogenous and groundwater systems like the karstic and hard rock groundwater systems of Los Pedroches. These types of systems are generally not very productive in terms of water quantity; however, they are a critical source of water for local populations (Larsson, 1984). The geological conditions that make up this type of aquifer vary drastically between regions, being closely linked to the local geological history. This means that the studies of these regions cannot be replicated to different case studies (Larsson, 1984). LK is a critical input to help characterize hydrogeological boundaries and estimate hydrogeological values to enhance groundwater modelling (e.g.: Clark and Blake, 2010). However, the collection of this type of qualitative information faces several limitations.

Different levels of knowledge among actors make it difficult to integrate LK into the model in a systematic and methodologically consistent manner. Given the sensitive nature of water uses in water scarce regions, some people are reluctant to answer questions related to water use, water levels, or measures undertaken to address water scarcity and droughts.

In the Spanish LL, semi structured interviews were conducted to gather LK regarding the historical functioning of the hydrologic cycle in the region. Interview guides were inspired by the approach developed in the T-RIVERS project to characterize seasonal rivers (Gallart et al., 2017). Guides included a variety of questions related to changing patterns of surface water flows, evolution of groundwater levels, and actions taken to address drought challenges. The information gathered from the interviews, together with four groundwater level monitoring campaigns and the limited existing information on groundwater dynamics, has served as critical input for the development of the local groundwater model, and to validate assumptions and preliminary results.

4.3 Participatory methods to characterise and evaluate adaptation strategies

Climate change impacts drive adaptation efforts (Berrang-Ford et al., 2021). Adaptation action is necessarily context dependent, linked to the socio-ecological context in which measures are implemented. LK plays a critical role in defining and implementing adaptation strategies. Understanding the decision-making context enables understanding the local adaptive capacity and distinguishing long-term adaptation from short-term responsive coping actions (Birkmann, 2011; Fischer & Denny, 2024).

In the region of Los Pedroches (Spanish LL), the increasing frequency and intensity of droughts pose a significant threat to the viability of the extensive agroforestry *dehesa* system that is a critical feature of the region's landscape, biodiversity, cultural heritage and economy; as well as to the viability of the historic and unique mountain olive growing production system; and the conservation of natural forest ecosystems in protected areas that also encompass *dehesa* landscapes. While local farming practices and the *dehesa* ecosystem are adapted to naturally recurring droughts, the recent drought period (2017-2024) have posed significant challenge to the viability of the system. Other climate-induced changes that impact farming practices are increasing temperatures and shifting seasonal precipitation and temperature patterns.

The goal of the work was to inventory, typify and characterize measures implemented by the livestock farming sector and the olive growers to address climate change-related challenges, and use an indicator system to assess the adaptive capacity of measures implemented by placing them along a coping-adaptation continuum. The ultimate objective was to understand and characterize adaptation strategies to help inform local decision making now and in the future.

Data collection involved a multi-phased participatory approach, involving in-depth semi-structured interviews, field visits, workshops and focus group discussions. This approach enabled the distinction between individual and collective action (through the work of local cooperatives for livestock farmers and for olive growers), as well as data collection for different sectors of the community (key informants, livestock farmers, cooperative technicians…). This allowed information triangulation to define the objective and characteristics of the measures implemented.

This study evidenced the limited knowledge of the region's groundwater dynamics that, added to the scarcity of locally scaled meteorological information and the uncertainty associated to climate forecast and projections, significantly limiting the adaptation options and the effectiveness of the responses to drought. In this context, LK plays a relevant role in coping with groundwater insufficiency. As in other drylands, where water is a scarce and seasonal resource (e.g.: Kwoyiga & Stefan, 2018), and where scientific and hydrogeological data is limited, LK is used to inform decisions to address drought risks, such as choosing the location of new wells, or improving soil quality and structure to facilitate infiltration and groundwater recharge.

Regions experiencing rapid changes due to climate variability or human activities have high needs for spatially and temporally adapted data to capture the natural dynamics of water systems (Borzì, 2025).

In the Andalucia-Los Pedroches LL two different approaches have been used to understand the long-term adaptation pathways and the response of the system to different climate scenarios and adaptation decisions. In a first stage, an attempt was made to co-define, co-develop and characterize adaptation pathways implemented by some of the different decision-making groups identified in the LL: *dehesa* livestock farmers, dairy farmers, olive growers, and technical staff in the cooperatives that work with each of these farmer types. As described in De Stefano et al (2024), adaptation pathways can be understood as sequences of decisions and actions that steer a social-ecological system towards a vision in response to biophysical and socio-economic drivers of change (Bruley et al., 2021). Framing the decision-making process as an evolving pathway that responds to changing ecological, social, and spatio-temporal context facilitates overcoming the dilemma of having to place risk-management decisions in a dichotomy of either incremental versus transformational or short versus long term actions. Rather, it supports understanding risk management as an evolving process and the adoption of flexible and anticipatory management strategies (Magnan et al., 2020)".

An attempt was made to work with the six types of decision-makers identified to characterize their adaptation pathways. In a focus group setting with each type of decision makers, we guided discussions to assess whether drought management strategies used so far have been effective to reduce their vulnerability to droughts both currently and in light of climate change projections. Focus groups worked on:

- The characterization of the temporal and spatial dimension of adaptation measures.
- Understanding the nature of adaptation strategies in terms of their long-term effectiveness.
- Understanding how barriers and levers (institutional, economic, technical, knowledge, etc.) prevent or favour the adoption of adaptation measures that reduce long-term vulnerability

However, while focus group participants were able to assess past actions in each socio-economic, institutional and geographic context, it was difficult to guide the discussion toward future climate scenarios and long-term effectiveness.

Finally, a new attempt to integrate experience with past actions with the future scenario information obtained through the CSs developed under I-CISK – particularly climate predictions and projections and hydrogeological modelling in in the coming months we will develop a participatory dynamic model to understand how decision making is affected by new CSs and generate potential future scenarios of evolution in water use and understand how improved CSs and knowledge can affect adaptation actions.

4.4 Decision Timelines

Building usable CS requires putting users at the centre of CS development and understanding their decision-making processes. 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" (Food and Agriculture Organization, 2005). Despite the importance of LK within decision-making, the two are seldom studied together within CS. There is a lack of a unified framework that allows for discussing LK in decision-making. To fill this gap, as part of I-CISK, we developed a participatory framework and methodology to understand the use of LK within decision-making.

Decision timelines are a valuable tool for visualising and understanding the decision-making process by mapping out users' decisions during the season (or seasons). It allows participants to visualise changes and patterns over periods of time (e.g., months, seasons, multiple years, etc). Decision timelines have a long legacy of being used under different names, for example, seasonal calendars or decision calendars across disciplines of development, forestry, agriculture, etc., to understand patterns and long-term changes in the local environment. Within CS, decision timelines have sometimes been used as boundary tools to “organise information about a user context and related climate knowledge” (Ray & Webb, 2016). Timelines have been used for various purposes, including documenting communities’ relationship with their environment (Chambers et al., 2020), mapping decisions to understand entry points for climate information (Haigh et al., 2015; Ray & Webb, 2016) and informing CS dissemination and communication strategies (Calvel et al., 2020). Therefore, depending on the purpose of the Decision Timeline, it can be set up to answer different questions.

Within I-CISK, we set up Decision Timelines to understand not only the process of decision-making but also factors influencing the timing of said decisions and LK or CS use underpinning it. The Decision Timeline comprises three main building blocks: **(1) weather and sectoral context**, **(2) decision-making process** and **(3) coping and adaptation actions** (see **Error! Reference source not found.**).

Weather and Sectoral Context

- How individuals or communities describe the (relevant) weather conditions in their local area over a selected time period.
- Key tactical or operational livelihood activities that are carried out across a given time period.
- External risks or factors (that recur seasonally) affecting the planning of livelihood activities.

Decision-making process

- LK (environmental or socioeconomic cues) based cues and CS used to inform decision-making.

Coping and Adaptation actions

- Actions (tactical, operational or strategic) carried out with aim of coping or reducing vulnerability to adverse conditions.

Figure 9 Different components of the Decision Timelines developed as part of I-CISK

Although the structure of the decision timeline established in each LL followed the template provided, the approach to creating the decision timeline (i.e. data collection) was not bound to a strict guideline. This was predominantly done because of the different contexts of each LL and how the MAPs are constituted. It is also important to consider that each LL is in a different phase of the co-creation process, resulting in the purpose for which decision timelines and the learning were different across LLs. Figure 7 (in Chapter 2) provide an example of a decision timeline developed for Georgian LL. For a complete overview of all decision timelines developed as part of I-CISK, please refer to Van den Homberg et al. (2024).

Decision timelines provide a powerful and effective tool for understanding links between different indicators, stimulating discussions, planning for change, and monitoring and evaluating risk management strategies. In addition to using the timelines to understand the decision-making process, I-CISK LLs also used them 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 used for multiple objectives across different phases of the co-creation process (co-exploration and ideation), developing user stories and personas, and informing the co-evaluation of tailored information. **Error! Reference source not found.** highlights the potential applicability of decision-making timelines at different stages of the co-creation cycle to collect LK.

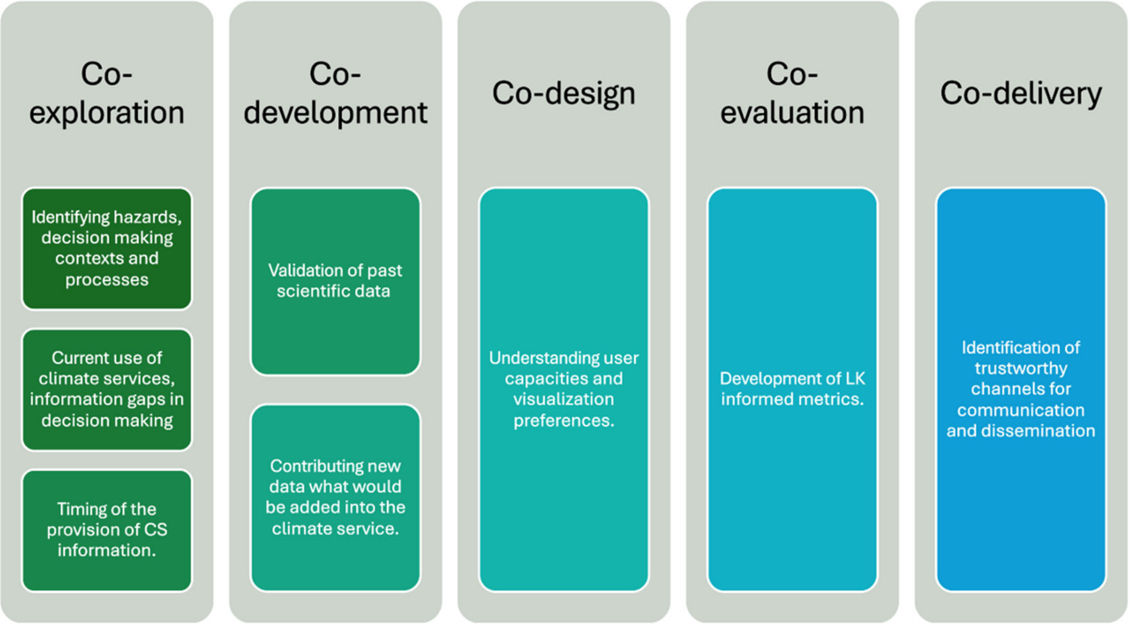


Figure 10 Added value of using decision timelines for LK exploration across co-creation phases

4.5 Discrete Choice Experiment

Participatory methods can be systematically capturing stakeholder preferences for different attributes of a policy, product, or service. Within I-CISK, Discrete choice experiments (DCEs) are used for understanding the factors that encourage or hinder the adoption and use of the CS. In a DCE, stakeholders are presented with a series of hypothetical choices, each involving distinct options with specific features (attributes). These features are carefully selected to ensure the choices feel realistic and relevant. By analyzing the decisions respondents make, researchers can quantify preferences and gain insights into the key drivers and barriers influencing behaviour.

As part of I-CISK, we developed a choice experiment to understand how boat owners in the Netherlands use climate information during droughts. Through a series of iterative workshops with harbour representatives and boat owners, we gained insights into how they mitigate the impacts of summer droughts and the decisions involved. We found that boat owners thoughtfully choose where to locate their boats during summer, considering key factors such as harbour costs, travel distance from home, and waterway connections to the standing-mast route (this is an inland waterway route with movable bridges that boats with mast can follow without needing to take down masts). By making these drought-related decisions explicit, the process of developing the DCE encouraged stakeholders to reflect on their past and future boating preferences.

Once the design of the survey was finalised, we disseminated the survey by engaging boat owners throughout the Netherlands. We disseminated the survey by, amongst others, visiting central shipping locks, which are important junctions where boat owners must wait to pass. At the shipping locks, we asked boat owners about their experiences with summer droughts, their preferences, as well as inviting them to complete the online survey. These face-to-face interactions not only helped disseminate the survey but also reinforced our understanding of stakeholder concerns and perspectives on summer droughts.

During the development and dissemination of our DCE, we observed variation in stakeholder engagement, reflecting the diverse impacts of summer droughts across the Netherlands. The diversity of drought impacts posed challenges in designing realistic hypothetical choices for respondents. To ensure relevance, we focused our study on drought-related accessibility issues, particularly in relation to the standing-mast route. We also included questions regarding ignored choice features, to be able to capture the heterogeneity between respondents. This can inform the need for tailoring CS to specific regions or types of users. Engaging harbour representatives and managers was challenging, especially when they perceived the topic as less relevant. This challenge was compounded by their limited availability, as our outreach coincided with the peak season, when they were focused on preparing harbours for summer operations. Similarly, boat owners with little direct experience of droughts seemed hesitant to participate. The face-to-face survey dissemination at shipping locks lowered the threshold for engagement, encouraging boat owners with varying exposure to droughts (to date) to share their preferences and experiences.

For further work, we will analyse the results of our DCE and will support the further development of CS for the Dutch recreational boating sector. Our results will be circulated not only to survey respondents and boating organisations, but also to the water authority. Our DCE can highlight potentially diverse CS needs of boaters, which can support inclusive decision making and strengthen future collaborations with the Water Authority and the recreational boating sector.

4.6 Participatory Model Evaluation

The role of CSs is particularly evident in agriculture and disaster risk reduction. Farmers use climate forecasts to adjust planting schedules, while water managers rely on hydrological predictions to optimize resource allocation (Bruno Soares et al., 2018; Hansen et al., 2019). Disaster response agencies integrate climate data into early warning systems, reducing casualties and economic losses (Braman et al., 2013; Wilkinson et al., 2018). CSs also support anticipatory action in humanitarian operations, shifting focus from reactive responses to proactive interventions (Clatworthy, 2022a, 2022b, 2023a, 2023b, 2023c).

Despite their benefits, the effectiveness of CSs is often evaluated based on user uptake rather than their long-term social, economic, and environmental impacts (Boon et al., 2022; Perrels et al., 2020). Many CSs prioritize short-term problem-solving, overlooking complex socio-ecological feedbacks that shape long-term system sustainability (Boon et al., 2021). Adaptation science increasingly highlights the need for a systemic perspective—one that accounts for interactions between human and ecological systems and the unintended consequences of adaptation measures (Di Baldassarre et al., 2017; Biella et al., 2024; Eriksen et al., 2015; Fedele et al., 2019; Garcia et al., 2020; Girons Lopez et al., 2017).

The traditional assumption that CSs are "no-regret" solutions has been challenged, as poorly designed services can contribute to maladaptation—actions that inadvertently increase vulnerability over time (Barnett and O’Neill, 2010; Biella et al., 2024). In these cases, CSs may reinforce unsustainable practices, delay transformative adaptation, or disproportionately benefit certain groups, creating new vulnerabilities (Hallett & Hobbs, 2020; Magnan et al., 2016).

In the work carried out within I-CISK (see Figure 11), Biella et al. (2024) identify three maladaptive dynamics in the use of CSs across five LLs: “fixes that fail,” “band-aid solutions,” and “success to the successful.” These archetypes illustrate how short-term reliance on CSs can either mask underlying vulnerabilities, discourage systemic change, or exacerbate socio-economic inequalities. For instance, in agricultural settings, reliance on seasonal forecasts may encourage unsustainable groundwater extraction, worsening long-term drought risks. Similarly, CSs developed primarily for well-organized industries, such as tourism, may marginalize other stakeholders like small-scale farmers. A key challenge in the implementation of CSs is the influence of sectoral power imbalances on adaptation decisions.

An ongoing study in the Greece LL investigates the interplay between power structures and the use of CSs in water management, emphasizing the broader implications across multiple sectors, including energy, agriculture, transport, and tourism. Understanding this interplay is critical for developing adaptation strategies that mitigate climate variability impacts while ensuring sustainable development and human well-being. The study addresses a crucial gap by analyzing how power asymmetries among stakeholders affect the effectiveness of CS-based decisions. Furthermore, it explores the integrated benefits and risks of CS products, which are often overlooked in traditional approaches that fail to capture the complex interdependencies between human and climate systems. In this work, the authors actively involve LL Leaders throughout the conceptual modelling process. Participatory modelling emphasizes collaboration between researchers and stakeholders, ensuring that conceptual models reflect real-world complexities and decision-making contexts (Mirchi et al. 2012; Elsawah et al., 2017). Stakeholders can be involved in the evaluation or validation of the model during its development, this can either be through their input, at the final stage, during one stage, or iteratively throughout several stages. In the research carried out with I-CISK, Biella et al. (2024) resorted to involving stakeholders throughout several steps of the methodology.

First, the authors conducted comprehensive desk research on each LL’s socio-ecological context to identify potential maladaptive processes. These preliminary findings were then shared with LL Leaders through a targeted questionnaire. Their insights, reflecting local conditions and challenges, directly informed the refinement of initial hypotheses. Next, the researchers created conceptual models—specifically system archetypes—that captured the dynamics uncovered by the questionnaire. These models were subsequently presented to LL Leaders in a series of interviews, wherein participants evaluated their accuracy, relevance, and completeness. The feedback collected in these interviews led to iterative adjustments, ensuring the models aligned with on-the-ground realities.

By inviting LL Leaders to iteratively evaluate and refine these conceptual models, the study bridges theoretical inquiry and stakeholder perspectives. This collaborative engagement exemplifies participatory modelling principles, yielding a deeper understanding of CSs and maladaptation risks that is strongly grounded in LK and experience.

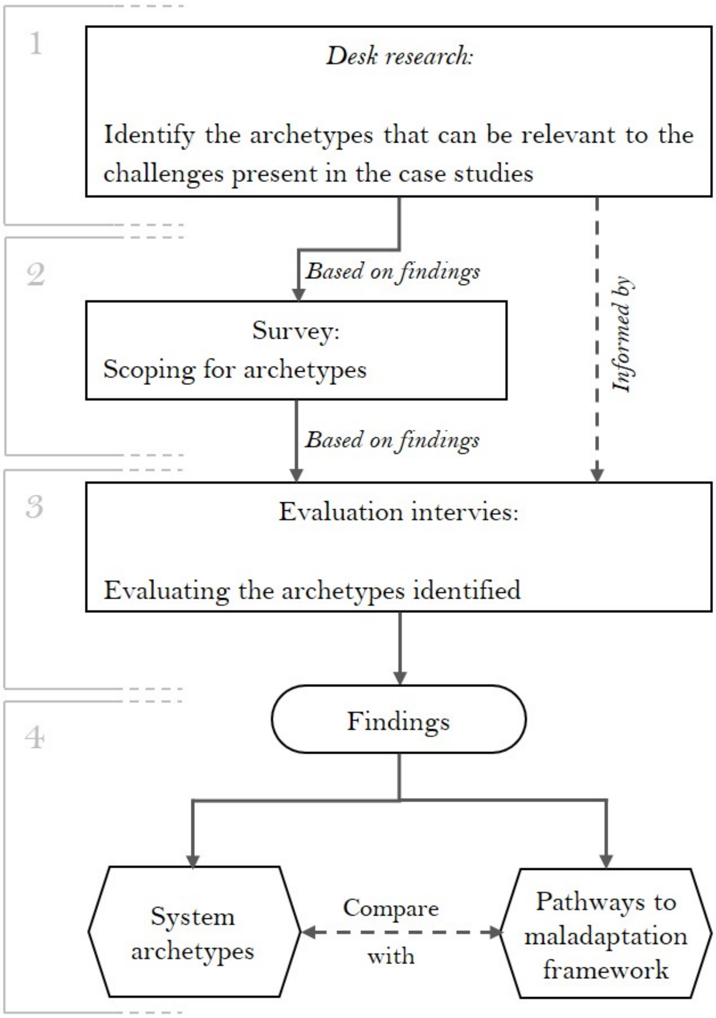


Figure 11 Methodological steps of the Biella et al. (2024) paper titled "Thinking systemically about CSs: Using archetypes to reveal maladaptation". Steps 1 to 3 were carried out through iterative consultation of the LL Leaders.

The socio-environmental model developed within the ICISK project, as described by Biella et al. (2024), effectively demonstrates the impact of CS products on informed and sector-specific decision-making processes across five interconnected sectors: tourism, energy, water, transport, and agriculture. A participatory approach was employed in the development of the model, engaging sector stakeholders in the conceptualization and contextualization of model components and parameters. Stakeholders were also involved in validating the model estimations and confirming model assumptions.

In the tourism sector, the model illustrates how CS products facilitate the formulation of targeted strategies to enhance tourist inflow. For the energy sector, it emphasizes the role of CS products in increasing energy availability, thereby enabling better adaptation to variable energy demands. In the transport sector, the model focuses on improving road usability through timely maintenance and the development of new infrastructure. Regarding water resources, it advocates for the augmentation of water storage capabilities and the optimization of resource reallocation strategies. In agriculture, the model demonstrates how CS products can enhance water harvesting practices to support increasing food requirements, thus moderating food costs. Collectively, the model elucidates the dynamic roles of CS products in promoting advancements across these sectors. The model also incorporates future climate projections to address fluctuations in water availability, while depicting human population growth as a gradual and consistent trend (Biella et al. 2024).

Using island of Crete LL as a case study, the model was instrumental in investigating power asymmetry dynamics, suggesting that power imbalances among stakeholders influence sectoral adaptation efficiencies. It was found that primary sectors benefit disproportionately, highlighting the need for a systems-thinking approach in CS co-design to account for long-term interdependencies and socio-environmental pressures (Biella et al. 2024). Model simulations underscored the necessity of integrating system dynamics modelling in CS product development to address sectoral interdependencies, mitigate unintended trade-offs, and optimize adaptation efficiencies equitably across sectors. Adapting the system dynamic approach in the early stages of CS products development can ensure that the benefits of CS products are distributed more evenly, promoting sustainable and resilient development across all sectors.

Preliminary results indicate that power imbalances significantly influence sectoral adaptation efficiencies and the overall sustainability of the human-environmental system. To ensure that CSs genuinely support sustainable adaptation, a shift is needed from short-term effectiveness metrics to systemic, long-term impact assessments. This requires integrating maladaptation risk assessments, such as the pathways to maladaptation framework (Magnan et al., 2016, Biella et al., 2024), and fostering inclusive co-creation processes to ensure CSs address the needs of all stakeholders equitably (Lemos et al., 2012; Perrels et al., 2020). The ongoing study provides valuable insights into the systemic impacts of power imbalances and the importance of inclusive and participatory CS development. Key lessons learned include the importance of stakeholder engagement in understanding sectoral dynamics and the need for balanced power among sectors to avoid maladaptation.

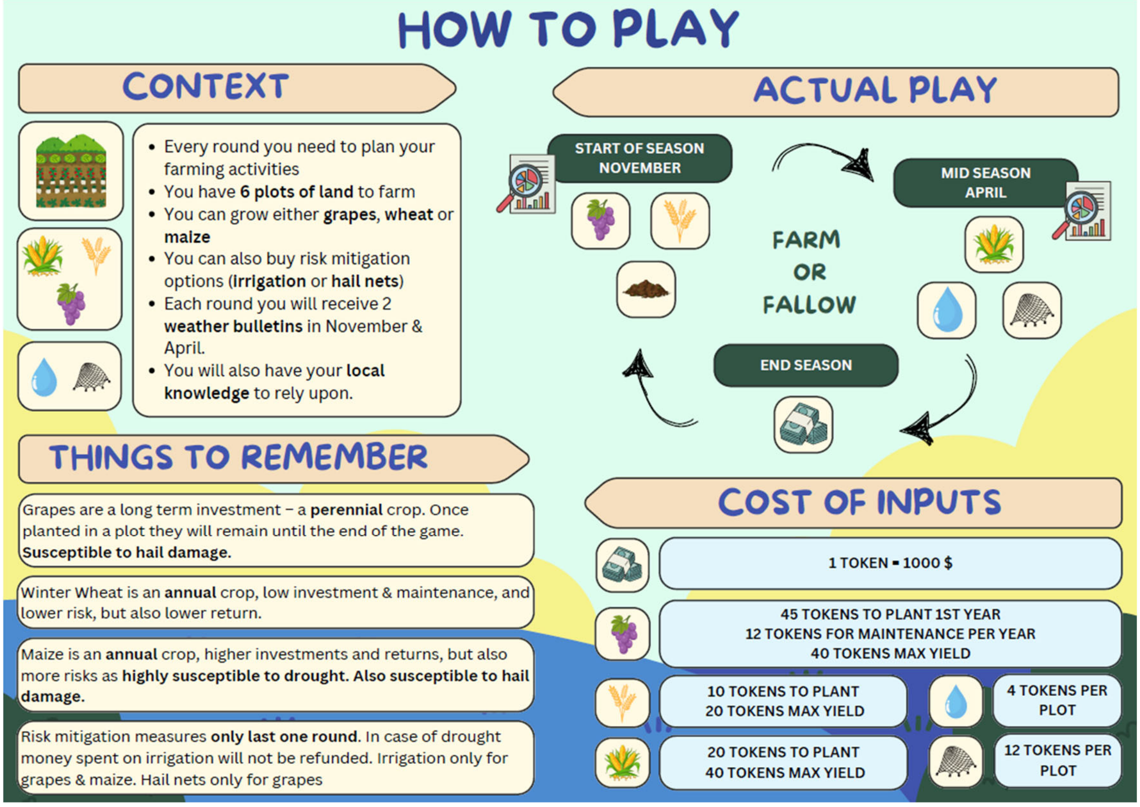
4.7 Serious Gaming to make citizens active players

Serious games, i.e., games developed for educational purposes, have gained traction in recent years as a way to communicate challenges associated with the environment, resource management, and planning in the face of climate change. They are effective storytelling tools that not only provide simplified representations of real-life situations and problems but also 'gamify' them to provide an immersive experience that can lead to learning. Within I-CISK, two serious games have been developed, Farm or Fallow and Terraform Your City, to facilitate participatory engagement and research.

4.7.1 Serious Game – Farm or Fallow

Within I-CISK, in addition to exploring and understanding decision-making processes and the LK underpinning them using decision timelines, we used serious gaming to understand how users of CS combine different knowledge. We develop and use the serious game, *Farm or Fallow*, to understand how CS users utilise different sources of information to make decisions under uncertainty. More specifically, the game is used to explore ways CS users combine different knowledge for decision making, whether integration of LK improves the accessibility of climate information and if serious gaming can help users in articulating the value add of CS.

The game simulates an agricultural livelihood, whereby players take on the role of farmers and manage their livelihoods through various activities (see Figure 12). Players are asked to play in teams of 3-4 persons. Facilitating the gameplay in groups encourages discussion and brings to the fore any implicit thoughts and judgements that players may have when deliberating on the provided information. Each round begins with players receiving a weather forecast bulletin that includes scientific forecasts (see Figure 13) and LK (see Figure 14). Each round represents a new farming season, with specific points throughout the round where players must make critical decisions. In addition to selecting which crops to plant and determining when to plant them, the game also offers options for coping with adverse weather conditions. The game is initialised based on information from the LL. For example, if the game is to be played in the Georgian LL, then the decision timelines co-developed with stakeholders in the LL and their LK and the CS co-created with the MAP are used as inputs to the play to make it as realistic as possible. In addition to the actual gameplay, a pre- and post-survey is developed, rapporteurs are instituted to record discussions during gameplay, and a debriefing session is conducted at the end of the game to collect data.



HOW TO PLAY

CONTEXT

- Every round you need to plan your farming activities
- You have **6 plots of land** to farm
- You can grow either **grapes**, **wheat** or **maize**
- You can also buy risk mitigation options (**irrigation** or **hail nets**)
- Each round you will receive 2 **weather bulletins** in November & April.
- You will also have your **local knowledge** to rely upon.

ACTUAL PLAY

START OF SEASON NOVEMBER

MID SEASON APRIL

FARM OR FALLOW

END SEASON

THINGS TO REMEMBER

Grapes are a long term investment – a **perennial** crop. Once planted in a plot they will remain until the end of the game. **Susceptible to hail damage.**

Winter Wheat is an **annual** crop, low investment & maintenance, and lower risk, but also lower return.

Maize is an **annual** crop, higher investments and returns, but also more risks as **highly susceptible to drought. Also susceptible to hail damage.**

Risk mitigation measures **only last one round**. In case of drought money spent on irrigation will not be refunded. Irrigation only for grapes & maize. Hail nets only for grapes

COST OF INPUTS

1 TOKEN = 1000 $

45 TOKENS TO PLANT 1ST YEAR
12 TOKENS FOR MAINTENANCE PER YEAR
40 TOKENS MAX YIELD

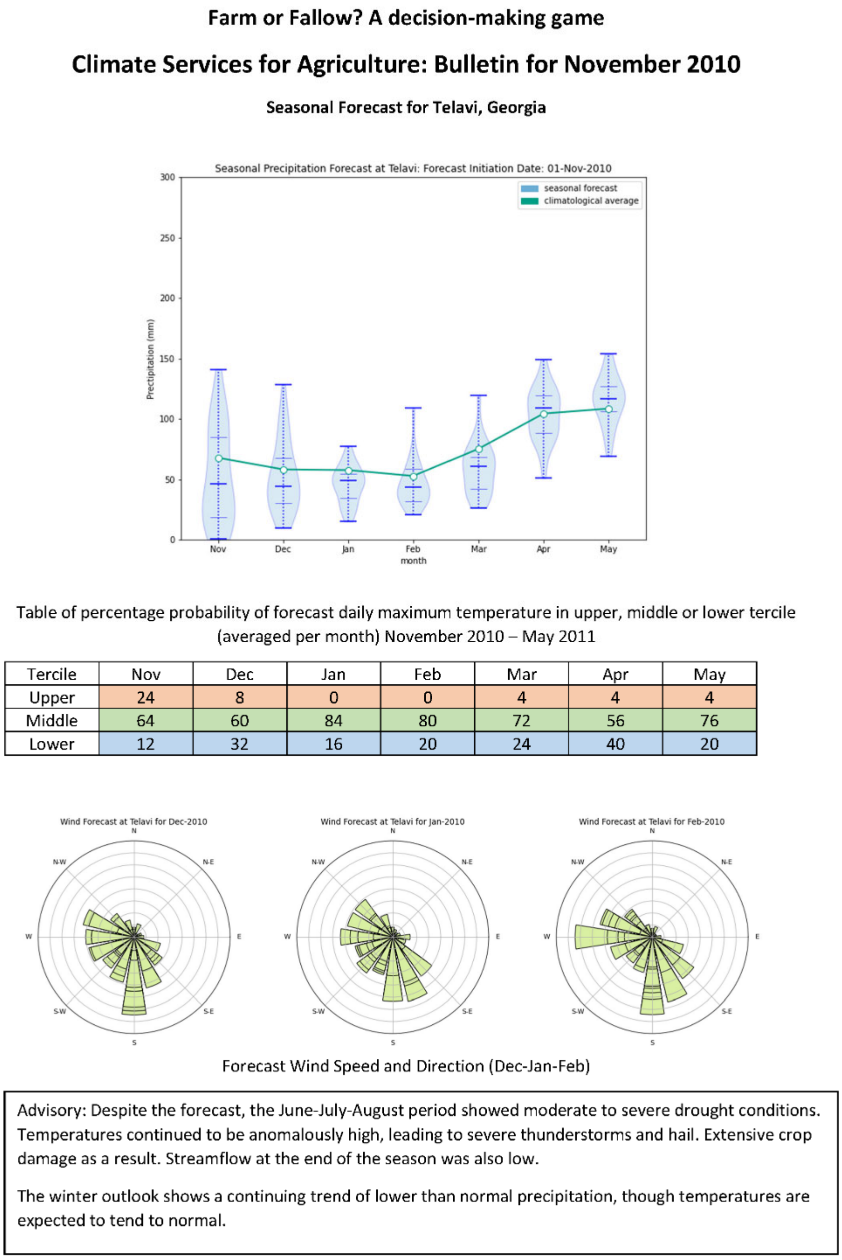
10 TOKENS TO PLANT
20 TOKENS MAX YIELD

4 TOKENS PER PLOT

20 TOKENS TO PLANT
40 TOKENS MAX YIELD

12 TOKENS PER PLOT

Figure 12 Game rules Farm or Fallow (game initialised for LL in Georgia)



Farm or Fallow? A decision-making game

Climate Services for Agriculture: Bulletin for November 2010

Seasonal Forecast for Telavi, Georgia

Table of percentage probability of forecast daily maximum temperature in upper, middle or lower tercile (averaged per month) November 2010 – May 2011

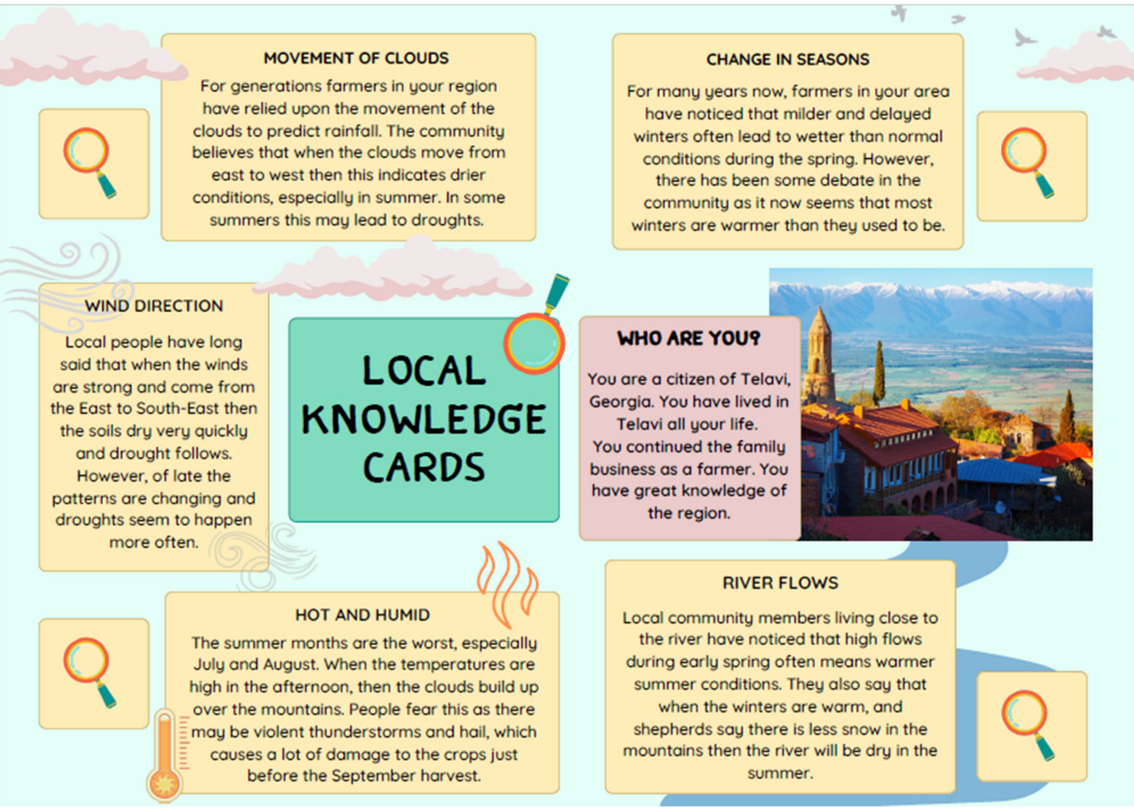
Tercile	Nov	Dec	Jan	Feb	Mar	Apr	May
Upper	24	8	0	0	4	4	4
Middle	64	60	84	80	72	56	76
Lower	12	32	16	20	24	40	20

Forecast Wind Speed and Direction (Dec-Jan-Feb)

Advisory: Despite the forecast, the June-July-August period showed moderate to severe drought conditions. Temperatures continued to be anomalously high, leading to severe thunderstorms and hail. Extensive crop damage as a result. Streamflow at the end of the season was also low.

The winter outlook shows a continuing trend of lower than normal precipitation, though temperatures are expected to tend to normal.

Figure 13 Scientific Knowledge provided to players through a seasonal bulleting (information-based CS in Georgian LL)



LOCAL KNOWLEDGE CARDS

MOVEMENT OF CLOUDS

For generations farmers in your region have relied upon the movement of the clouds to predict rainfall. The community believes that when the clouds move from east to west then this indicates drier conditions, especially in summer. In some summers this may lead to droughts.

CHANGE IN SEASONS

For many years now, farmers in your area have noticed that milder and delayed winters often lead to wetter than normal conditions during the spring. However, there has been some debate in the community as it now seems that most winters are warmer than they used to be.

WIND DIRECTION

Local people have long said that when the winds are strong and come from the East to South-East then the soils dry very quickly and drought follows. However, of late the patterns are changing and droughts seem to happen more often.

WHO ARE YOU?

You are a citizen of Telavi, Georgia. You have lived in Telavi all your life. You continued the family business as a farmer. You have great knowledge of the region.

HOT AND HUMID

The summer months are the worst, especially July and August. When the temperatures are high in the afternoon, then the clouds build up over the mountains. People fear this as there may be violent thunderstorms and hail, which causes a lot of damage to the crops just before the September harvest.

RIVER FLOWS

Local community members living close to the river have noticed that high flows during early spring often means warmer summer conditions. They also say that when the winters are warm, and shepherds say there is less snow in the mountains then the river will be dry in the summer.

Figure 14 LK cards handed out to players (information based on fieldwork in Georgian LL)

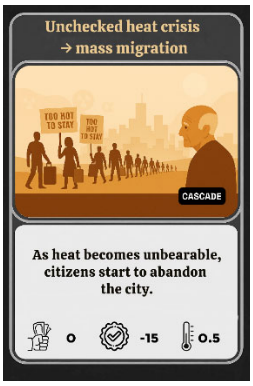
One of the key learning outcomes of the game is to help participants understand how CS and LK can complement each other, ultimately improving the accessibility and usability of climate information. Players assess the value of incorporating LK into CS and explore whether it enhances their ability to interpret and apply weather forecasts effectively. Through interactive gameplay, they also gain insights into the strengths and limitations of different climate information sources, enabling them to evaluate their reliability and relevance in real-world farming contexts critically. Additionally, *Farm or Fallow* encourages players to articulate the value of CSs in enhancing resilience to climate variability. Players reflect on how CS contributes to risk management and adaptive strategies by engaging in discussions during and after gameplay. The post-game debriefing session allowed participants to consolidate their learning, share their experiences, and discuss how the insights gained from the game can be applied to their farming practices.

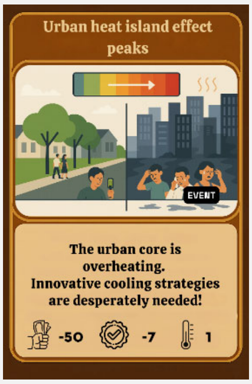
4.6.2 Serious Game – Terraform Your City

Terraform Your City is a serious board game set in a near-future urban environment facing the escalating challenges of climate change. Players take on the role of urban visionaries - city planners, policy advisors or civic leaders - working together to protect a city on the edge. The game combines strategic planning, resource management and interactive storytelling, using a 3-card system as its core mechanic:

- **Action cards** represent city-scale adaptation and mitigation projects (e.g. green roof initiatives, public awareness campaigns, reflective pavement installations).
- **Event cards** introduce unpredictable, often humorous twists, such as unexpected heat waves, or budget cuts representing real-world uncertainty and the cascading consequences of poor planning.

- **Cascade cards** play a critical role in simulating the chain reactions and compounding effects of climate-related urban challenges. These cards represent events that are not isolated, but triggered by previous in-game conditions or player decisions - often as a result of neglected issues, systemic weaknesses, or failure to act early. For example: An unaddressed heat crisis can lead to mass moving out (Unaddressed Heat Crisis → Mass outmigration). Lack of trees can trigger dust storms, worsening air quality (Lack of Trees → Dust Storms). Spreading misinformation can lead to public distrust, eroding support for green policies (Fake News → Public Distrust). Unlike standard event cards, cascade cards often appear after a series of negative conditions accumulate, reflecting how urban systems are interconnected and vulnerable to spiralling disruptions.





Both the physical and digital versions of the game feature analogue dashboards that track three key resources: 1. Money (budget impact), 2. Public approval, 3. Thermal debt (urban heat pressure). Each card affects these indicators, prompting players to weigh the cost-benefit ratio of their decisions within a dynamically changing urban system. Dice rolls introduce additional variability, influencing the severity of events or triggering cascading effects that reflect the interdependence of climate-related urban stressors.

The primary educational objectives of Terraform Your City are to:

- Promote systems thinking in the context of urban climate adaptation.
- Raise awareness of the trade-offs and dilemmas of sustainable policy making.
- Introduce players to different planning strategies' social, environmental and financial impacts.

- Encourage players to experience the complexity of real-world urban governance under environmental stress.

By simulating decision-making under pressure, the game provides a hands-on learning environment where players can explore how integrated urban policies interact, succeed or fail in the face of climate change. The game is designed for:

- University students from urban planning, sustainability, public administration or environmental studies.
- Policy makers and municipal staff involved in resilience planning.
- Climate educators and trainers looking for engaging tools for public outreach.
- Gamified learning settings, such as citizen science programmes or co-creation workshops in LLs.

A multi-layered assessment strategy has been integrated into the development and dissemination process to ensure that Terraform Your City functions effectively as an experiential learning tool. Before the game's public release, a pilot testing phase will be conducted with a group of young volunteers, during which structured debriefing sessions will help gather reflective feedback. Participants will be encouraged to answer key questions such as: *What trade-offs did you encounter? Which strategy was most effective? How does the game reflect real-world city planning challenges?* These insights will guide both the refinement of the game mechanics and the educational framing of the content. Simultaneously, the game's public release will be accompanied by post-game surveys designed to assess knowledge acquisition and shifts in perception. These surveys will evaluate participants' understanding of core urban climate concepts (e.g., urban heat island, green infrastructure), their grasp of key climate data, their awareness of trade-offs inherent in climate governance, and their perception of CSs and their role in urban resilience. In the digital version of the game, gameplay analytics will also be employed to examine decision-making patterns and player behaviour, including indicators of risk tolerance, cooperation, and strategic adaptability. This combination of reflective discussion, structured evaluation, and behavioural data aims to offer a comprehensive view of how the game supports learning, engagement, and the development of systems thinking around urban climate challenges. The game will be available in both digital and physical formats.

5 Synthesis and Reflection

Participatory methods were used across the I-CISK project to: (i) facilitate the co-creation process and (ii) to support research and innovation.

5.1 Participatory methods to facilitate co-creation

We find that participatory methods are used across the phases of co-creation to achieve varied outcomes. **Error! Reference source not found.** plots the participatory approaches used per phase of co-creation against the level of engagement (based on the ladder of engagement by Basco-Carrera et al., 2017). Additionally, the colours of the circles denote the outcome achieved per participatory process. When focusing on the outcomes, we also distinguish between product-related outcomes (enhancing salience, enhancing credibility and product development) and process-related outcomes (Supporting legitimacy, capacity building, informing policy and enhancing sustainability). The former predominantly deals with improvements in the technical or informational aspects of the CS. Process-related outcomes, on the other hand, encompass changes in how knowledge is shared, how decisions are made, and how power is distributed among stakeholders. These outcomes are critical for building trust, ensuring continued engagement, and fostering social learning (Fazey et al., 2014; Vincent et al., 2018).

The cornerstone to building usable CS is developing information that is credible, salient and legitimate (Cash et al., 2003). Across the co-creation process, we see participatory methods being used to enhance and support these outcomes. Enhancing credibility, for instance, was prioritised by several LLs across the co-development and co-design phases. In the case of the Italian LL, for instance, this meant incorporating local data to produce forecasts that better reflect local conditions. Similarly, in Lesotho, local data generated by LMS was pinpointed as being most effective in predicting the start of the rainy season and could be used to enhance the accuracy of downscaled forecasts. In the Hungarian LL, on the other hand, credibility was enhanced through citizen science interventions.

Enhancing salience was the most frequently addressed outcome, predominantly referring to better understanding user needs and priorities in the earlier stages of the process (co-exploration and co-identification phases). In the Spanish LL, this included not only characterising ongoing decision-making processes and adaptation strategies but also looking ahead and coming up with new adaptation options, and CS needs associated with the same. In the LLs, where more upstream CS users (like service providers) were involved (like Italy, Netherlands and Lesotho), discussion on salience already included considerations on spatial and temporal resolution of CS and integration of this information to inform policy actions. Salience was also supported in the LL in Greece through a better understanding of different levels of CS use and readiness across MAP members. LLs also addressed salience in the middle and later phases through user-testing the developed CS and seeking feedback on the usefulness of the information, whether it meets expectations discussed on the outset, and potential decisions users will take using the information.

Supporting legitimacy, in the form of fostering collaboration, exploring synergies and partnership was explicitly mentioned in some LLs. This was done from the outset, for example, in the LL in Georgia, where, since CS are still up-and-coming efforts were made to explore synergies and complementarities with other ongoing projects and national interventions to strengthen participation and collaboration with key stakeholders. Similarly, in the Spanish LL, supporting legitimacy meant seeking active participation of the MAP members in designing and approving the working methodology for the LL. Other LLs, like Lesotho and Greece, focused on improving legitimacy in the middle to later stages of the co-creation process. In Greece, for example, during the co-evaluation phase, the MAP members were brought together to identify potential CS value chain and inform the business development process.

Outcome associated with product development is also frequently cited by LLs. This includes interactions that lead to improvements in data and information accessibility, design, user interface etc. In most cases, product development is central to the co-creation process from the co-design phase onward, often culminating into some form of user-testing and feedback session. In addition to these outcomes, we also find participatory methods being instrumental in capacity building, informing policy and enhancing sustainability. However, capacity building interventions were an explicit focus of only three out of seven LLs. This may be due to the presence of very technical users in other LLs who are well versed with CS and their use. In the Budapest LL, capacity building is carried out repeatedly through information sessions, citizen science interventions and serious gaming. Informing policy similarly is only explicitly addressed in two out of 7 LLs. In the Italian LL, during the co-identification phase efforts are made to have structured discussions on adaptation pathways and provide policy recommendations. Similarly, in Hungary, policy integration of results from urban heat island mapping campaigns was also central to the co-creation process. Lastly in terms of enhancing sustainability, we find that most LLs focus on this during co-evaluation and co-delivery stages of co-creation. In the Italian LL, for example, CS value exploration and drafting of a business plan was carried out with the members of the MAP which included several institutional actors. In Lesotho, sustainability is enhanced through Lesotho Red Cross Society leveraging their position in the local context to reach out to other stakeholders for testing and identifying options for the CS uptake and use. **Error! Reference source not found.** also brings into focus the iterative nature of CS production process. Providing space for iteration is crucial in improving and realising outcomes (Bojovic et al., 2021).

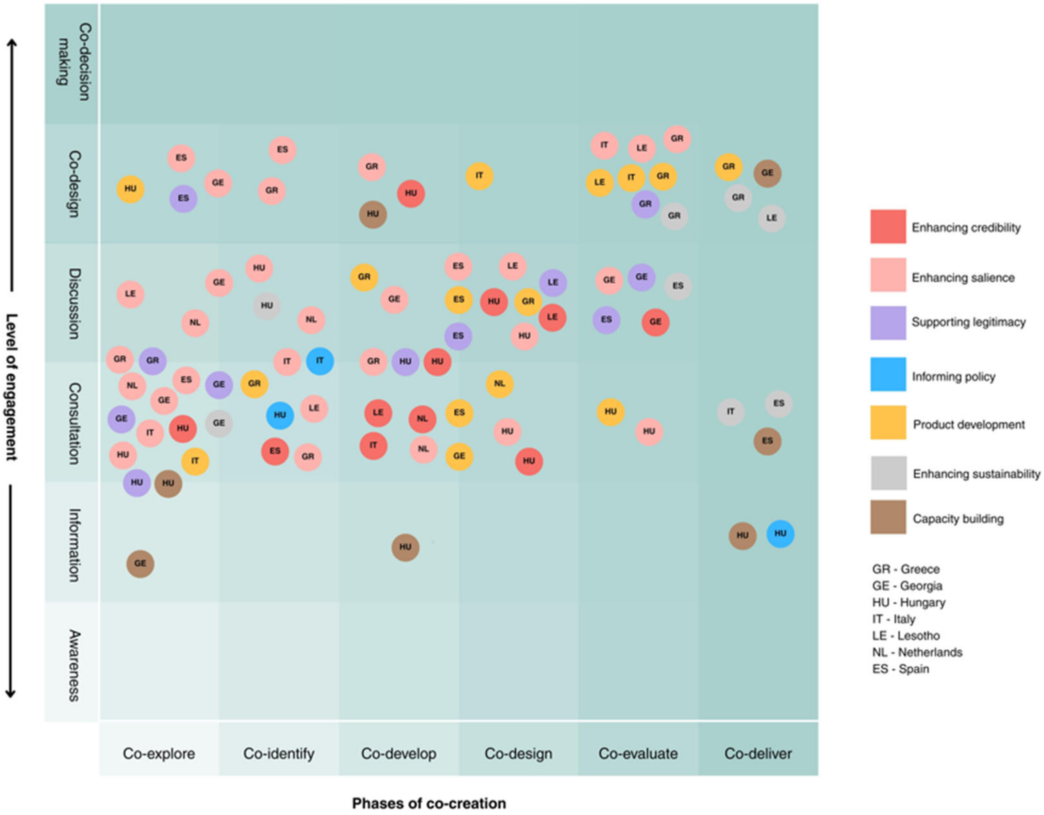


Figure 15 Overview of different degrees of engagement with MAP members across I-CISK LLs per phase of co-creation and to achieve product or process-related outcomes.

In terms of the level of engagement, we find that most of the participatory interventions lie within the consultation or discussion space. Co-design, in terms of level of engagement, was achieved through participatory methodologies like the Decision Timelines or User Testing workshops. This presents an interesting picture whereby despite the overarching approach to co-create CS, the level of engagement with the users rarely reaches co-design or co-decision-making stage. This may suggest that in reality there are limits to the extent to which co-creation can be achieved. This may be due to barriers to co-creation process such as, mismatched expectations between scientists and users, differing timelines and priorities, and institutional constraints that discourage genuine collaboration (Lemos et al., 2012; Vincent et al., 2018). We, therefore, suggest that a more intentional discussion on the method of engagement and drawing on different techniques for the same (see Table 1, Chapter 1) can help in enriching participation during the co-creation process. Additionally, challenges such as power asymmetries, limited capacity among users to influence technical content, and a lack of time, resources and capacity to run participatory engagement (Harjanne, 2021; Bremer & Meisch, 2017). Lastly, while the figure gives an overview on outcomes and levels of engagement overall, it must be acknowledged that differences may exist among different MAP members. The ability of different MAP members to engage in a participatory process may be contingent on several factors including the design of the process, their own capacity, time and trust in the process (Newig & Fritsch, 2009).

5.2 Participatory methods to facilitate learning across LLs

Social learning is a critical component in making CS more inclusive and usable. Resulting from a process of iterative reflection that occurs when people with diverse knowledge, values, and experiences collaborate to solve complex problems (Reed, 2008), social learning can lead to shared understanding, mutual trust, and more democratic decision-making. In the context of CS, it fosters not only the exchange of information between scientists and stakeholders, but also the transformation of how climate knowledge is understood, interpreted, and used.

The experience across I-CISK LLs demonstrates how participatory methods can foster social learning and empower citizens and stakeholders as active players in climate action. Participatory approaches brought together diverse actors to develop shared understandings of climate risks, decision-making challenges, and potential solutions. Through iterative engagement, stakeholders moved from being passive recipients of information to active contributors shaping the design and function of CS.

In Italy, engagement processes helped institutional actors articulate their tacit knowledge and identify operational thresholds, which were directly integrated into the CS. This built mutual trust and made the service more actionable and credible within local water management context. In Lesotho, the participatory process bridged scientific and indigenous knowledge systems, enabling joint exploration of new ways of delivering timely and usable drought information. In Georgia, participatory tools allowed users to reflect on the varied climate information needs of farmers and upstream agencies, revealing a nuanced understanding of existing practices and opportunities for improvement. Meanwhile, Spain’s LL highlighted how ongoing, open collaboration can turn CS into platforms for sustained engagement. Here, LK filled critical data gaps, especially in hydrogeological modelling, and citizens became co-researchers in identifying indicators for agricultural resilience. Importantly social learning can extend beyond the initial project, catalysing further collaborations and integrating climate thinking into new research, governance, and community initiatives.

Collectively, these cases show that when participation is approached as a process of mutual learning—not just consultation—citizens and institutions are better equipped to understand, anticipate, and act on climate challenges. Empowering stakeholders in this way builds not only better CS, but also stronger collaboration for climate resilience. It shifts the paradigm from delivering information to building capacity and agency, laying the foundation for more inclusive, democratic, and sustainable climate action.

5.3 Participatory methods to support research & innovation

We find that participatory methods were used to explore and investigate various research themes across the I-CISK project. Given that much of this research was led by individuals (such as Early Career Researchers), we find that the research was very targeted often focusing on a particular LL, constrained by the context of the LL as well as the specific research objectives of the researchers. The participatory methods used include methods to design and create awareness about CS, characterise and understand adaptation strategies evaluating the role of co-creation processes in affecting adoption of CS, and understanding the impact of CS use. These participatory approaches varied in degree of engagement with stakeholders—from information-sharing and consultation to deeper engagement through co-design, co-learning, and joint evaluation. For example, the use of Decision Timelines allowed for the visualization of seasonal decision-making processes in collaboration with stakeholders, highlighting the temporal and cultural cues that influence when and how decisions are made. Such tools align with calls for participatory “boundary work” that helps mediate between knowledge systems and supports iterative learning (Cash et al., 2003; Kirchhoff et al., 2013). In this way, participatory tools not only supported mutual understanding but also enabled the co-production of services more attuned to decision-makers’ needs and constraints.

Participatory methods were also used to support research and innovation within LLs. For instance, in Spain, participatory methods were used in the co-development of a local groundwater model and the characterization of long-term adaptation strategies in the Andalusia-Los Pedroches LL (LL), highlighting the value of integrating LK with scientific and technical data to inform CSs and decision-making. These approaches allowed for the triangulation of knowledge sources and revealed crucial insights into local hydrological patterns, adaptive responses to drought, and the barriers shaping adaptation decisions. In another example, participatory methods like Direct Choice Experiments (DCE) were used within the Rijnland LL to demonstrate how stakeholder engagement can actively contribute to research innovation, especially in understanding the socio-behavioural dynamics behind CS adoption. DCE provided an avenue for surfacing context-specific values and barriers that often remain hidden in more top-down approaches to CS design. For example, it revealed the nuanced ways in which boat owners weigh trade-offs between harbour fees, travel distances, and navigability in drought-affected waterways. By making these decisions explicit and quantifiable, the DCE helped uncover potential entry points for tailoring CSs to user needs.

The integration of system dynamics and participatory modelling approaches, as exemplified in the work of Biella et al. (2024), demonstrates how inclusive engagement can bridge scientific inquiry with local realities. In particular, participatory modelling enabled LL leaders and sectoral stakeholders to co-construct conceptual frameworks that better reflect the socio-ecological complexities and decision-making challenges they face. By iteratively involving stakeholders in hypothesis development, model validation, and feedback loops, the research process itself became a site of learning and innovation—one in which scientific and LK systems were synthesized to produce more grounded, relevant, and adaptive insights. The participatory process itself acted as an enabler of innovation, helping stakeholders to reflect on unintended consequences, test new assumptions, and identify leverage points for transformative change. In doing so, it moved the field beyond narrow, short-term metrics of service "uptake" and toward a more systemic, inclusive and reflexive understanding of how CSs can support equitable climate adaptation.

Participatory research was critical in supporting evaluation and reflexive learning. Contribution Analysis approach in Lesotho LL offers an example of a methodological approach that uses participatory evaluation strategy to critically evaluate underlying assumption in CS research: that co-creation automatically leads to service uptake and use**.** By integrating a participatory evaluation framework into the I-CISK co-creation process, the team was able to move beyond anecdotal or assumed impact and instead begin to systematically interrogate how, why, and under what conditions co-created CS are actually used in decision-making. This shift from prescriptive co-creation models to evidence-based contribution mapping represents a methodological innovation that supports both learning and accountability in transdisciplinary research. The use of CA also reframed the role of participation from being solely a co-design function to also serving as a means of evidencing and validating the impact of CS over time. This emphasis on understanding causal linkages and intermediate outcomes aligns with growing calls for more evidence-based evaluation of co-production impacts (Wall et al., 2017; Lemos & Morehouse, 2005).

In addition to the above methods, Serious Games (Farm or Fallow and Terraform Your City) were used as participatory tools with the I-CISK project. Both games operate not only as pedagogical instruments but also as co-creative spaces where stakeholders and researchers collaboratively explore uncertainty, decision-making dynamics, and the accessibility and value of CS. By immersing players in simulated but context-specific decision environments, the games enable participants to engage with CS not in abstract terms but through lived, strategic choices—whether as farmers navigating seasonal variability or city planners confronting cascading urban stressors. The interactive nature of serious gaming stimulates discussion, surfaces implicit knowledge, and supports articulation of values and trade-offs that might otherwise remain unspoken in more conventional workshop settings. Moreover, both games integrate robust assessment strategies, including structured feedback sessions, surveys, and even gameplay analytics in the digital version of *Terraform*, offering multi-dimensional insights into learning outcomes, behavioural shifts, and system understandings. Ultimately, these serious games do not merely simulate CS use—they create a safe, engaging environment for participants to negotiate knowledge systems, articulate values, and test strategies, making them especially powerful in co-creation processes.

Finally, these participatory approaches also resonate with principles of Action Research**,** an iterative, participatory method rooted in democratic inquiry and designed to link research with action (Reason & Bradbury, 2001; Coghlan & Brannick, 2010). In I-CISK, action research principles were reflected in the recursive cycles of planning, acting, observing, and reflecting embedded in LL. By positioning researchers and stakeholders as co-investigators, Action research promotes mutual learning and facilitates context-sensitive innovations, a necessary condition for usable and inclusive CSs (van der Hel, 2016; Fazey et al., 2018). This framing repositions participatory research not only as a tool for inclusion but also aimed at transformation—towards knowledge that is actionable, reflexive, and socially embedded.

6 Conclusion

The I-ICISK project uses participatory methods to engage and inform end-users, encouraging them to become active players in climate action. Participatory methods were, therefore, applied across LLs to facilitate the co-creation process and support user-centred research and innovation across the I-CISK project

We find that participatory methods are not merely supportive tools but are central to the co-creation, learning, and innovation processes essential for developing inclusive and actionable CSs (CS). These methods, when applied across different phases of co-creation, enable the generation of both product-related and process-related outcomes, enhancing the salience, credibility, and legitimacy of CS. Importantly, outcomes such as capacity building, informing policy, and improving sustainability further underscore the multifaceted value of stakeholder engagement. The participatory approaches adopted also played a critical role in fostering social learning and building long-term collaborations. By facilitating reflection, dialogue, and joint problem-solving among diverse actors, these methods helped shift users from passive recipients of climate data to active contributors in knowledge production. Examples from I-CISK LLs show that how different participatory tools (like decision timelines, serious gaming) catalyse mutual understanding, trust-building, and co-production of knowledge that is contextually grounded and relevant Through these processes, participatory engagement goes beyond delivering more usable CS—it becomes a mechanism for strengthening local agency, embedding climate thinking into wider governance systems, and supporting climate action.

Despite the power of participatory engagement, we also recognise that running such processes can be resource-intensive and require experience and capacity to do it successfully. Within I-CISK, we find that much of the engagement sits within the consultation or discussion space unless a co-design session has been intentionally introduced (like decision timelines or user testing workshops). We therefore recommend more intentional discussion of different participatory methodologies to ensure a more deliberate design and commitment to inclusive and meaningful engagement. Lastly, purposeful consideration and use of participatory methods must be embedded across the different phases of co-creation in order to encourage sustainable uptake of CS.

References

Alexander, S., Block, P. (2022). Integration of seasonal precipitation forecast information into local-level agricultural decision-making using an agent-based model to support community adaptation. Climate Risk https://doi.org/10.1016/J.CRM.2022.100417

Apgar, M., Hernandez, K., & Ton, G. (2020). Contribution analysis for adaptive management. *Briefing Note*.

Barnett, J. and O'Neill, S. (2010), "Maladaptation", Global Environmental Change, Pergamon, Vol. 20 No. 2, pp. 211–213, doi: 10.1016/J.GLOENVCHA.2009.11.004.

Basco-Carrera, L., Warren, A., van Beek, E., Jonoski, A., & Giardino, A. (2017). Collaborative modelling or participatory modelling? A framework for water resources management. *Environmental Modelling & Software*, *91*, 95-110. https://doi.org/10.1016/j.envsoft.2017.01.014

Bell, Simon, Tessa Berg, and Stephen Morse. 2016. "Rich Pictures: Sustainable Development and Stakeholders - The Benefits of Content Analysis." Sustainable Development 24 (2): 136–48. https://doi.org/10.1002/sd.1614.

Berrang-Ford, L., Siders, A. R., Lesnikowski, A., Fischer, A. P., Callaghan, M. W., Haddaway, N. R., ... & Abu, T. Z. (2021). A systematic global stocktake of evidence on human adaptation to climate change. *Nature climate change*, *11*(11), 989-1000. https://doi.org/10.1038/s41558-021-01170-y

Biella, R., Mazzoleni, M., Brandimarte, L., & Di Baldassarre, G. (2024). Thinking systemically about CSs: Using archetypes to reveal maladaptation. *CSs*, *34*, 100490. https://doi.org/10.1016/j.cliser.2024.100490

Birkmann, J. (2011). First-and second-order adaptation to natural hazards and extreme events in the context of climate change. *Natural Hazards*, *58*(2), 811-840. https://doi.org/10.1007/s11069-011-9806-8

Blackett, Paula, Stephen FitzHerbert, Jordan Luttrell, Tania Hopmans, Hayley Lawrence, and Jackie Colliar. 2022. "Marae-Opoly: Supporting Localised Māori Climate Adaptation Decisions with Serious Games in Aotearoa New Zealand." Sustainability Science 17 (2): 415–31. https://doi.org/10.1007/s11625-021-00998-9.

Bojovic, D., Clair, A. L. S., Christel, I., Terrado, M., Stanzel, P., Gonzalez, P., & Palin, E. J. (2021). Engagement, involvement and empowerment: Three realms of a coproduction framework for CSs. *Global Environmental Change*, *68*, 102271. https://doi.org/10.1016/j.gloenvcha.2021.102271

Boon, E., Goosen, H., van Veldhoven, F. and Swart, R. (2021), "Does Transformational Adaptation Require a Transformation of CSs?", Frontiers in Climate, Frontiers Media S.A., Vol. 3, doi: 10.3389/fclim.2021.615291.

Boon, E., Wright, S.J., Biesbroek, R., Goosen, H. and Ludwig, F. (2022), "Successful CSs for adaptation: What we know, don't know and need to know", CSs, Elsevier B.V., Vol. 27, doi: 10.1016/J.CLISER.2022.100314.

Borzì, I. (2025). Assessing impacts of climate crisis on water distribution systems though service inefficiency indicator. *Journal of Water and Climate Change*, jwc2025276. https://doi.org/10.2166/wcc.2025.276

Braman, L.M., van Aalst, M.K., Mason, S.J., Suarez, P., Ait-Chellouche, Y. and Tall, A. (2013), “Climate forecasts in disaster management: Red Cross flood operations in West Africa, 2008”, Disasters, John Wiley & Sons, Ltd, Vol. 37 No. 1, pp. 144–164, doi: 10.1111/J.1467-7717.2012.01297.X

Bremer, S., & Meisch, S. (2017). Co-production in climate change research: reviewing different perspectives. *Wiley Interdisciplinary Reviews: Climate Change*, *8*(6), e482. **https://doi.org/10.1002/wcc.482**

Bruley, E., Locatelli, B., Colloff, M. J., Salliou, N., Métris, T., & Lavorel, S. (2021). Actions and leverage points for ecosystem-based adaptation pathways in the Alps. https://hdl.handle.net/10568/115058

Bwambale, Bosco, Kewan Mertens, Thaddeo Kahigwa Tibasiima, and Matthieu Kervyn. 2022. “ The Socio-
Epistemic Process of Indigenous Disaster Risk Reduction: Evidence of Adapting yet Endangered Indigenous Strategies.” International Journal of Disaster Risk Reduction 75 (April): 102953. https://doi.org/10.1016/j.ijdrr.2022.102953

Calvel, Alexia, Micha Werner, Marc van den Homberg, Andrés Cabrera Flamini, Ileen Streefkerk, Neha Mittal, Stephen Whitfield, Charles Langton Vanya, and Clement Boyce. 2020. “Communication Structures and Decision Making Cues and Criteria to Support Effective Drought Warning in Central Malawi.” *Frontiers in Climate* 2 (November): 16. https://doi.org/10.3389/FCLIM.2020.578327/BIBTEX.

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., ... & Mitchell, R. B. (2003). Knowledge systems for sustainable development. *Proceedings of the national academy of sciences*, *100*(14), 8086-8091. 1 https://doi.org/10.1073/pnas.1231332100

Chiputwa, B., Wainaina, P., Nakelse, T., Makui, P., Zougmoré, R.B., Ndiaye, O. and Minang, P.A., 2020. Transforming climate science into usable services: The effectiveness of co-production in promoting uptake of climate information by smallholder farmers in Senegal. CSs, 20, p.100203.

Clark, I., & Brake, L. (2009). Using LK to improve understanding of groundwater supplies in parts of arid South Australia. *GeoJournal*, *74*, 441-450. https://doi.org/10.1007/s10708-008-9236-7

Clatworthy, Y. (2022a), Quick and Reliable Funding: How FbA by the DREF Supported a Shift from Reaction to Anticipation in 2020, Berlin.

Clatworthy, Y. (2022b), Developing Triggers for Forecast-Based Financing: How Partnerships Can Strengthen Anticipatory Action, Berlin.

Clatworthy, Y. (2023a), Anticipatory Action in Practice: Acting Early Ahead of Typhoons in the Philippines, Berlin.

Clatworthy, Y. (2023b), Heat Waves in Hanoi: How Anticipatory Action Can Help to Mitigate a Growing Urban Threat The FbF Ready Project: Forecast-Based Financing for Heat Waves, Berlin.

Clatworthy, Y. (2023c), The Co-Benefits of Forecast-Based Financing and Anticipatory Action, Berlin.

Clifford, K. R., Travis, W. R., & Nordgren, L. T. (2020). A climate knowledges approach to CSs. CS s, 18. https://doi.org/10.1016/J.CLISER.2020.100155

Coghlan, D. (2019). Doing action research in your own organization.

Cruz-Bello, G. M., M. Alfie-Cohen, N. A. Morales-Zaragoza, A. H. Larralde-Corona, and J. Reyes Perez. 2018. "Flood Vulnerability Reduction, Using a Partial Participatory GIS Approach. A Study Case in Baja California Sur, Mexico." International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives 42 (3W4): 185–90. https://doi.org/10.5194/isprs-archives-XLII-3-W4-185-2018.

Di Baldassarre, G., Martinez, F., Kalantari, Z. and Viglione, A. (2017), "Drought and flood in the Anthropocene: Feedback mechanisms in reservoir operation", Earth System Dynamics, Copernicus GmbH, Vol. 8 No. 1, pp. 225–233, doi: 10.5194/ESD-8-225-2017.

Elsawah, S., Pierce, S.A., Hamilton, S.H., Van Delden, H., Haase, D., Elmahdi, A. and Jakeman, A.J. (2017), "An overview of the system dynamics process for integrated modelling of socio-ecological systems: Lessons on good modelling practice from five case studies", Environmental Modelling and Software, Vol. 93, pp. 127–145, doi: 10.1016/j.envsoft.2017.03.001.

Eriksen, S.H., Nightingale, A.J. and Eakin, H. (2015), "Reframing adaptation: The political nature of climate change adaptation", Global Environmental Change, Pergamon, Vol. 35, pp. 523–533, doi: 10.1016/J.GLOENVCHA.2015.09.014.

Food and Agriculture Organization. 2005. "Building on Gender, Agrobiodiversity and LK Training Manual." https://www.fao.org/3/y5956e/y5956e.pdf.

Fazey, I., Bunse, L., Msika, J., Pinke, M., Preedy, K., Evely, A. C., ... & Reed, M. S. (2014). Evaluating knowledge exchange in interdisciplinary and multi-stakeholder research. *Global Environmental Change*, *25*, 204-220. https://doi.org/10.1016/j.gloenvcha.2013.12.012

Fazey, I., Schäpke, N., Caniglia, G., Patterson, J., Hultman, J., Van Mierlo, B., ... & Wyborn, C. (2018). Ten essentials for action-oriented and second order energy transitions, transformations and climate change research. *Energy Research & Social Science*, *40*, 54-70.https://doi.org/10.1016/j.erss.2017.11.026

Fedele, G., Donatti, C.I., Harvey, C.A., Hannah, L. and Hole, D.G. (2019), "Transformative adaptation to climate change for sustainable social-ecological systems", Environmental Science and Policy, Elsevier Ltd, Vol. 101, pp. 116–125, doi: 10.1016/j.envsci.2019.07.001.

Fischer, A. P., & Denny, R. C. (2024). Evaluating behavioral responses to climate change in terms of coping and adaptation: An index approach. *Global Environmental Change*, *86*, 102837. https://doi.org/10.1016/j.gloenvcha.2024.102837

Gallart, F., Cid, N., Latron, J., Llorens, P., Bonada, N., Jeuffroy, J., ... & Prat, N. (2017). TREHS: An open-access software tool for investigating and evaluating temporary river regimes as a first step for their ecological status assessment. *Science of the Total Environment*, *607*, 519-540. https://doi.org/10.1016/j.scitotenv.2017.06.209

Garcia, M., Ridolfi, E. and Di Baldassarre, G. (2020), "The interplay between reservoir storage and operating rules under evolving conditions", Journal of Hydrology, Elsevier B.V., Vol. 590, doi: 10.1016/J.JHYDROL.2020.125270.

Giordano, Raffaele, Elisabetta Preziosi, and Emanuele Romano. 2013. "Drought Impact Monito ring : Some Hints from an Italian Case Study," 523–44. https://doi.org/10.1007/s11069-013-0724-9.

Girons Lopez, M., Di Baldassarre, G. and Seibert, J. (2017), "Impact of social preparedness on flood early warning systems", Water Resources Research, John Wiley & Sons, Ltd, Vol. 53 No. 1, pp. 522–534, doi: 10.1002/2016WR019387.

Grossi, A. and Dinku, T., 2022. Enhancing national CSs: How systems thinking can accelerate locally led adaptation. One Earth, 5(1), pp.74-83.

Haigh, Tonya, Eugene Takle, Jeffrey Andresen, Melissa Widhalm, J. Stuart Carlton, and Jim Angel. 2015. "Mapping the Decision Points and Climate Information Use of Agricultural Producers across the U.S. Corn Belt." *Climate Risk Management* 7: 20–30. https://doi.org/10.1016/j.crm.2015.01.004.

Hallett, L. M., & Hobbs, R. J. (2020). Thinking systemically about ecological interventions: what do system archetypes teach us?. *Restoration Ecology*, *28*(5), 1017-1025.https://doi.org/10.1111/rec.13220

Harjanne, A. (2017). Servitizing climate science—Institutional analysis of CSs discourse and its implications. *Global environmental change*, *46*, 1-16. https://doi.org/10.1016/j.gloenvcha.2017.06.008

Haque, Anika Nasra. 2021. "Climate Risk Responses and the Urban Poor in the Global South: Th e Case of Dhaka's Flood Risk in the Low-Income Settlements." International Journal of Disaster Risk Reduction 64 (August): 102534. https://doi.org/10.1016/j.ijdrr.2021.102534.

Haasnoot, Marjolijn, Jan H. Kwakkel, Warren E. Walker, and Judith ter Maat. 2013. "Dynamic A daptive Policy Pathways: A Method for Crafting Robust Decisions for a Deeply Uncertain World ." Global Environmental Change https://doi.org/10.1016/j.gloenvcha.2012.12.006. 23 (2): 485–98.

Hesed, Christine D.Miller, Michael Paolisso, Elizabeth R. Van Dolah, and Katherine J. Johnson. 2 022. "Using Cultural Consensus Analysis to Measure Diversity in Social–Ecological Knowledge for Inclusive Climate Adaptation Planning." Weather, Climate, and Societ y 14 (1): 51–64. https://doi.org/10.1175/WCAS-D-21-0047.1.

Hewitt, C. D., & Stone, R. (2021). CSs for managing societal risks and opportunities. *CSs*, *23*, 100240. https://doi.org/10.1016/j.cliser.2021.100240

Hirons, L., Thompson, E., Dione, C., Indasi, V.S., Kilavi, M., Nkiaka, E., Talib, J., Visman, E., Adefisan, E.A., de Andrade, F. and Ashong, J., 2021. Using co-production to improve the appropriate use of sub-seasonal forecasts in Africa. CSs, 23, p.100246.

I-CISK MS10, 2022: A prototype framework on co-creating end-user CSs. I-CISK Milestone Report MS10

IFRC, International Federation of the Red Cross. Vulnerability and Capacity Assessment toolbox . https://www.ifrcvca.org/toolbox

Kirchhoff, C. J., Carmen Lemos, M., & Dessai, S. (2013). Actionable knowledge for environmental decision making: broadening the usability of climate science. *Annual review of environment and resources*, *38*(1), 393-414. **https://doi.org/10.1146/annurev-environ-022112-112828**

Kwoyiga, L., & Stefan, C. (2018). Groundwater development for dry season irrigation in North East Ghana: The place of LK. *Water*, *10*(12), 1724. **https://doi.org/10.3390/w10121724**

Larsson, I. (1984). *Ground water in hard rocks*. Paris: Unesco.

Lemos, M. C., & Morehouse, B. J. (2005). The co-production of science and policy in integrated climate assessments. *Global environmental change*, *15*(1), 57-68. https://doi.org/10.1016/j.gloenvcha.2004.09.004

Lemos, M. C., Kirchhoff, C. J., & Ramprasad, V. (2012). Narrowing the climate information usability gap. *Nature climate change*, *2*(11), 789-794. https://doi.org/10.1038/nclimate1614

Magnan, A. K., Schipper, E. L. F., Burkett, M., Bharwani, S., Burton, I., Eriksen, S., ... & Ziervogel, G. (2016). Addressing the risk of maladaptation to climate change. *Wiley Interdisciplinary Reviews: Climate Change*, *7*(5), 646-665. https://doi.org/10.1002/wcc.409

Marschütz, Benedikt, Scott Bremer,Hens Runhaar, Dries Hegger, Heleen Mees,Joost Vervoort, and Arjan Wardekker. 2020."Local Narratives of Change as an Entry Point for Building Urban Climate Resilience."Climate Risk Management 28 (July 2019): 100223.https://doi.org/10.1016/j.crm.2020.100223.

Masih, I., Van Cauwenbergh, N., et al., 2022. Characterization of the I-CISK LLs, I-CISK Deliverable 1.1, Available online at www.icisk.eu/resources

Mayne, J., 2008. Contribution analysis: An approach to exploring cause and effect. ILAC brief.

Mirchi, A., Madani, K., Watkins, D. and Ahmad, S. (2012), "Synthesis of System Dynamics Tools for Holistic Conceptualization of Water Resources Problems", *Water Resources Management*, Vol. 26 No. 9, pp. 2421–2442, doi: 10.1007/s11269-012-0024-2.

Neset, T. S., Wilk, J., Cruz, S., Graça, M., Rød, J. K., Maarse, M. J., ... & Andersson, L. (2021). Co-designing a citizen science CS. *CSs*, *24*, 100273. https://doi.org/10.1016/j.cliser.2021.100273

Newig, J., & Fritsch, O. (2009). Environmental governance: participatory, multi-level–and effective?. *Environmental policy and governance*, *19*(3), 197-214. **https://doi.org/10.1002/eet.509**

Pauli, N., Williams, M., Henningsen, S., Davies, K., Chhom, C., Ogtrop, F. Van, Hak, S., Boruff, B., & Pauli, N. (2021). '" Listening to the Sounds of the Water "': Bringing Together LK and Biophysical Data to Understand Climate-Related Hazard Dynamics. International Journal of Disaster https://doi.org/10.1007/s13753-021-00336-8 Risk Science, 12(3), 326–340.

Perrels, A., Le, T.T., Cortekar, J., Hoa, E. and Stegmaier, P. (2020), "How much unnoticed merit is there in CSs?", CSs, Elsevier B.V., Vol. 17, doi: 10.1016/j.cliser.2020.100153.

Ray, A. J., & Webb, R. S. (2016). Understanding the user context: decision calendars as frameworks for linking climate to policy, planning, and decision-making. *Climate in context:*

Science and society partnering for adaptation, 27-50. https://doi.org/10.1002/9781118474785.ch2

Reason, P., & Bradbury, H. (Eds.). (2001). *Handbook of action research: Participative inquiry and practice*. sage.

Reed, M. S. (2008). Stakeholder participation for environmental management: a literature review. *Biological conservation*, *141*(10), 2417-2431. https://doi.org/10.1016/j.biocon.2008.07.014

Singh, Naveen P., Bhawna Anand, S. K. Srivastava, N. R. Kumar, Shirish Sharma, S. K. Bal, K. V. R ao, and M. Prabhakar. 2022. "Risk, Perception and Adaptation to Climate Change: Evidence fro m Arid Region, India." Natural Hazards 112 (2): 1015–37. https://doi.org/10.1007/s11069-022-05216-y.

Tesfaye, A., Hansen, J., Kassie, G. T., Radeny, M., & Solomon, D. (2019). Estimating the economic value of CSs for strengthening resilience of smallholder farmers to climate risks in Ethiopia: A choice experiment approach. *Ecological Economics*, *162*, 157-168. https://doi.org/10.1016/j.ecolecon.2019.04.019

Tesfaye, Abonesh, James Hansen, Maren Radeny, Sebsib Belay, and Dawit Solomon. 2020. Clim ate "Actor Roles and Networks in Agricultural CSs in Ethiopia: A Social Network Analysis." and Development https://doi.org/10.1080/17565529.2019.1691485.

Van den Homberg M., Rastogi S., et al. (2024) User-centred validation of climate risk knowledge integration. www.icisk.eu

van der Hel, S. (2016). New science for global sustainability? The institutionalisation of knowledge co-production in Future Earth. *Environmental science & policy*, *61*, 165-175.https://doi.org/10.1016/j.envsci.2016.03.012

Vincent, K., Daly, M., Scannell, C., & Leathes, B. (2018). What can CSs learn from theory and practice of co-production?. *CSs*, *12*, 48-58. https://doi.org/10.1016/j.cliser.2018.11.001

Vogel, C., Steynor, A. and Manyuchi, A., 2019. CSs in Africa: Re-imagining an inclusive, robust and sustainable service. *CSs, 15*, p.100107.

Voinov, A., & Gaddis, E. J. B. (2008). Lessons for successful participatory watershed modeling: a perspective from modeling practitioners. *Ecological modelling*, *216*(2), 197-207. https://doi.org/10.1016/j.ecolmodel.2008.03.010

Voinov, A., Jenni, K., Gray, S., Kolagani, N., Glynn, P. D., Bommel, P., ... & Smajgl, A. (2018). Tools and methods in participatory modeling: Selecting the right tool for the job. *Environmental Modelling & Software*, *109*, 232-255. https://doi.org/10.1016/j.envsoft.2018.08.028

Wall, T. U., McNie, E., & Garfin, G. M. (2017). Use-inspired science: making science usable by and useful to decision makers. *Frontiers in Ecology and the Environment*, *15*(10), 551-559. **https://doi.org/10.1002/fee.1735**

Wilkinson, E., Weingärtner, L., Choularton, R., Bailey, M., Todd, M., Kniveton, D. and Cabot Venton, C. (2018), Forecasting Hazards, Averting Disasters Implementing Forecast-Based Early Action at Scale.