I-CISK

HUMAN CENTRED CLIMATE SERVICES

Deliverable D2.4

Information on climate service needs and gaps

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I-CISK

Innovating Climate Services through Integrating Scientific and local Knowledge

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Executive Summary

Co-exploring user-needs for climate data and information to support critical decision making is key to the design and development of useful and usable Climate Services (CS). It is important to understand barriers to the use of existing CS and how these issues can be addressed through effective design and communication.

This report (Egan, Emerton, et al., 2025 [D2.4]) provides a detailed overview of the use of existing climate services (CS) at the start of the I-CISK project in early 2022 in each of the seven participating Living Labs (LLs; located in The Netherlands, Spain, Italy, Greece, Hungary, Georgia and Lesotho). It identifies user needs and barriers to the use of these existing services, then demonstrates how new, tailored CS, co-created through the I-CISK project, are addressing them.

A preliminary version of this report, Moschini, Emerton, et al., 2022 [D2.1], published in April 2022, provided an initial understanding of decision-making and CS needs in each LL, obtained through the project scoping process, initial discussion meetings, the establishing of the LLs, reports on the characteristics of each LL (Masih, Van Cauwenbergh, et al., 2022 [D1.1]) and targeted questionnaires and interviews. Throughout the I-CISK project, further questionnaires and interviews, along with information from workshops within the LLs, were used at regular intervals (~annually) to hear from the LLs about additional barriers, decision-making contexts and user needs identified during the course of co-development.

This final report summarises information from the preliminary deliverable and two further iterations completed in 2023 and 2024, drawing conclusions on the progress made towards providing user-centred CS that address the gaps identified in existing provisions. It further documents the experience gained and lessons learnt throughout the project.

Some of the key challenges identified in the use of existing CS for decision-making include insufficient resolution (spatial and/or temporal), or forecasts that are aggregated in such a way that doesn't allow users to identify key patterns and distributions. A lack of useful variables/indicators and issues related to the accessibility and usability of CS, including data availability, download difficulties, and challenges in communication, including language, and dissemination, were also highlighted. In response to these barriers, users expressed a need for services that provide forecasts at different and extended timescales (e.g., sub-seasonal and seasonal), tailoring to specific sectors and decision-making contexts, impact- and action-based forecasts, additional variables such as streamflow or vegetation indices, higher resolutions, and improved access and communication channels.

The evolving role of visualisation in CS was noted across all LLs, with map-based interfaces, time series plots, uncertainty ranges, alert thresholds, and summary dashboards all used and adapted based on user feedback. The co-development process played a central role in ensuring that visualisations were meaningful, accessible, and suited to real-world decision-making. Visual elements were iteratively improved through workshops, mock-ups, and user testing, with feedback informing everything from colour schemes and icons to interactivity and layering options. Efforts to communicate uncertainty and probabilistic information varied by context, with some LLs favouring simplified outputs and others incorporating best- and worst-case scenarios or user-adjustable percentile displays.

A key area identified for future research is how best to incorporate both forecast uncertainty and skill (performance and accuracy) information into CS. Co-evaluation conducted as part of I-CISK demonstrates the benefit of helping users understand uncertainty, for example through serious games

or workshops. However, even when uncertainty is understood, it can still be difficult to know how it should be incorporated into user decision making - for example, how do we deal with probability when there is a set threshold that triggers an action? Not including information on forecast skill (performance and accuracy) may prove to be a gap in a number of the new CS developed here, for example if the underlying forecasts are not 'good enough' to support users' decision-making, but this is not clear to the users. At this stage, only two of the new CS consider providing information on forecast skill.

This report brings together these findings and highlights common themes across the LLs, while recognising the value of local context and knowledge. It offers a synthesis of the barriers, needs and co-developed solutions, and documents best practices and lessons learned in co-producing CS that are inclusive, practical, and locally relevant.

Overall, this work demonstrates the value of participatory, user-centred approaches in the development of CS. Through sustained engagement with diverse users, the I-CISK project has helped to shift the design of CS from a one-size-fits-all approach to services that reflect real decision-making contexts, improve accessibility and trust, and build capacity for climate resilience. These lessons provide a strong basis for continuing to enhance the usefulness and impact of CS in the years ahead.

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1 Introduction

Climate services (CS)[1] are crucial in empowering citizens, stakeholders and decision-makers in defining resilient pathways to prepare for hazards and extreme events and adapt to climate change. Availability of CS has improved significantly in recent years, alongside advances in scientific knowledge and data, with CS such as those from Copernicus or GEOSS (Global Earth Observation System of Systems) providing a range of data, training, access to scientific knowledge and forecasts (e.g. the Copernicus Emergency Management Service (CEMS), Climate Change Service (C3S) and Atmosphere Monitoring Service (CAMS), www.copernicus.eu/en/copernicus-services; the GEOSS portal, earthobservations.org/geoss.php). Despite this, there remain challenges for end-users to make the best use of the potential of such CS and data, including accessibility, local applicability and the translation of scientific data into actionable information, social and behavioural factors and varying needs of decision-makers.

The typical approach in the development of CS is the top-down approach and has often been "one-size-fits-all" (Jacobs and Street, 2020; WISER, 2020), but approaches to developing and providing CS are continually evolving and moving towards those that account for a broad range of societal challenges and potential users.

A co-creation[2] approach, used throughout the I-CISK project and incorporating co-exploration, co-design, co-production, co-implementation and co-evaluation, can help to overcome challenges that lead to a lack of usability of CS, and provides the opportunity to meet climate information needs at relevant spatial and temporal scales across a range of regions and sectors (WISER, 2020; Hirons et al., 2021). I-CISK has involved and engaged stakeholders[3] (including CS providers, purveyors and end-users) at each step of the co-creation process, in order to co-produce tailored CS that integrate local knowledge and experiences with large-scale data and information.

Co-exploring needs surrounding the value of CS, climate data and information is key in the design and development of CS. It is important to understand the decision-making context of CS end-users, the barriers to use of existing CS and how these issues can be addressed in the development of next-generation CS to provide CS that are useful, usable and effectively address user needs.

[1] The I-CISK *prototype framework on co-creating end-user centred climate services* (MS10, 2022) includes discussion of 'what do we mean by Climate Services?', from which the following is adapted: "climate services" is broadly defined as "the transformation of climate-related data — together with other relevant knowledge — into customized products such as projections, forecasts, warnings, trends, economic analysis, and risk assessment, which allows to deliver information on best practices, to develop and evaluate solutions, and to provide any other service in relation to climate that may be of use for the society at large" (Street et al., 2015; MS10, 2022).

[2] Co-creation is the interdisciplinary, interactive and iterative approach to developing CS, as a way to overcome the divide between climate science and decision-makers. It is often used interchangeably with co-production or co-design. In the I-CISK project, we use the term co-creation to describe the collaborative process encompassing the co-design, co-production, co-implementation, co-evaluation and dissemination of user-centred CS (MS10, 2022).

[3] ***Stakeholders*** is the general term that encompasses all CS producers, intermediaries and consumers, or others who are affecting/affected by the decisions informed by CS (or absence thereof). Within I-CISK (MS10, 2022), the following stakeholder categories are defined: (1) ***actors*** – stakeholders that play an active role in the technology, institutional and investment readiness of CS. These are the stakeholders affecting decisions, by creating either drivers or barriers. They include, for example, the project team, scientists, practitioners, decision-makers, private sector, public authorities, providers, end-users, etc. (2) ***providers*** – actors who provide the necessary data, investment, regulatory context for the CS to be sustained; they supply climate information and knowledge, operating on a range of scales and in different sectors. (3) ***purveyors*** – act as knowledge brokers providing guidance on ways that CS can address regional problems. They also ensure that products, scientific results and business opportunities are adequately communicated to end-users. (4) ***end-users*** – actors who use CS at different levels of the decision chain. They employ climate information and knowledge for decision-making, and may or may not participate in developing the CS itself, or may also pass information on to others, making them both users and providers. They include civilians, companies, developers, private organisations, local communities, governments etc.

The I-CISK project has been working with seven so-called 'Living Labs' (LLs) in Europe and Africa, located in climate change hotspots with specific geographical and climatic settings. LLs are defined as "places for innovation - multidisciplinary ecosystems in which the I-CISK co-creation process will take place. They are an experimental setting and a safe space for stakeholder involvement (Fuglsang et al., 2019); real-life environments in which multiple heterogeneous stakeholders are connected through public-private-people partnerships and in which innovation-development activities can be conducted (Hossain et al., 2019) (MS10, 2022). These LLs have provided the space for CS to be co-produced with stakeholders from multiple sectors to meet their climate information needs. They are located in The Netherlands, Spain, Italy, Hungary, Greece, Georgia and Lesotho.

A preliminary version of this report (Moschini, Emerton, et al., 2022 [D2.1], published in April 2022 and referred to from here on as D2.1) summarised the decision-making context for stakeholders in each of the LLs, with the exception of Lesotho where the LL was established after publication, and provided an initial overview of existing CS, barriers to their effective use, and needs for improved and tailored CS. The intent was to give an overview of our current understanding of decision-making and CS needs that could be used by other tasks and work packages within I-CISK. At regular intervals throughout the project (~annually), D2.1 was iteratively updated to incorporate new information from all LLs.

This deliverable (Egan, Emerton, et al., 2025 [D2.4]), provides a final overview of the use of existing CS, the barriers to their effective employment, and the need for improved and tailored CS. It summarises how the CS that have been co-developed during the I-CISK project have made progress towards overcoming these barriers and filling in the gaps where improved CS were needed. This information is provided for each of the seven LLs, followed by overarching remarks on barriers and needs, uncertainty and skill, effective visualisation and communication, and overall conclusions.

2 Method

The content of this report is based on the preliminary version, D2.1, two iterations that updated D2.1 in 2023 and 2024, and additional feedback from the LLs gathered specifically for this final document. Throughout the I-CISK task related to this deliverable (T2.1), questionnaires and interviews were designed with clear objectives at each iteration. For the preliminary deliverable, two distinct questionnaires allowed LLs to seek and provide information on (1) the use of existing CS at the start of the project, the barriers to their use and needs for improved CS, and (2) additional technical details about the CS that were already being used for decision-making, where possible. These questionnaires are provided in D2.1 via www.icisk.eu.

The second iteration of D2.1 expanded on the first by broadening the information to cover the use, needs and gaps of CS in the more recently established Lesotho LL. It also covered new information from questionnaires and interviews with the Netherlands and Hungary LLs, and provided detailed information on the production and use of CS by each actor in the Spanish LL Multi-Actor Platform (MAP). Further barriers were identified, including lack of sector-specific information, and the report highlighted the diverse decision-making contexts and variety of sectors involved. The number of participants providing responses to the questionnaires and interviews increased from 21 for the first iteration to 35 for the second.

The third iteration recorded any additional user needs and challenges discussed since the second iteration, built an increased understanding of the co-creation process, and gathered new information to understand how the CS that were being co-developed at the time would address the barriers and needs identified previously. It also aimed to begin evaluating effective design and communication, through a new questionnaire.

For this final report, a further set of interviews was undertaken through a questionnaire disseminated once significant progress had been made in the development of the co-created and tailored CS. The questions covered topics relating to the CS design, visualisation and communication, to gain an understanding of how the final CS developed during the I-CISK project have made progress in addressing the barriers and needs identified in the preliminary version of this deliverable (D2.1). Feedback was sought from the LL leads on the questionnaire design and content, which was adapted based on their input. The questionnaire was circulated to each of the LL leads to complete directly or to undertake interviews with stakeholders in the LLs, as best fit with the status and structure of each LL. The LL leads could also choose to provide additional reports and supporting information where relevant.

3 Summary of findings

Table 1 provides an overview of key LL information: the main hazards faced, the sectors impacted, barriers to effective use of existing CS, needs for improved CS, and how the newly-developed CS help to address the identified needs.

Table 1 Summary of user needs, gaps/barriers in existing CS, and how the new CS address these needs.

Living Lab	Main Hazards	Primary Sectors Impacted	Barriers Identified	Needs Identified	How the New Services Address the Identified Needs
Netherlands	Drought	Water management; Recreation/tourism; Agriculture	Limited lead times; CS not tailored; stakeholder disconnect	Longer lead times; stakeholder engagement; user-friendly visualisation	Developed streamflow forecasts with sub-seasonal to seasonal outlooks; thresholds and historical context integrated; simplified interface to aid water management and policy coordination.
Spain	Water scarcity; Drought	Agriculture; Livestock; Forestry	Insufficient spatio-temporal resolution; lack of tailored info; poor dissemination	Sector-specific forecasts (rainfall, temperature); improved temporal and spatial resolution	Using map-based and interactive visualisations, provided (1) subseasonal to seasonal predictions, (2) 10 year projections; and (3) historical P and T data; (4) agroclimatic indicators; ; and (5) improved hydrogeological characterization. CS tailored to drought response with improved lead time, spatial resolution and accessibility.
Italy	Water scarcity; Drought; Variable water supply	Water resource management; Agriculture; Industry; Energy	Insufficient resolution; limited forecast variables; uncertainty information unclear	River discharge forecasts; local data integration; intuitive uncertainty displays	Delivered streamflow forecasts at daily and monthly timescales with colour-coded thresholds; local stakeholder sites integrated; visual simplification of probabilistic outputs.
Greece	Water scarcity; Drought; Landslides; Flooding; Heatwaves; Wildfires	Tourism; Water resource management; Transport; Infrastructure	No cross-sector integration; complex data; lack of trust in information	Tourism indicators; cross-sector forecasting; clarity and accessibility	Created dashboard of 12 user-defined indicators across water, transport infrastructure, and tourism; scenario-based outputs with spatial interactivity and simplified charts; users helped define layout. Seasonal forecasting supports operational decision making. Indicator values up to end-of-century support long-term planning.
Hungary	Heatwaves; Urban heat; Drought	Urban Planning; Health; Tourism	Lack of detailed urban heat data; inaccessible or overly technical CS	Urban heat mapping; health-impact forecasting; greening strategy support	Built high-resolution thermal maps and vegetation overlays; enabled identification of heat hotspots and monitoring greening efforts; interface tailored for policy and public communication.
Georgia	Water scarcity; Drought; Flooding; Landslides	Water resource management; Hydropower; Agriculture; Tourism	Service discontinuity; fragmented information; language barriers	Streamflow predictions; early warning; locally adapted services	Designed river forecast portal with probabilistic shading and percentile views; included observed data and educational tools (e.g. serious game); user training and iterative feedback loop included.
Lesotho	Drought; Water scarcity; Cold Waves	Disaster Risk Reduction; Humanitarian aid; Agriculture	Discontinuous updates; fragmented information; difficult user interfaces	District-level forecasts; centralised platform; trigger-based early warning	Developed drought forecast tool with district-level triggers, population impact overlays, and side-by-side forecast comparisons; aligned with Early Action Protocol.

4 Use and development of climate services

In this section, a detailed overview is provided for each LL, answering the following set of questions:

- What is the decision-making context considered?
- What existing CS were already in use at the start of the I-CISK project, if any?
- What were the barriers to using existing CS?
- What needs were identified for improved and tailored CS?
- What information does the new CS co-created through I-CISK provide?
- How is the new information visualised and communicated?
- How does the new CS address the identified barriers and needs?

Where possible, links to the new CS or snapshots from these are provided, alongside any other feedback received from the LLs with regards to how well the new CS address the needs identified at the start of the project, and the effectiveness and usability of the new CS.

The reader is referred to Van Andel et al., 2025 [D3.5] on 'categorisation and evaluation of visualisation practices for communicating uncertain predictions in climate services' for more information on the visualisation choices, and to Bagli, S., Demmich, Gräler, Mazzoli, et al, 2023 [D5.1] and Bagli et al., 2024 [D5.2] for more information on the technical specifications of the I-CISK platform and CS. For information on the forecast performance and accuracy associated with several of the newly-developed CS, with a user-centred methodology ensuring usefulness of this information for the CS users, the reader is referred to Baugh, Egan, et al., 2025 [D3.4] 'Assessment of existing and tailored climate services using a range of user-driven evaluation metrics'. Once published, these deliverables are available online at: www.icisk.eu/resources

4.1 Georgia

Figure 1 Overview of the barriers to the use of existing CS identified at the start of the project, the needs for improved CS, and how the newly-developed CS addresses these barriers and needs, for the LL in Georgia.

What is the decision-making context?

The Georgia LL (Alazani-Iori River Basins) has a wide range of user needs related to water scarcity, drought, flooding and landslides. These include economic activity planning, policy and regulation support, extreme event mitigation (multi-hazard early warning services, impact-based forecasts), maintenance of the observation network and integration of observed data, and sector tailored information (Table 1; Masih, Van Cauqenburgh, et al., 2022 [D1.1] and D2.1 Iteration 2).

The National Environmental Agency (NEA), which falls under the Ministry of Environment Protection and Agriculture of Georgia (MEPA) is the main provider of CS in the country. Under the NEA, the Department of Hydrometeorology is mandated to provide meteorological and hydrological information and warning services, distributing these to governmental bodies at all levels and to the public. The LEPL State Military Scientific-Technical Center "DELTA" operates a weather radar in the region, which is used by other organisations for the purpose of forecasting and early warning.

The NEA also has a network of hydrometeorological stations recording observation data, although the mountainous regions in particular have a sparse, or in some places non-existing, observational network. In these regions, satellite data is used to complement the in situ observations.

What existing CS were already in use at the start of the I-CISK project, if any?

A range of existing CS were identified, including:

- **Observation data** including river flow, precipitation, temperature and others, provided by the NEA, and radar provided by the LEPL state military scientific-technical Centre 'DELTA'. These were identified as being used by the NEA in relation to meteorological hazards.
- **Daily forecasts with a 1 week – 10 day forecast horizon** covering temperature, precipitation and river flow for hazards such as floods, drought and thunderstorms were in use by various sectors, including the public, from sources including the department of hydrometeorology, Windy.com and the Samsung Global Goals app.
- Various sectors make use of **extreme event warnings and advice** from the Department of Hydrometeorology, received via SMS and social media
- **Agrometeorological bulletins** from the FAO were mentioned as useful to farmers for information on drought, but D2.1 highlighted that at the time of writing, these were **not operational** due to lack of observations.
- A **frost early warning service** was also mentioned as useful to farmers, provided by the Turkish State Meteorological Service but further information was not available as the **service was not operational** at the time of writing.
- **Seasonal outlooks** were used by various sectors, including government, energy companies and the water sector. These were identified as being available twice per year, for the winter and summer seasons, using information based on outlook forums (such as SEECOF and MEDCOF) and the ECMWF monthly and seasonal forecasts.
- **Climate projections from the NEA** and the regional climate model RegCM4 were in use by sectors such as agriculture, water and energy for the preparation of reports on the impacts of climate change.

Respondents to the questionnaires for D2.1 generally trusted the CS information used, some comparing information from different sources to ascertain trust, and others because there is no other tool they can use.

What were the barriers to using these existing CS?

Availability / open access
Some of these CS are available only to certain sectors and stakeholders, such as government organisations, energy companies or agriculture, while others are openly available.

Service discontinuity
One of the challenges highlighted is the lack of a long-term national strategy for user-driven CS. CS are produced on demand but are not available on a continuous basis. CS were noted as being so scarce that it is difficult to discuss solutions and take decisions.

Fragmented information
Stakeholder responses indicated that one challenge with the use of CS is that existing information is fragmented – there exists no single complete dataset where a wide range of information is accessible.

Language barriers
One stakeholder noted that while the language of CS (typically English) was not an issue for them personally, it can be a serious problem for end users they work with (such as local farmers).

What needs were identified for improved and tailored CS?

Multi-hazard early warning system
The LL expressed the need for an early warning system for floods, landslides, debris flow/mudflow, snow avalanches, drought, hailstorm and windstorm. An ongoing project, "Scaling-Up Multi-Hazard Early Warning Systems and use of Climate Information", which is supported by the Green Climate Fund, will develop forecasting systems for weather- and climate-related hazards. The lead time will be three days, which will aid with flood management but is not sufficient for planning in sectors such as hydropower, irrigation, water supply and environmental and ecosystem protection.

Impact based forecasts
In the water resources management and agriculture sectors, there is a need for impact-based forecasts to better inform and alert the public on climate hazards and inform decision-making.

Observation network maintenance and integration
The LL has identified that data from the observing networks are crucial for strengthening CS for the purposes of climate adaptation strategies, and with this, the critical need for regular maintenance of the network of automatic weather stations. This also includes the integration of the data from this network into operational data flows and international data exchange.

Sector-tailored information
Survey responses indicated a lack of CS in the region, and the clear need for CS that can consistently provide local farmers with information about potential climate hazards and allow agricultural planning. It would be useful to provide information in a relevant language for local decision-makers.

What information does the new CS co-created through I-CISK provide?

The Georgian MAP (Multi-Actor Platform), made up of policy makers, research and academia, civil society organisations and individual partners, identified the development of a **streamflow prediction system** as the primary focus of the I-CISK project. This reflects the importance of water resource management in the Alazani and Iori River Basins, especially for agriculture and energy (hydropower). In the context of a changing climate, and with further hydropower plants planned, the pressure on water resources is likely to increase in the coming decades (Masih, van Cauwenburgh, et al., 2022 [D1.1]).

To address the need for sector tailored streamflow predictions a, 'Water Resource Planning Service' has been developed, and a mock-up is available on the I-CISK Living Labs Server (https://i-cisk.dev.52north.org/living-labs/alazani--ge/). The primary function of the service is the planning and management of water resources in the Alazani-Iori River Basins at various lead times (LL survey). It will provide ensemble streamflow forecasts for the Alazani and Iori River Basins, covering lead times >3 days and including sub-seasonal and seasonal forecasts. Two new, tailored methods are in development, one for sub-seasonal and seasonal drought forecasts and the other a downscaling of hydrological forecasts to sub-catchments or points of interest (MS11).

The CS uses historical rainfall data from meteorological stations and real-time river flow data from Shakriani hydrological stations as additional input. The development has considered multiple sources of streamflow forecasts for the CS, including from SMHI's W-HYPE model and from the Copernicus Emergency Management Service's (CEMS) Global Flood Awareness System (GloFAS) and European Flood Awareness System (EFAS). The CS also incorporates the Standardised Precipition Index (SPI) for drought monitoring, based on the ERA5-Land reanalysis dataset, and bias-corrected (using ERA5 data as a reference) seasonal forecasts of precipitation and temperature from ECMWF's SEAS5 seasonal forecasting system. Precipitation forecasts are displayed as monthly accumulations, and temperatures as the average daily maximum and minimum over a month.

Maintenance of the observation network and integration of observed data are also being addressed as part of the I-CISK project; the LL have undertaken field work to assess the amelioration (irrigation) system and streamflow monitoring sites, as well as the quality of streamflow data. The aim is to use these within the stream flow model, but high-quality calibration is challenging due to the limitations of the historical data. Work is currently underway to find a solution.

How is the new information visualised and communicated?

Figure 1 provides a snapshot from the online portal developed for the tailored CS, showing a map of the region and rivers covered by the CS, and an example of a streamflow forecast for one of the locations indicated by the red dots. The forecast is displayed using shading to indicate the forecast according to ensemble percentiles. The user can select from a range of time horizons, and can view observed data in the time series underneath the forecast.

During the co-development of the CS, the LL team engaged in discussions on ensemble forecasting, probabilistic information and uncertainty. As the CS was planned to make use of ensemble forecasts, meetings were arranged to explain the benefits of probabilistic information in managing flood and drought risks. It was noted in the recent survey that initially, farmers were unfamiliar with probabilistic forecasts, posing challenges for conveying the concept effectively. Workshops were therefore arranged, aiming to simplify the concept by using visual aids and local examples to help farmers to understand and engage with the forecasting features of the new CS. A 'serious game' was also developed based around the user stories and decision-making context of farmers in Georgia (Rastogi et al., 2024).

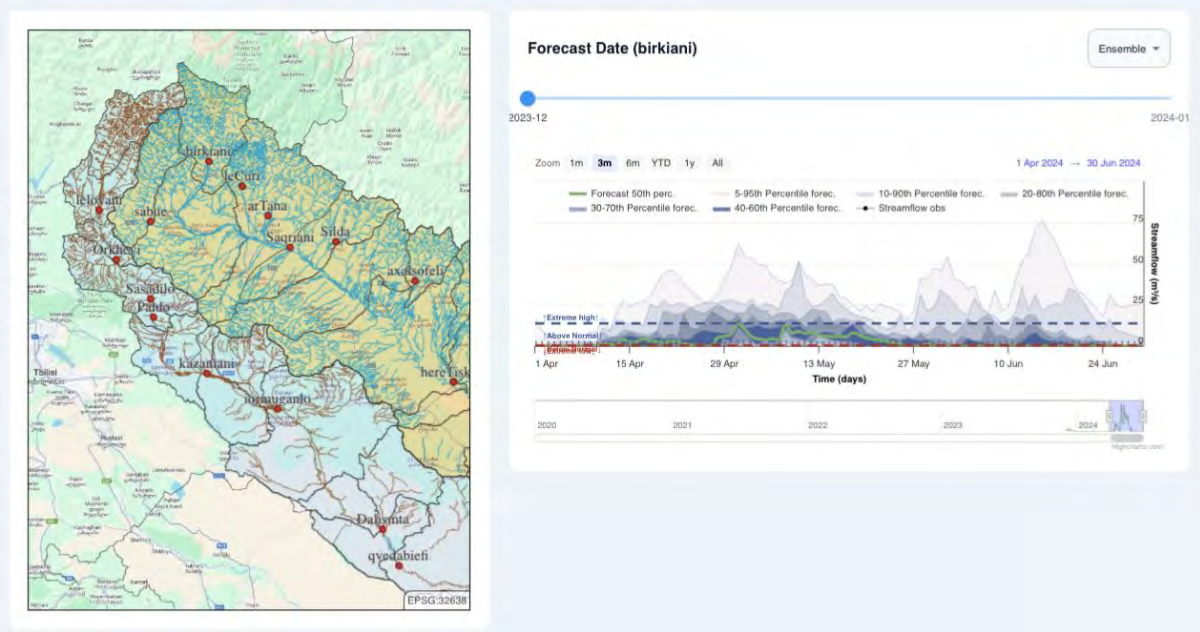

Figure 2 Example screenshot from the Georgian LL climate service.

The LL plans to gather feedback from the end users regarding the visualisation used in the CS, and to discuss new features and the portal's usability. The feedback will be used to further refine the portal's features for improved accessibility. Information on forecast skill (see Baugh, Egan, et al., 2025 [D3.4]) will also be incorporated into the CS in future, to help users understand the accuracy and usability of the forecasts.

How does the new CS address the identified barriers and needs?

Decision making by the National Environmental Agency (NEA), Georgian Amelioration, and the Rural Development Agency will be supported by the provision of streamflow forecasts at point locations of interest to them. The system will also support planning in the agricultural sector, flood control and hydropower operations.

There has previously been no provision of streamflow forecasts in Georgia, and users instead rely on weather forecasts of precipitation. Whilst the NEA does produce runoff forecasts, these are available only for the spring period (D2.1 Iteration 3 survey). The provision of continuous streamflow forecasts at points of interest to the NEA will address these issues, making this a unique service within Georgia.

Feedback from the LL from the most recent survey also indicates that this new service introduces drought-focussed CS with the possibility of downloading historical data and enabling users to access and analyse trends for the first time. New data provided by the service include historical rainfall data and 'live' hydrological data from the gauge at Shakriani on the Alazani River, with improved accessibility and integrated forecasting system.

While the multi-hazard service under development through the Green Climate Fund will address some of the identified needs at short timescales, the new CS developed through I-CISK will address the identified need for monthly, sub-seasonal and seasonal forecasts (LL survey) throughout the year and support economic activity planning for multiple sectors.

4.2 Greece

Figure 3 Overview of the barriers to the use of existing CS identified at the start of the project, the needs for improved CS, and how the newly-developed CS addresses these barriers and needs, for the LL in Crete, Greece.

What is the decision-making context?

The Island of Crete is the focus area of the Greek LL where the main weather/climate hazards are heatwaves, floods, wildfires and droughts. In the I-CISK project, the hazards considered in the development of new and tailored CS include water scarcity, drought (indirectly), landslides, the combination of wind waves and swell, flooding, high winds and heatwaves. The sectors impacted and involved include tourism, water resource management, transport, infrastructure and accommodation. The main end users of the CS include tourism enterprises, tourists, citizens, road and port managers and the water supply and energy sectors.

Decisions related to climate hazards are linked to water allocation in periods of droughts, planning of tourist activities and energy demand (due to higher usage of cooling systems) in relation to heatwaves, tourism and transportation disruption related to flash floods, and port traffic planning when strong winds are anticipated. Stakeholders take different decisions on a daily, weekly and seasonal basis in relation to the activities of their sector.

What existing CS were already in use at the start of the I-CISK project, if any?

At the start of the project, it was noted that information already in use included daily weather forecasts, short-term forecasts of reservoir water quantity and quality, and climate change impact assessments and vulnerability analysis at district level. It was found that in the tourism sector, decision-making was typically based on weather forecast information, whereas water management decisions may have been based on current conditions, experience, conditions during previous years, and past managing practices, rather than on forecast information.

The existing CS identified included:

- **Weather forecasts** provided by national services via mobile apps and internet in the form of maps, charts and tables of precipitation, temperature and wind. These were being used by water management and tourism sectors for decisions on water allocation, and planning outdoor activities and construction. This information was seen to be trusted.
- **Climate change impact assessment and vulnerability analysis** information is available at national and regional scales, alongside **climate change adaptation plans** and research studies, including from private (consultancy) companies. These included information on river flow, precipitation, temperature, drought index and water exploitation index, with information feeding into longer-term strategies for public water management and tourism (e.g. long-term construction planning).
- **Hindcasts** were mentioned as being used by the water resources management sector for water allocation and analysis of climate impacts on water availability.
- A bespoke **short-term forecast service for reservoir water quality and quantity** was also in use by the water resources management for water allocation and information on water quality, in relation to both drought and extreme precipitation.

What were the barriers to using existing CS?

The barriers to using these existing CS effectively include the fact that climate change information lacked cross-sector links, the CS were not tailored for specific sectors, there was a lack of accessibility for non-expert users, and a lack of trust in the information.

Lack of cross-sector links
Climate change vulnerability assessments are available, however, they focus on single sectors and lack information on cross-sectoral-links. Studies were mostly designed for governmental and administrative level.

Lack of tailored information
While the climate change vulnerability assessments are available for specific sectors, in general there is a lack of CS information on different timescales that is tailored to support the needs of different sectors, for example with the most useful variables and indicators, and including a lack of information on the severity of predicted hazards or compound impacts of multiple hazards.

Accessibility to non-expert users
CS that use climate projections, seasonal and sub-seasonal information would be of great use in this LL to inform local administration, local authorities and local businesses to better plan development and management activities. At the moment, this information is accessible only by researchers and consultancies and therefore does not reach a wider audience of potential users and stakeholders. The main barrier is the lack of expertise/resources needed to extract and convert this data into useful information for the LL. Also related to accessibility and usability of CS by non-expert decision-makers, a lack of information/clarity regarding the reliability and uncertainty of CS was noted.

Lack of trust
In the recent survey, feedback was received that during the course of the project, it became apparent through various discussions within the LL context, that an additional barrier not reported in the preliminary deliverable was an element of lack of trust in the information.

What needs were identified for improved and tailored CS?

In the Greece LL (Crete), user requirements are focused on the tourism sector, where there is a need to alleviate drinking water and irrigation need conflicts in summer (peak of tourist period), cope with increased energy needs, ensure access to touristic destinations (i.e. a functional transport network), and to increase preparedness and adaptation (Table 1). Specific user needs within the sector are variable and pertain to a range of natural/socio-natural hazards, which affect different sectors that subsequently impact on tourism. Water scarcity, drought, flooding and heatwaves all affect tourism and the economy due to their impacts on guest experience, energy demand for cooling, and transportation via roads and ports. Climate projections for decreased precipitation and increased temperature suggest these impacts will worsen (Masih, van Cauwenburgh, et al., 2022 [D1.1]). As a result, the following needs were identified:

Sector- tailored information
A lack of information on a range of timescales, tailored to support sector needs indicated the need for new sector-specific indicators and variables. In the case of climate change assessments, it was seen as potentially useful to identify links between sectors, providing information to support decision-makers outside of the government and administrative level and increase accessibility for non-expert users.

Improved spatio-temporal resolution
The stakeholders expressed the desire to have CS of least 10 km spatial resolution covering the Island of Crete, and access to information on monthly, subseasonal and seasonal timescales.

Climate hazard severity
An identified gap was in information on the predicted severity of an event, and therefore there is a need for the provision of forecasts that include severity.

Reliability and uncertainty
Both responses highlighted that there was a lack of information or clarity regarding reliability and uncertainty information related to the CS they were using, and such information would be useful for decision-making.

Compound / multi-hazard information
According to the LL report (Masih, I., van Cauwenburgh, N., et al., 2022 [D1.1]), the need was identified for CS that "*help to assess synergistic effect of multiple climatic threats, water and energy needs (availability of resources) and infrastructure (e.g. resorts, ports, marinas, roads, etc.) physical security due to extreme events (flooding, surging, snow fall, icing etc.). The service should also be able to target a diversity of seasonal and spatial coverage (summer coastal activities / winter mountainous activities)*."

What information does the new CS co-created through I-CISK provide?
To address these needs, a 'Cross-Sector Planning Service for Tourism' has been developed, available on the EmvisWater platform: https://icisk.emvis.gr

This new CS includes sub-services for users involved in water, road, port and resort management. Data are provided in the form of 12 indices identified as helpful by users during the co-design process and decision time-lines exercise (Van den Homberg, Rastogi, et al., 2024 [D2.5]).

While some of the indices included are based on essential variables that may be available from other CS, this new CS aims to provide access to all relevant information in one easy-to-access location. Other variables are newly-developed and not previously available through any existing CS.

The **water management** dashboard includes wet period surface water availability for reservoir basins, with specific indices including, for example, surface water discharge for November to February (4 months) relative to historical conditions. This will support decisions on water allocations for public and private (agricultural) clients, and management of water reserves (flood control, storage or release to the environment). The service will aid decision-making by providing data at critical periods, which will allow water to be allocated and used more effectively. Decisions on water restrictions will also be better informed, when they are required.

The **hydrology** part of the CS provides maps and graphs of forecast seasonal outflow for subcatchments with a lead time up to 7 months ahead.

The **climatic** part of the CS provides information from climate projections based on two forcing scenarios (RCP 4.5 and RCP 8.5), including temperature and precipitation, broken down into the following indicators: mean annual, summer, winter and monthly temperature, hot days, cold days, cooling degree days, heating degree days, total annual precipitation, high precipitation days, extreme precipitation days and monthly precipitation profiles. Information is provided as both absolute values and as anomalies from a reference baseline (1980-2005).

The **seasonal indicators for tourism** part of the CS provides seasonal forecasts of indices related to extreme weather conditions relevant for the tourism sector, including extended hot spells and long-period precipitation. Indices include:

- temperature and precipitation (aggregated over 15 days out to 7 months)
- the 'Tourism Climatic Index' (a variable evaluating climate favourability for outdoor tourism through the combination of seven variables related to human comfort levels)
- the frequency of light/high/extreme precipitation (frequency of days where the daily precipitation exceeds 1/10/50 mm)
- the frequency of extreme hot days (number of days where the maximum temperature exceeds 35°C)
- the frequency of tropical nights (number of nights where the temperature does not drop below 20°C)
- cooling degree days (related to energy demand for cooling, this variable tracks by how much and for how long the temperature exceeds 25°C)
- 'Instability Index (quantifying the susceptibility to landslides in a specific area, accounting for rainfall, soil properties, slope inclination, geology)
- the frequency of strong north, northwesterly, and southerly wind gusts (exceeding Beaufort Force 7).

These will support decisions on which summer activities to provide, when to carry out development and maintenance works, and future investment/expansion, for example of hotels or resorts in the tourism sector.

The CS makes use of a range of data, including observations of precipitation and temperature, forecasts from ECMWF's seasonal forecasting system (SEAS5), regional climate projections (CORDEX, the Coordinated Regional Downscaling Experiment) through C3S, and seasonal river discharge forecasts from SMHI, produced by driving the E-HYPE model with seasonal meteorological forecasts.

How is the new information visualised and communicated?

Through the co-creation of the CS during the I-CISK project, the decision-makers and end users' journey through the interface was considered. Early mock-ups of the CS were presented and discussed, providing hands-on experience using the CS from the early stages of the concept. Feedback led to including the ability to customise the charts, with positive responses from the users, who also indicated that uncertainty information would be useful, alongside 'infoboxes' providing further information within the CS. Some screenshots are provided below.

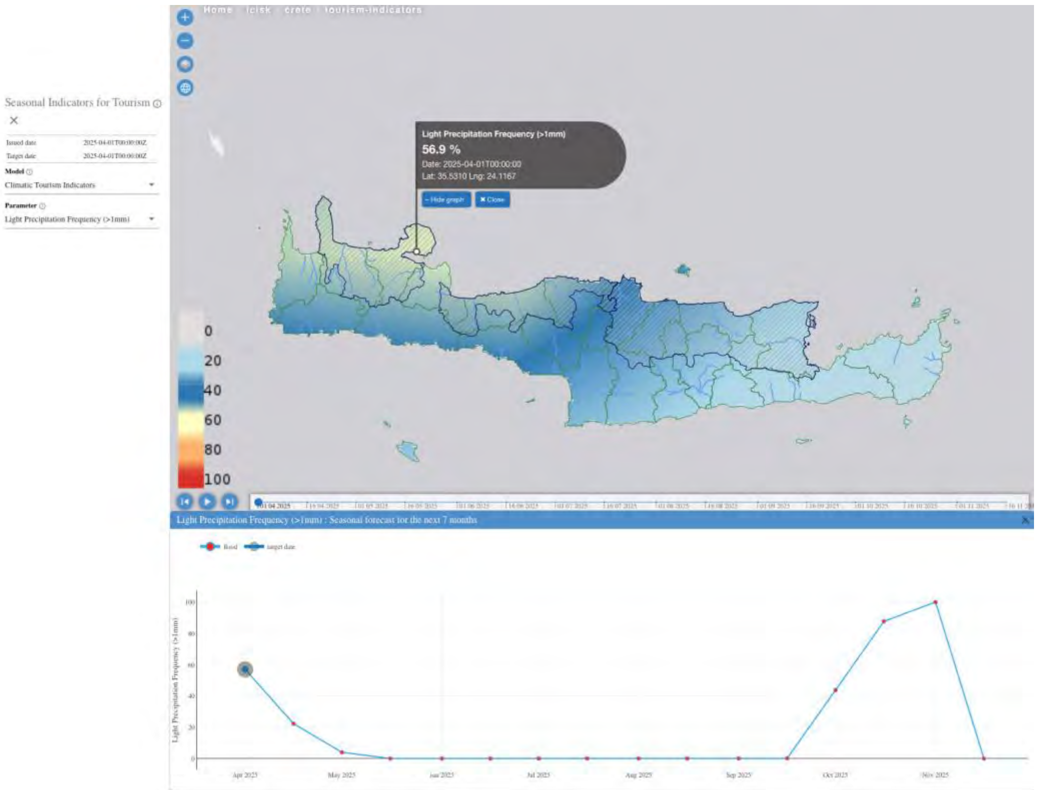

Figure 4 Example screenshot from the Cross-Sector Planning Service for Tourism, displaying a map of the seasonal forecast of the frequency of light precipitation. A map is provided for Crete, and clicking on a location indicates the frequency for the current month and shows a graph of the forecast frequency over the next seven months.

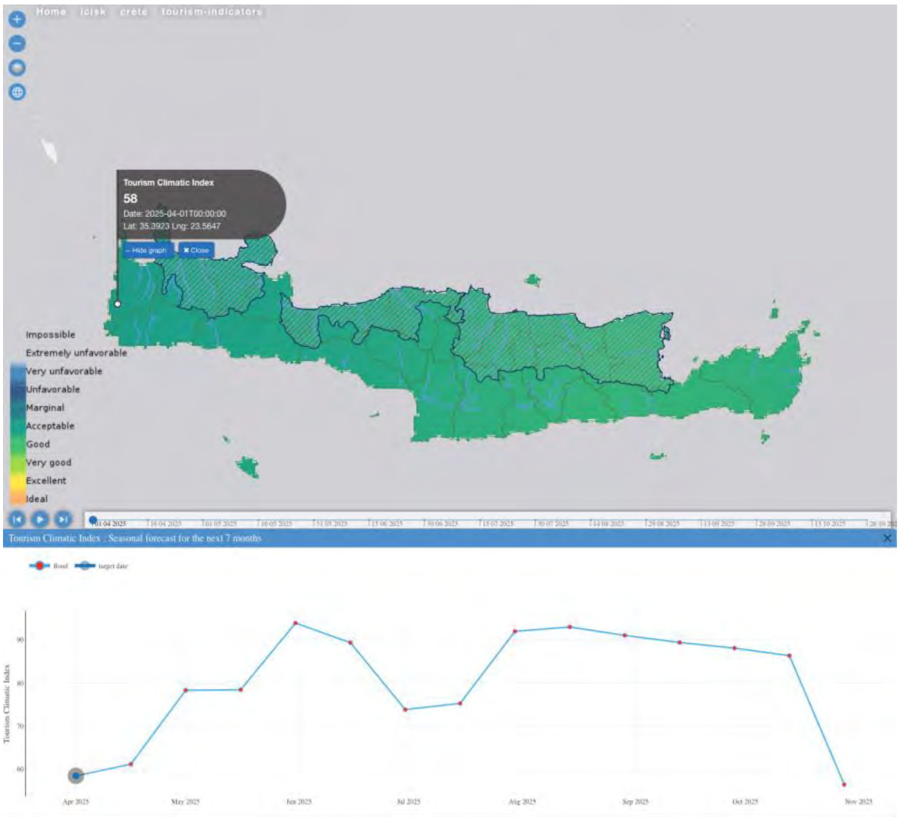

Figure 5 Example screenshot from the Cross-Sector Planning Service for Tourism, displaying a map of the seasonal forecast for the 'tourism climatic index'. A map is provided for Crete, and clicking on a location indicates the current value and shows a graph of the forecast over the next seven months.

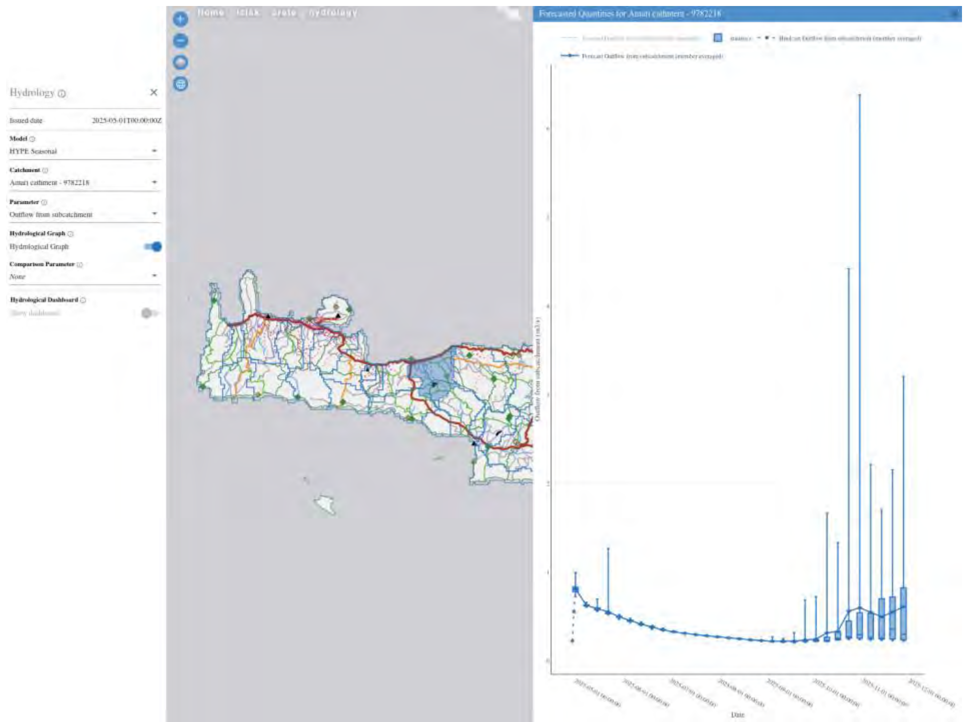

Figure 6 Example screenshot from the Cross-Sector Planning Service for Tourism, displaying a map of the seasonal hydrological forecast. A map is provided for Crete, and clicking on a subcatchment displays shows a box plot graph of the probabilistic forecast over the next seven months.

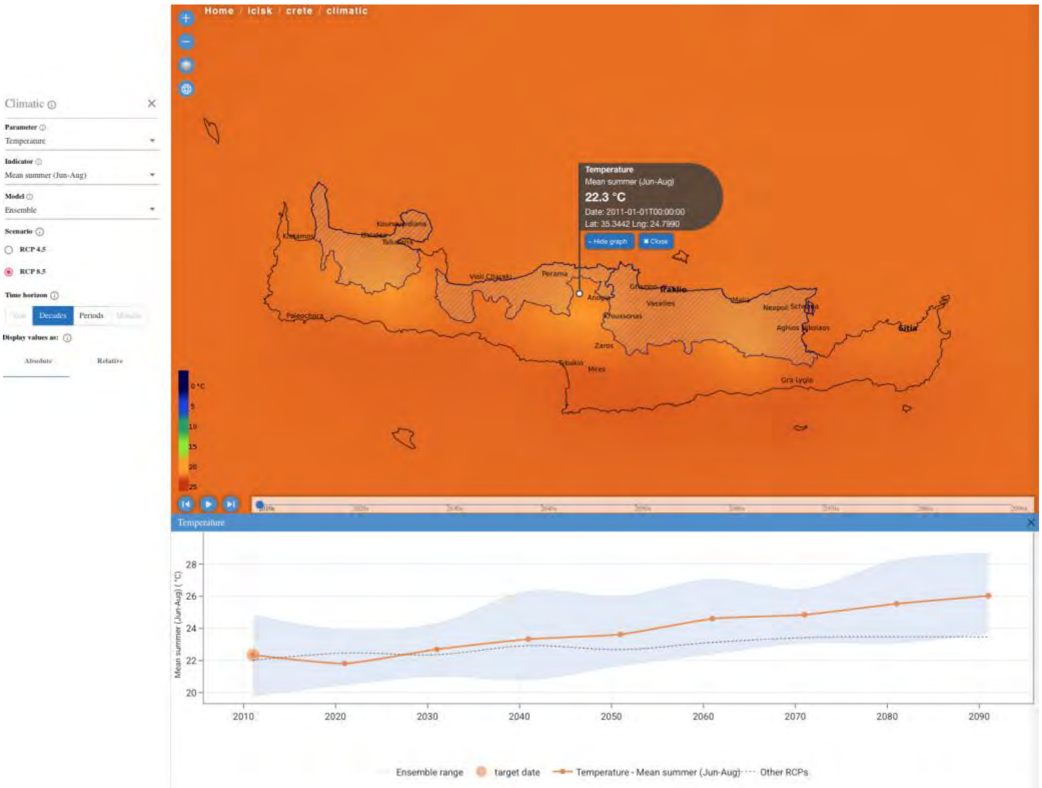

Figure 7 Example screenshot from the Cross-Sector Planning Service for Tourism, displaying a map from the climatic part of the service, indicating the current and projected average summer temperature. A map is provided for Crete, and clicking on a location displays the current mean summer temperature, and displays a graph indicating the projected change in mean summer temperature out to 2090. The map can be changed to display the mean summer temperature in future decades.

Feedback on the new CS suggests that it improves on the information available through existing CS by providing more comprehensive charts that are based on and tailored to user needs, alongside the ability to modify the charts using information the user has added, allowing for quick customisation of the information based on sector- or user-specific needs.

Based on the identified need for uncertainty information, and feedback received during the co-creation process, the LL communicated with users regarding uncertainty and probabilistic information. This was found to be challenging to communicate, identifying the need to build a common understanding of uncertainty, with dedicated time for these discussions. The CS will provide probabilistic and uncertainty information, with particular interest from users in information on 'best-' and 'worst-case' scenarios. Discussion with users indicates that the uncertainty information is generally considered to be very useful, but if the uncertainty is large it can discourage the user. Other users prefer not to have uncertainty information, and more work is needed around how to use the information.

How does the new CS address the identified barriers and needs?

The newly-developed CS provides tailored information in a multi-sectoral framework, making information available across sectors allowing for links between them, and provides a large range of sector-specific and tailored variables, addressing the barriers related to sector-specific information and information that was not tailored to the user needs. It provides a range of information on different forecast horizons and time periods, and incorporates elements of uncertainty information and hazard severity, while being designed in a way that is intended to be accessible for non-expert users.

Overall, the service will support evidence-based decisions in the tourism, water and transport sectors, facilitating improved tourism planning, better informed decision making, and improved water resource planning and efficiency, leading to a more climate resilient tourism sector.

4.3 Hungary

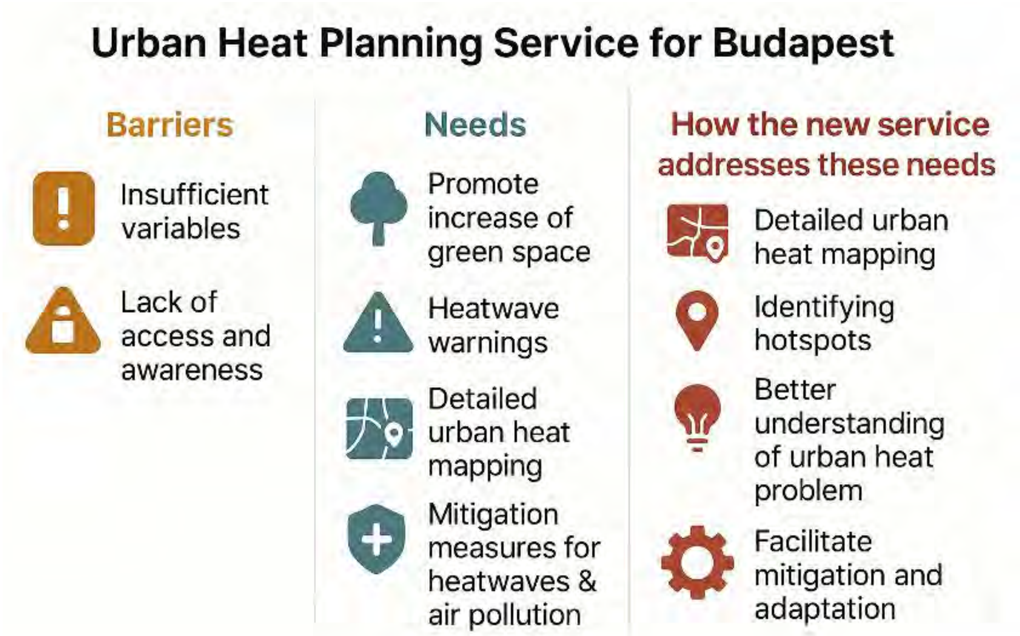

Figure 8 Overview of the barriers to the use of existing CS identified at the start of the project, the needs for improved CS, and how the newly-developed CS addresses these barriers and needs, for the LL in Hungary.

What is the decision-making context?

The focus of the Hungarian LL is on urban heat islands, in particular in Erzsébetváros, an inner district of Budapest and the most populated. This district has a low percentage of green spaces, with a high density of buildings, and therefore is particularly exposed to heatwaves, which impact a range of sectors in the city. In Erzsébetváros, small businesses are a key part of the economy, which is based primarily around tourism. Alongside the impacts of heatwaves on the tourism sector, a significant impact in Budapest is on the health sector.

Key motivations for this LL include the consequences of climate change that are observed and projected, including an increase in the mean annual temperature and sunshine duration, alongside more frequent temperature and precipitation extremes. In Budapest, the urban heat island effect exacerbates the impacts of summer heatwaves, with temperatures in inner parts of the city reaching up to 7°C above the greener areas surrounding the city (Masih, I., van Cauwenburgh, N., et al., 2022 [D1.1]; Budapest SECAP, 2021).

The district aims to implement adaptation strategies including increasing the percentage of green areas (such as green roofs, green walls), shading buildings and adding drinking fountains or other places to provide water during heatwaves, alongside developing a heatwave alarm system and educating the public on adaptation strategies (Masih, I., van Cauwenburgh, N., et al., 2022 [D1.1]).

What existing CS were already in use at the start of the I-CISK project, if any?

During the second iteration of the preliminary report, it was indicated that CS were being used to take decisions such as how to improve green spaces, for example though tree planting, and water preservation, mostly on long-term timescales over many years.

The existing CS identified at the start of the project included the following, with the first two indicated as already being used for decision-making:

- **Land cover and land use data** for urban areas, for 2006, 2012 and 2018, from the Copernicus Land Monitoring Service (CLMS) Urban Atlas, used to decide how to influence urban planning and the increase of green spaces.
- **Meteorological data** on temperature and air quality on a daily timescale, from the Hungarian Meteorological Information Service, used by the National Institute of Public Health to issue warnings for heatwaves.
- **Hazard alerts** from MeteoAlarm, for multiple hazards including heatwaves, floods, thunderstorms, winds, forest fires, fog and many more.
- **Green area monitoring** through the BP Fatár app, which provides maps of trees, tree belts and a park register.
- **Biodiversity monitoring** by INaturalist, providing maps of observations of birds, insects and plants.
- **Land surface temperature** from the Copernicus Global Land Service.
- **Meteorological data** provided by idokep including maps and graphs of precipitation, snow, pressure, temperature, solar flares, humidity, pollen, wind, smog, tornadoes, lightning, UV and water temperature.
- **Air quality monitoring** using citizen data collection to produce maps.
- **Air quality information** from the OKIR National Environmental Information System, providing information on air quality and annual emissions from reporting parties.

What were the barriers to using existing CS?

Two key barriers to the use of existing CS were noted:

Insufficient variables

It was highlighted in the LL characterisation report (Masih, van Cauwenburgh, et al., 2022 [D1.1]) that while the existing CS used by stakeholders in the LL are important for detecting heatwaves, a key limitation is that the information available doesn’t consider other important factors related to heatwaves, such as wind, direct sunshine, building density, health impacts etc.

Lack of access

Barriers to the use of CS also included accessibility concerns, where climate data and services are not being used due to lack of resources, both human and financial, in some circumstances. This is in combination with a lack of knowledge on how such data and information can be used.

What needs were identified for improved and tailored CS?

The ambition under I-CISK is to increase preparedness and adaptation strategies for urban planning and public awareness, alleviating heat impacts on health and tourism. The main user need in the Hungarian LL is for accessible, tailored CSs with a wider range of variables related to heatwaves and health impacts.

The Hungarian LL identified the need to develop a tailored CS to assist the Budapest municipality in the planning of adaptation strategies considering the increase in frequency and severity of heatwaves. The four key needs identified for this service were:

- promote the increase of green spaces, and green infrastructure in the city
- heatwaves warnings
- mapping of urban and micro heat island spots and buildings
- health impacts and mitigation measures in relation to heatwaves and air pollution

What information does the new CS co-created through I-CISK provide?

To address these needs, the Hungary LL has been developing an 'Urban Heat Planning Service'. The service will have two main components: urban heat data and mapping, and information for heatwave management plans. The aim is to provide a range of new information through the tailored CS, including satellite-drone Thermal Infrared Imagery (TIR) data fusion, three machine learning methods for enhanced pattern recognition, orthophotos (aerial photos that are geometrically corrected to give a uniform scale), aided vegetation indexing, timeseries analysis and energy balance modelling (MS11).

Three elements: visual orthophotos, measured thermal orthophotos, and predicted thermal projection images, are available in the prototype, for two districts in Budapest (https://i-cisk.dev.52north.org/living-labs/budapest--hu/).

How is the new information visualised and communicated?

The CS under development for the Hungary LL provides a simple-to-use interface displaying different map layers for two districts in Budapest. The first drop-down menu allows the user to choose the district, and the second dropdown allows the user to choose the map layer of interest, from the elements described above.

Figure 9 Screenshot from the Hungary LL climate service. This display shows the measured thermal orthophoto for Budapest VI district.

How does the new CS address the identified barriers and needs?

The main users of the service will be residents, urban designers and local authorities, who are all interested in addressing the issue of urban heat. By providing detailed urban heat mapping, at street and block level, and identifying hotspots and heat emitters with high precision, the service will provide more accurate information and a better understanding of the urban heat problem. Machine learning techniques will help identify the heat properties of different surfaces. This will allow the effectiveness of various adaptation interventions to be evaluated, facilitating improved heat mitigation interventions at individual, block and district level. Overall, the urban heat problem will be easier to understand and more demonstrable, which will support informed and effective decision making.

4.4 Italy

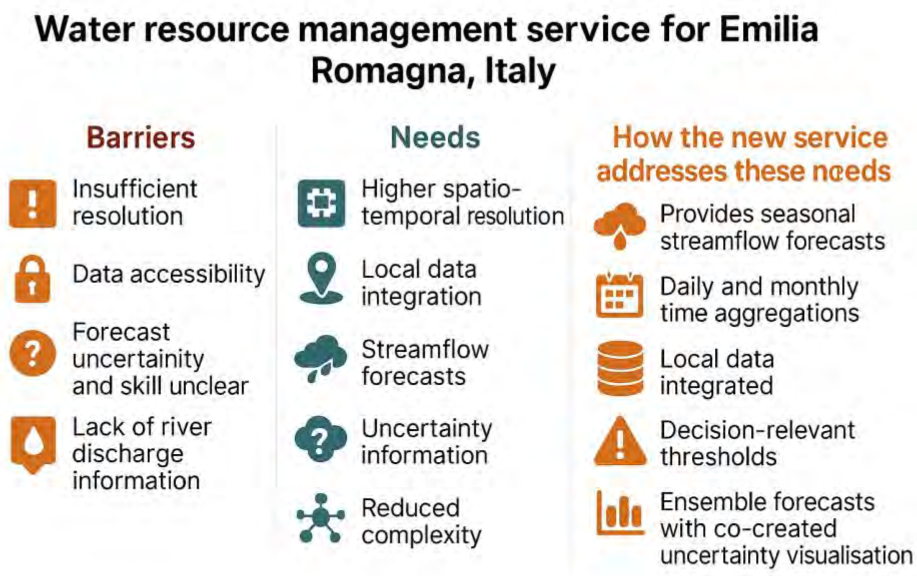

Figure 10 Overview of the barriers to the use of existing CS identified at the start of the project, the needs for improved CS, and how the newly-developed CS addresses these barriers and needs, for the LL in Italy.

What is the decision-making context?

The focus region of the Italian LL is in the upper part of the Panaro and Secchia rivers, in the Modena and Reggio Emilia provinces. The area is vulnerable to droughts and floods, due to a change in seasonal precipitation patterns and increase in temperature. The sectors affected by droughts and the resulting water shortage are tourism, agriculture, infrastructure, energy, manufacturing and production, which all compete for water and energy, especially during the warmer season.

A challenge noted in the initial questionnaire/interview responses is the management of water resources, particularly in relation to managing conflicts of interest around withdrawals from users. This is something that is likely to increase further with impacts of climate change on water availability.

What existing CS were already in use at the start of the I-CISK project, if any?

The CS used and available in the Italian LL at the start of the I-CISK project are produced by ARPAE, the regional environmental protection agency. ARPAE produces and distributes climatic, meteorological and hydrological data such as: climate projection summary reports and bulletins, historical data and data from monitoring. Initial questionnaire responses were received from four private local institutions that are primarily involved with water allocation and management in different sectors. In general, based on the sample of responses received, it was perceived that CS information is not considered to be completely reliable, due to the effects of climate change and unexpected events related to this.

The existing CS identified at the start of the project were:

- **Regional climate projections:** Provided by ARPAE as summary reports and bulletins.

- **Historical and current hydro-meteorological data** from a monitoring network, provided by ARPAE as maps, tables, graphs, charts, text and raw data. Variables included are temperature, soil moisture, precipitation and river discharge, on daily, monthly and yearly timescales. These were noted as used by the Emilia Romagna regional government to decide on water withdrawal limitations and river water balance maintenance, and by a multi-utility company for decisions related to water allocations for industry.
- **Agriculture water demand seasonal forecast (iCOLT)** from ARPAE, providing information on water deficit in the first metre of soil, rainfall, crop evapotranspiration, seasonal irrigation demand anomalies and irrigation demand, as maps and tabulated values for irrigation demand. The forecasts are provided with uncertainty information. They were noted as being used by the Burana water irrigation consortium for decisions on water management and allocation for agriculture.

What were the barriers to using existing CS?

Insufficient temporal resolution

Users of the iCOLT CS, designed for predicting irrigation water demands in the Burana area, highlighted that currently, rainfall forecasts are provided as weekly precipitation totals. However, a higher temporal resolution, ideally with 3-day totals, would be more useful for decision-making and ascertaining if a rainfall event will be a positive or negative event for crops. A single intense precipitation event could be damaging for crops, whereas rainfall that is more evenly distributed throughout the week could be beneficial.

Data accessibility

Some stakeholders highlighted that it can be challenging to download historical data from the ARPAE website. Others noted that ftp and CS interfaces are convenient, highlighting that ease of access to CS and data varies between stakeholders, and varies depending on the CS and data required.

Forecast uncertainty and skill unclear

Some stakeholders noted that uncertainty information, where provided, can be challenging to use and is not very 'user-friendly', and in cases where uncertainty and/or skill information is not provided, it is challenging to understand whether forecast information is reliable and this impacts decision-making.

What needs were identified for improved and tailored CS?

User needs in the Italy LL (Emilia Romagna region) are focussed on water resource management, and its importance for sectors such as agriculture, industry, energy, environmental management and utilities. The I-CISK project ambition in the Italy LL has been to alleviate water conflict during the dry season. This reflects the vulnerability of the Emilia Romagna Region to seasonal variations in water availability, especially given the potential for further reductions in dry season precipitation with climate change (Masih, Van Cauwenburgh, et al., 2022 [D1.1]).

Higher spatio-temporal resolution

The LL highlighted that they would like to use existing climate projections and seasonal forecasts provided by the Copernicus Climate Change Service (C3S) and Copernicus Emergency Management Service (CEMS) through the Copernicus Climate Data Store (CDS). However, the variables of interest (precipitation, temperature, snow cover and river discharge) are currently available at 1° to 0.1° resolution. Stakeholders highlighted that they would need those variables to be downscaled to catchment (or even station) resolution in order to be useful for decision-making. Temporal resolution was also mentioned as a barrier to the use of existing CS, implying that availability of CS at different temporal aggregations (e.g. 3 days compared to the currently available weekly aggregated variables) would be beneficial and useful.

Local data integration

There was a need to integrate water withdrawals from water users, as the lack of this information is seen by most stakeholders as a challenge for sustainable water management.

River discharge forecasts

A crucial missing variable is the river discharge forecast for the Secchia River, from which various sectors withdraw water. Requirements were identified for river discharge forecasts at daily, sub-seasonal and seasonal timescales, for the catchment and at station level.

Uncertainty information

Questionnaire/interview responses indicated an interest in better provision of uncertainty information that is explained in a way that is effective for local decision-makers.

Reduce complexity

Further information from interviews and engagement during the project highlighted the need to reduce the complexity of the information provided. The information should be presented in a way that facilitates a move from reactive to proactive management practices.

What information does the new CS co-created through I-CISK provide?

The LL has been developing a 'Water Resource Management Service' that will provide streamflow forecasts for the Emilia-Romagna region. A mock-up is available on the I-CISK Living Labs Server (https://i-cisk.dev.52north.org/living-labs/emilia-romagna--it/). Streamflow data will include historical time series using observed river discharge data at monitoring stations, and forecast values, utilising ensemble data and considering different time-averaging periods, downscaled to a single sub-catchment. Forecast data may include downscaled seasonal forecasts from SMHI, or seasonal river discharge forecasts from GloFAS (Emerton et al., 2018), with a preference for linking to open data sources, such as Copernicus, for sustainability of the CS post-project. The forecasts will have daily timesteps, offer cumulative volume outlooks, and be provided for the Castellarano station on the River Secchia, from which most of the stakeholders derive their water. Decision-based threshold levels will be shown, and aggregations over longer periods will also be provided. The service is expected to support a move to decisions based on standardised protocols underpinned by forecast data, and a shift from reactive to proactive and anticipatory drought management.

How is the new information visualised and communicated?

The CS user's journey through the CS interface was considered throughout the development, based on feedback that visualisation of existing CS and tools lacked clarity and direct support for operational decisions. To address this challenge, the new CS integrates local data with forecasts, including displaying historical climatology information alongside forecasts, and highlights key thresholds relevant to the decisions that are being made based on the CS. Feedback from stakeholders throughout the co-creation process led to improvements such as reducing map size to prioritise important charts, simplifying the navigation between stations and legend information (for example, introducing traffic light colours), and allowing users to toggle different layers of information (such as ensemble forecast percentiles and uncertainty ranges) on and off, so that users can focus on the most relevant information for them. The users can also choose between different chart types, such as box plots or line charts.

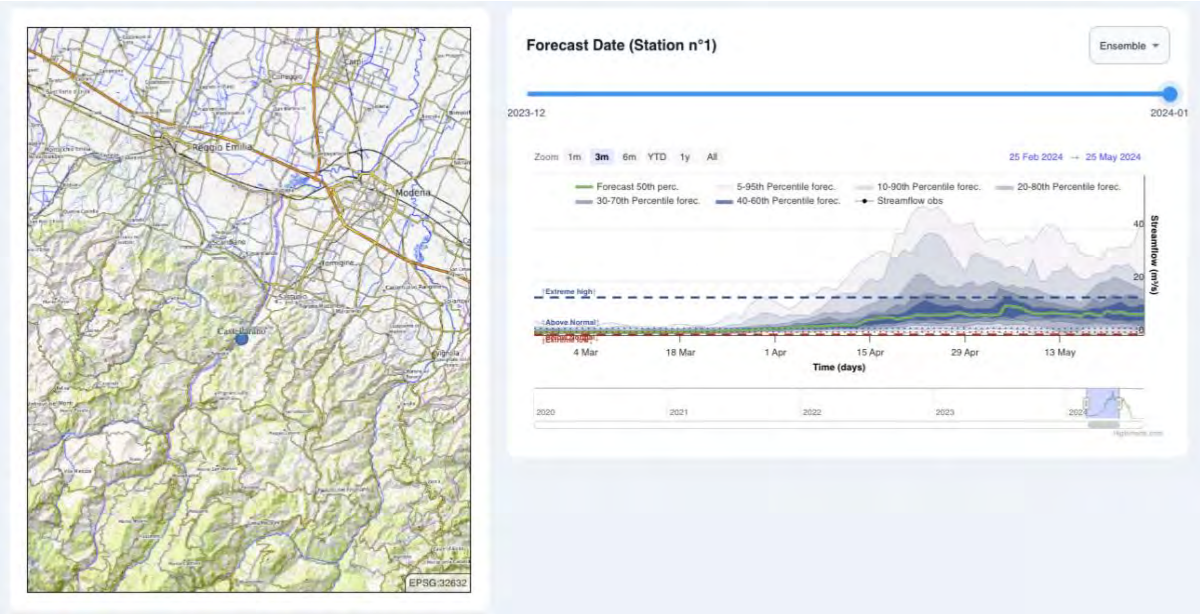

Figure 11 Example screen shot from the Italian LL climate service mock-up, displaying the map and station location (left) and ensemble seasonal forecast of river flow with daily timestep and with thresholds marked (right).

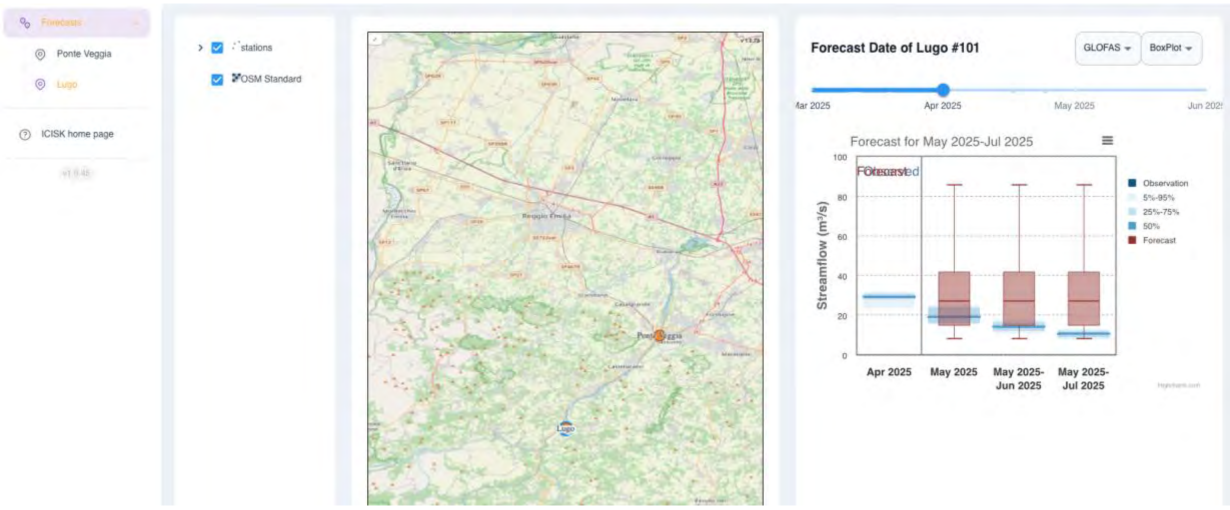

Figure 12 Example screenshot from the Italian LL climate service mock-up, displaying the map and station location (left) and ensemble seasonal forecast from GloFAS with a monthly timestep, alongside climatological percentiles, displayed as a box plot (right).

During the iterative feedback sessions, it was highlighted that there were challenges around the complexity of ensemble forecasts, which were unfamiliar to some stakeholders. The decision was made to try to simplify the visualisation as much as possible, and focus on percentile information with options to view more information if needed. As such, the median is always shown as the default forecast information, and the user can choose to display uncertainty ranges, such as the 25^{th}-75^{th} percentiles of the forecast, when needed. Recent feedback suggests that there remains some confusion around the link between forecast data and historical information, and emphasises the need for further development to clearly explain this within the interface.

How does the new CS address the identified barriers and needs?

The new service will address a lack of streamflow forecasts for the region. Information is tailored to the sector and decision-maker, supplying the streamflow forecasts required at a point location relevant to the end user and with decision-based thresholds and integrated local data. Forecasts with daily timesteps will be the main source of information, which were not previously available, complemented by data aggregated over longer (monthly) scales. The use of ensembles will provide an assessment of uncertainty, with the visualisation co-designed with stakeholders to reduce complexity compared to existing CS.

Expected benefits include improved water allocation and reduced water shortages. In turn, this will benefit agricultural and industrial planning, as well as reducing agricultural production loss (LL survey). The CS will enable early warning and risk assessment, as users can evaluate the likelihood of river flows falling below critical ecological thresholds, helping with decisions on when to activate measures such as irrigation restrictions. It will support flexible and forecast-based decision-making that is both precautionary and proportional to the forecasted risk, with uncertainty information allowing planning for different scenarios (best-case, worst-case) – important information in managing drought risks and complying with regulatory requirements.

4.5 Lesotho

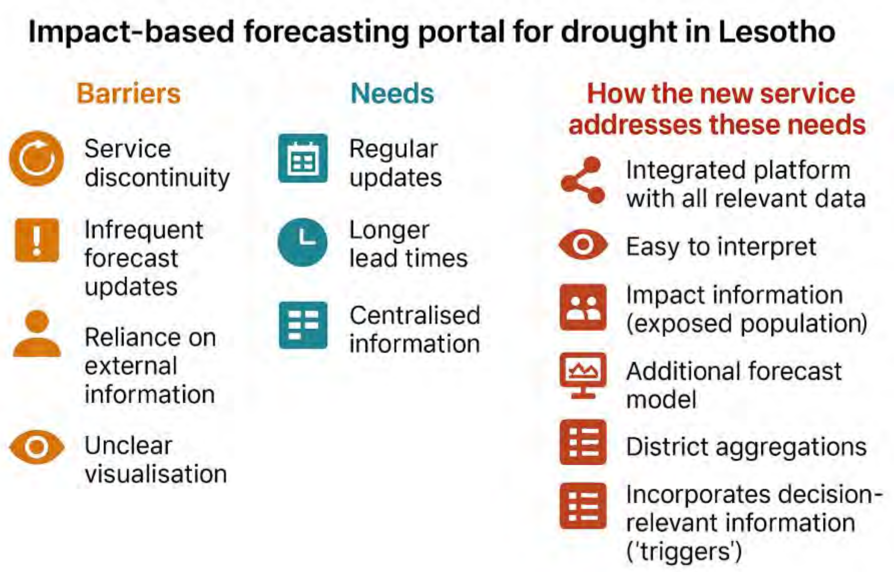

Figure 13 Overview of the barriers to the use of existing CS identified at the start of the project, the needs for improved CS, and how the newly-developed CS addresses these barriers and needs, for the LL in Lesotho.

What is the decision-making context?

The Lesotho LL is focussed on Disaster Risk Reduction (DRR), Anticipatory Action (AA) and humanitarian aid for drought, water scarcity and cold waves. The ambition of the LL within I-CISK has been to support a move from reactive to proactive drought and cold wave impact management in the humanitarian sector.

Lesotho is reliant on rainfed agriculture, which is heavily affected by recurring droughts. Agricultural and socio-economic droughts are the most impactful, going beyond rainfall patterns to impact water availability for agriculture and human consumption. Rainfall projections under a changing climate are variable, however temperature is expected to increase (Masih, Van Cauwenburgh, et al., 2022 [D1.1]).

In addition, people living and working in highland areas are vulnerable to cold and snow impacts; although temperature is likely to rise with climate change, a transition to less frequent snow/cold events could mean that individuals and communities are less aware of the risk and hence become more vulnerable.

What existing CS were already in use at the start of the I-CISK project, if any?

The Lesotho Meteorological Service (LMS) has access to global and regional meteorological forecasting products, global hydrological models and crop monitoring services. From these, LMS provides customised forecasting at a range of lead times. The most frequently mentioned CS during the initial interviews were the seasonal forecasts from LMS.

The CS already in use at the start of the I-CISK project include:

- **Meteorological forecasts** of precipitation and temperature for the next 6 to 24 hours from LMS, provided by radio, television, social media and mailing list.
- **Seasonal forecasts** of precipitation and temperature for the rainy season from LMS. Released in September with an update in January using observed data for the season so far, distributed through workshops, press and mailing list.
- **Agromet bulletins** from LMS providing rainfall, temperature and vegetation index (NDVI) with both 10-day and 3-month forecast horizons.
- **Climate projections** from LMS covering the periods 2011-2040, 2041-2070 and 2071-2100.
- **Crop Monitor for Early Warning** providing maps of crop performance and yield through GeoGLAM.
- **Seasonal soil moisture outlooks** from NHyFAS (the NASA hydrological forecast and analysis system), for maps of root zone soil moisture out to three months ahead.
- **River flow forecasts** from GloFAS with daily time steps and seasonal outlooks.
- **Socioeconomic outlooks** from FEWSNET (the famine early warning systems network) IPC providing bulletins on food security classification and the seasonal soil moisture forecasts, with information on the current situation and a forecast out to 4 months ahead.

What were the barriers to using existing CS?

Service discontinuity and infrequent forecast updates

A key challenge discussed during the initial interviews is the rapid change in weather patterns observed in Lesotho. Through further discussion, it was understood that weather forecasts are not updated frequently enough and are not detailed enough to capture some events.

Reliance on external information

Participants mentioned that a barrier to the use of CS can be a lack of in-house information, which results in the stakeholders relying on external data and services.

Visualisation

The user experience of CS was a concern expressed during the initial interviews. Two participants found that user interfaces and product visualisations were difficult to use and required expert knowledge and training.

What needs were identified for improved and tailored CS?

Longer lead times

For cold wave forecasts, longer lead times were required to aid decision-making and anticipatory humanitarian action ahead of an event, based on forecast information. Existing lead times were not found to provide enough time for some relevant actions to be taken before an event. For drought, information on potential drought during the rainy season is required earlier than is currently available to enable preparedness activities.

Centralised information

The need for users to be able to find all the relevant information from a centralised location was identified, as much of the existing information required finding information from a range of sources, adding complexity to the decision-making process.

What information does the new CS co-created through I-CISK provide?

The new CS for drought risk aims to provide an interface for users, with a focus on tailored information, and is expected to contribute to informed decision making for DRR and agriculture by supporting early action and adaptation policies.

The new CS makes use of seasonal precipitation forecasts from ECMWF's SEAS5 forecasting system. These forecasts are processed to calculate the tercile probabilities (below, near or above average) of precipitation throughout the rainy season, and these probabilities are translated into a binary classification of 'drought risk' or 'no drought risk', based on thresholds defined in the Lesotho Red Cross' Early Action Protocol. The forecasts are also spatially aggregated per district, to provide information at relevant scales. Expert users are also able to access the probability information as a separate layer.

Beyond the forecasts, the new CS also uses population data aggregated over the same districts and information on the location of Red Cross branches. To tailor the information further, users can manually input data based on seasonal precipitation forecasts from LMS using the same binary classification of drought risk or no drought risk. This allows comparison of two seasonal outlooks.

The information is tailored to the needs of the users. For example, some layers, such as population and Red Cross branch locations, were specifically requested by users. The CS is also designed to align with existing decision-making processes, particularly as outlined in the Early Action Protocol, which defines who has the authority to issue forecasts and act on them. While forecasts data from a global model are used for comparison, the required input of the official seasonal outlook from LMS ensures that actions are confirmed and triggered based on locally-relevant information, in line with national protocols.

This CS does not directly include information on uncertainty, as it is not currently incorporated into the existing decision-making processes such as the Early Action Protocol. While the forecast data used to compute the tailored information is an ensemble forecast and the lower tercile of precipitation probability is considered for assessing the drought risk, the drought classification is binary as this is the current need of the users, although as noted above, 'expert users' can choose to access probability information.

How is the new information visualised and communicated?

The new CS provides an intuitive map-based interface that visualises both forecast and impact data. Additionally, the CS sends notifications by email (and potentially WhatsApp), ensuring timely and wider dissemination.

The navigation of the CS by users was considered throughout the co-creation process. Interviews with users allowed the CS developers to understand existing workflows and specific needs. Once a prototype CS was available, it was tested with users to ensure it aligns well with real-word processes and effectively supports users.

Accessibility of the information was also considered, with the CS using accessible font sizes and colour schemes. For effective and accessible communication, a combination of icons and colours is used to convey key messages, such as alerts.

Feedback from users confirms that the visualisations used are generally clear and easy to interpret, the different sources of information are both understood and trusted, and the various user roles and their needs are well-defined. It also identified some areas for further improvement before the CS is finalised, such as improved colours of rainfall data layers, and clearer instructions for use. Future updates will also see the addition of early action information in the CS.

A user guide will also be developed, which will be used for training purposes, and users of the new CS will receive training.

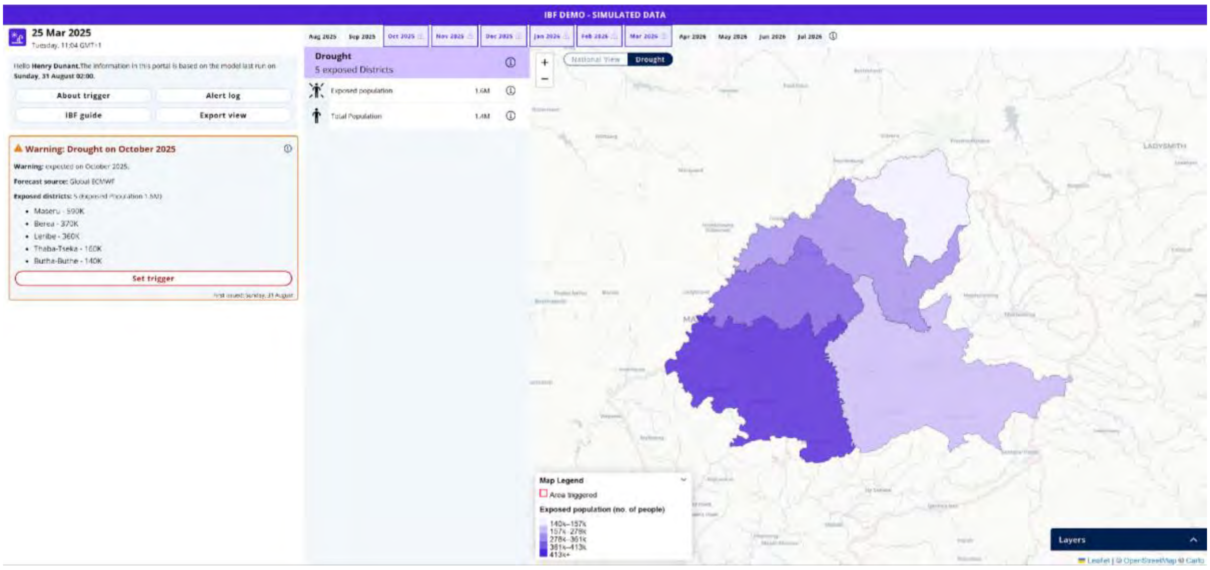

Figure 14 Screenshot from the Lesotho LL CS, indicating what users will see if there is a warning for drought in several districts, based on the ECMWF SEAS5 forecast. Icons indicate warnings for the upcoming six months, and the interface highlights that a trigger is expected for drought, the exposed districts and the associated populations. This is based on mock data and does not indicate a real forecast.

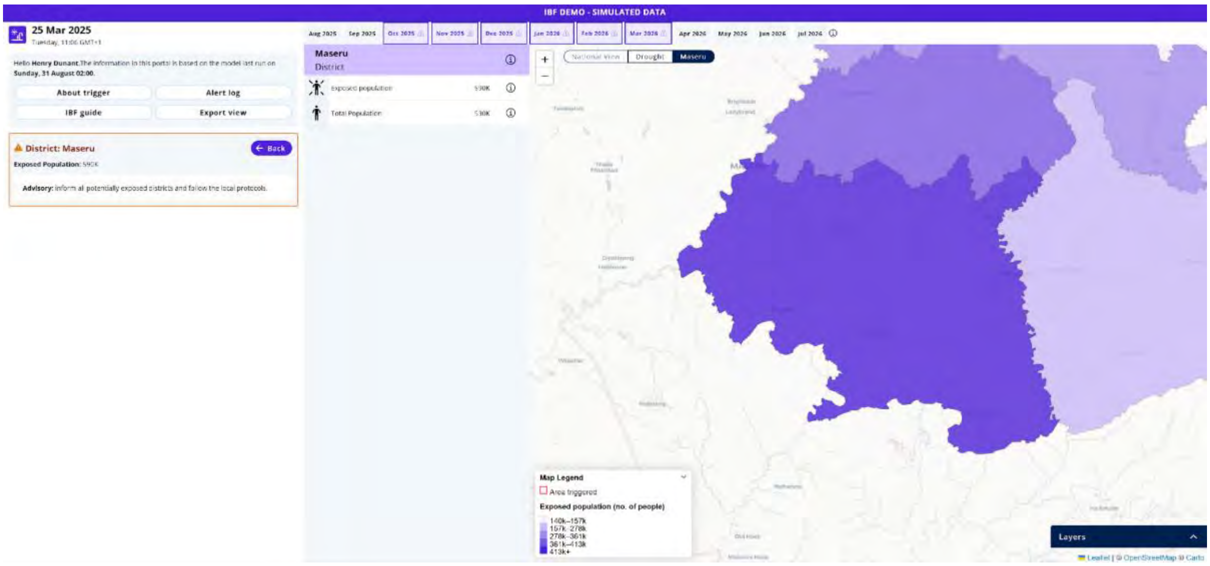

Figure 15 Screenshot from the Lesotho LL CS, indicating what users will see when clicking on a specific district from the display shown in figure 14. The exposed population in the chosen district is shown, and an advisory to inform potentially exposed districts and follow local protocols.

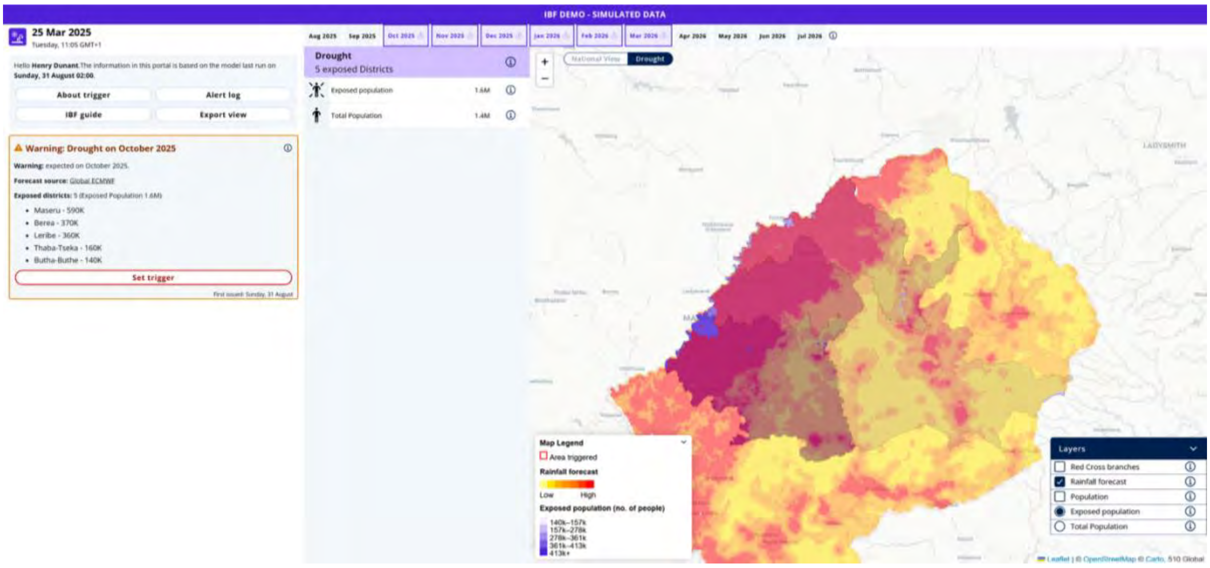

Figure 16 Screenshot from the Lesotho LL CS, displaying an additional layer that users can choose to visualise if they are interested in the probability of drought according to the global forecast from ECMWF's SEAS5 seasonal forecasting system.

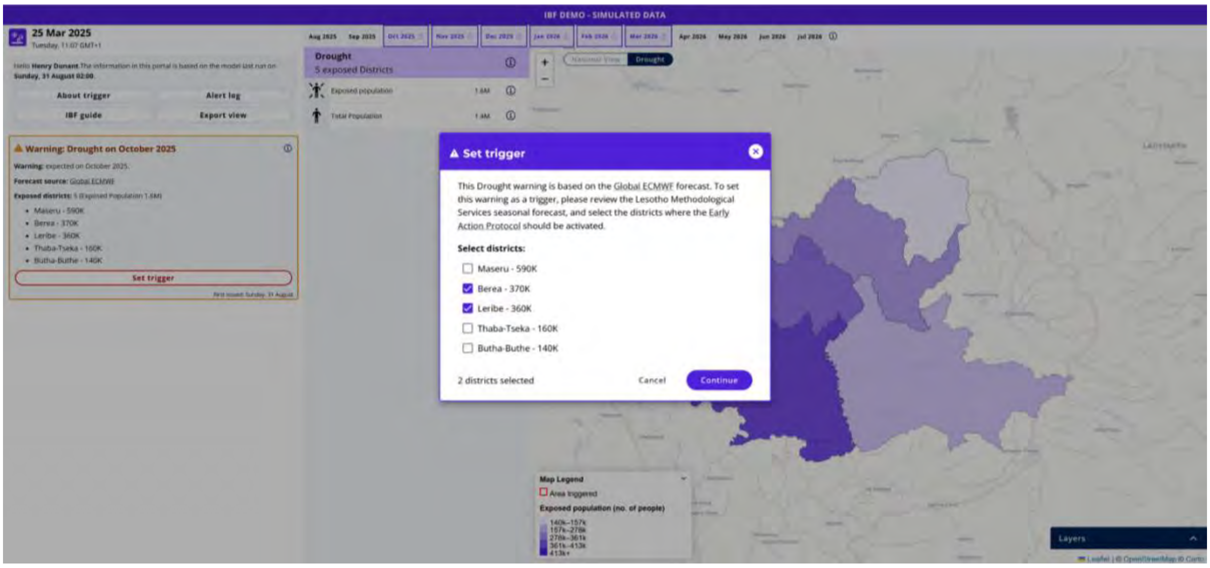

Figure 17 Screenshot from the Lesotho LL CS, indicating what users will see if they choose the option to 'set trigger' – this option allows the user to select the districts where the Red Cross Early Action Protocol should be activated.

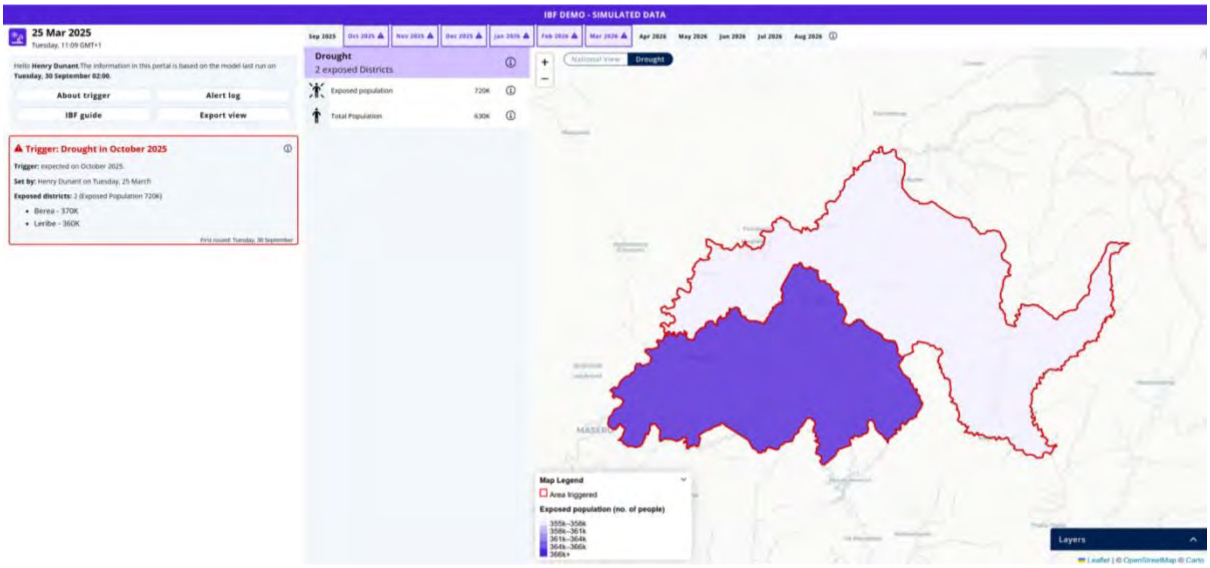

Figure 18 Screenshot from the Lesotho LL CS, indicating what users will see when the trigger has been set. The districts highlighted in red are at risk of drought, according to the official seasonal forecast from LMS.

How does the new CS address the identified barriers and needs?

A significant benefit is that the new CS brings together all relevant data in one integrated platform, addressing the need for centralised information.

A key aspect of the new CS is that it will provide information in a timely, easy-to-understand fashion that indicates not only the weather but its potential impacts, enabling early action to be taken. The CS adds a new layer of forecast information from another forecast centre (SEAS5 from ECMWF), in addition to the existing seasonal forecast information from LMS which can be input manually, allowing comparison of multiple forecasts to aid in assessing confidence in the predictions, and extending the lead time of forecasts to ensure there is information available throughout the rainy season – a key gap and need identified in the existing services.

Previously, there was also no visualisation associated with the seasonal forecasts from LMS. The new CS addresses this gap by allowing input of the seasonal forecast from LMS to display it as a map, alongside other relevant information aggregated over the same districts.

The new CS is expected to contribute to informed decision-making processes that also include impact data, for disaster management agencies and the agricultural sector, and support the transition from reactive to proactive disaster risk management. This will support early action and adaptation strategies, and reduce the impacts of drought on food, water and livelihoods in local communities.

While a new CS has not been developed for cold waves, support has been provided through the I-CISK project to co-explore ways to improve the existing cold wave forecasts provided by LMS. For example, research undertaken through I-CISK has assessed the forecast performance of cold wave forecasts from ECMWF at different lead times. Forecasts from ECMWF were already in use by LMS, and other potentially useful forecast products were discussed and identified through this collaboration. The results of this work help to address the need for cold wave forecasts at longer lead times, by better understanding the ability of forecasts to predict these events, and at which lead times the forecasts can be reliably used for decision-making. Baugh, Egan, et al., 2025 [D3.4], 'assessment of existing and tailored CS using a range of user-driven evaluation metrics', provides further information.

4.6 The Netherlands

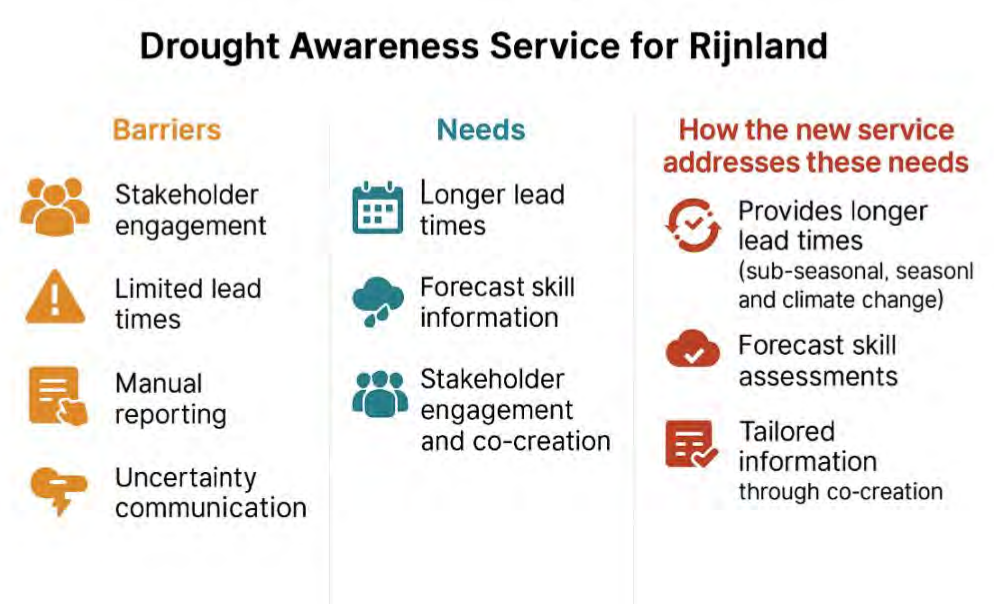

Figure 19 Overview of the barriers to the use of existing CS identified at the start of the project, the needs for improved CS, and how the newly-developed CS addresses these barriers and needs, for the LL in the Netherlands.

What is the decision-making context?

The Netherlands LL is focussed in Rijnland, a sub-region of the Rhine delta in the Netherlands where the Rijnland water authority is responsible for governance of the surface water system and waste water treatment. Surface water is highly controlled in Rijnland and is used for both irrigation and drainage. The main climate hazards in this region are pluvial flooding and drought, with drought being the key focus for this LL. Droughts strongly impact water tourism (by limiting recreational shipping) and agriculture (by affecting irrigation water management and water quality). In particular, during spring and summer, local meteorological drought in combination with low flow in the Rhine can cause issues with salinity.

Examples of the decision-making required include whether to limit ship-lock operation, and management decisions such as changing drought alert levels, inspecting dikes, planning for staff availability, and starting or increasing the frequency of drought committee meetings regarding the activation (or not) of the alternative fresh surface water supply route due to the primary source of freshwater becoming too saline. Other relevant decisions are those involving long-term investments for ensuring the water system is robust in a changing climate.

What existing CS were already in use at the start of the I-CISK project, if any?

At the start of the project, CS were already being used by the water board for monitoring and operating the water system according to current and future forecast state up to 15 days ahead. These were used to support decisions for a range of activities including emergency management, short-term planning and daily decision-making, and weekly monitoring and prediction.

Information already in use included:

- **Drought bulletins** provided by the water board of Rijnland, using forecasts from KNMI, ECMWF, MeteoGroup and the HydroLogic water balance model. The bulletins assess the drought condition and provide drought warnings colour-coded according to water use restrictions, as well as graphs and forecast plumes. An associated monitoring network monitors precipitation, potential evapotranspiration, water levels, pumped discharge, inflow and salinity. Forecasts include spatially distributed potential rainfall deficit and river discharge for the Rhine. The bulletins are produced every week and provide forecasts out to 14 days ahead.
- **Streamflow monitoring and prediction** for the Rhine at Lobith. Rijkswaterstaat provides river discharge monitoring and 15 day predictions at this location.

What were the barriers to using existing CS?

Stakeholder engagement

The CS available is produced for the water authority of Rijnland, lead stakeholder of the LL. Water tourism and agricultural sector representatives were not necessarily aware of the various CS and climate information available.

Limited lead times

Current CS provide forecasts out to 14 days ahead, resulting in challenges for decision-making that relies on information on timescales longer than 2 weeks ahead.

Manual reporting

The drought monitor reports are circulated and used widely by water authorities, key water-related stakeholders in the area, and the general public. A challenge identified for this CS is that the report is generated manually, and is typically a long report aimed at including all relevant information for a wide range of stakeholders.

Uncertainty communication

In general, information provided by the CS is ensemble-based, and presented using uncertainty plumes. A challenge highlighted through the initial surveys is that guidance on the use of probabilistic forecasts, for example for the alert levels, is not available.

Negative consequences of action

While not a barrier to the use of a CS itself, participants from the Netherlands LL highlighted that a challenge associated with decision-making based on CS is that some drought management measures negatively affect some of the stakeholders (for example, recreational water use and shipping), while taking measures too late can negatively impact other stakeholders (such as agriculture).

What needs were identified for improved and tailored CS?

Seasonal, sub-seasonal and climate change information

Longer lead times would allow stakeholders to prepare better for upcoming drought events and, by incorporating climate change information, develop climate adaptation plans that account for the frequency and severity of droughts anticipated in the future.

Forecast skill information

Information on forecast skill is limited beyond 2 days, and additional information on forecast skill at a range of lead times would be beneficial, to supplement the general knowledge that forecasts are uncertain and that misses and false alarms can occur.

Stakeholder engagement and co-creation

Within the I-CISK project, the water authority of Rijnland aims to strengthen communication and engagement with other sectors and stakeholders such as those from the agriculture and water tourism/recreation sectors, in order to co-create tailored CS that are informative for their decision-making processes.

What information does the new CS co-created through I-CISK provide?

The Netherlands LL has developed a 'Drought Awareness Service' (https://i-cisk.dev.52north.org/living-labs/rijnland--nl/app/) with two sub-services: one for upcoming drought forecasts (including streamflow and potential precipitation deficit forecasts) and the other assessing drought in climate change projections (covering various parameters of interest to users e.g. streamflow, temperature, precipitation). Two new sub-seasonal to seasonal drought forecasts are included, one based on potential precipitation deficit and the other on River Rhine discharge.

Streamflow forecasts in the new service are provided for the Lobith station, where The Rhine enters The Netherlands, which is used as the key indicator for low flows and drought in Rijnland.

The new CS makes use of a range of data, including observed precipitation and temperature. The seasonal river discharge forecasts are based on ECMWF SEAS5 meteorological (precipitation and temperature) forecasts, which have been bias-corrected using HydroGFD and used to drive the E-HYPE hydrological model. The bias-corrected meteorological forecasts are also used for predicting the cumulative precipitation deficit. The bias correction step is seen to increase trust in the forecast by limiting the deviation at the initial time.

The CS users will also receive information on forecast performance/skill, including the maximum lead time of positive skill (using climatology as a reference), contingency tables and graphs of re-forecasts compared to historical observations. The stakeholders in the LL were presented with a range of forecast evaluation metrics and graphs, and these choices represent the preference of the stakeholders for the skill information most relevant to their decision-making.

How is the new information visualised and communicated?

A range of visualisations are used in the new CS, which has been developed with the user's journey through the CS interface in mind. For example, the welcome page of the CS provides a simple selection process allowing the user to select their sector, and then the type of information they are interested in, including drought alerts, river discharge forecasts, precipitation deficit forecasts and climate change impact information. Each sub-type has a different visualisation, tailored to the decisions that will be made based on the information.

During the co-creation process, mock-ups with various options for the CS interface and navigation were prepared and presented in one-to-one feedback sessions with the stakeholders in the LL. Development proceeded based on the majority preferences. There are plans to collect further feedback on the new CS once all aspects are fully implemented. Another aspect of the co-creation process involved discussions around forecast uncertainty, that aimed to address challenges around the use and understanding of uncertainty information, which was highlighted as a barrier to the use of existing CS. Discussions focussed on presenting uncertainty in accessible terminology, with sources of uncertainty described and examples of different ensemble forecast visualisations introduced. Uncertainty was generally well understood, although not necessarily fully accepted as part of the decision-making process yet. The majority of users preferred the forecast plume visualisation, which displays percentiles from the forecast ensemble, as opposed to 'spaghetti' charts displaying individual ensemble members, or a single shaded area showing the full uncertainty.

Information buttons with snippets of information in relevant places within the dashboard have been used to provide guidance on the use of the CS.

Figure 20 Screenshot of the welcome page of the Netherlands LL CS. The user can select their sector (recreational boating, agriculture or water management), which provides a dropdown of CS options tailored to that sector – including drought alerts, discharge at Lobith, precipitation deficits and climate.

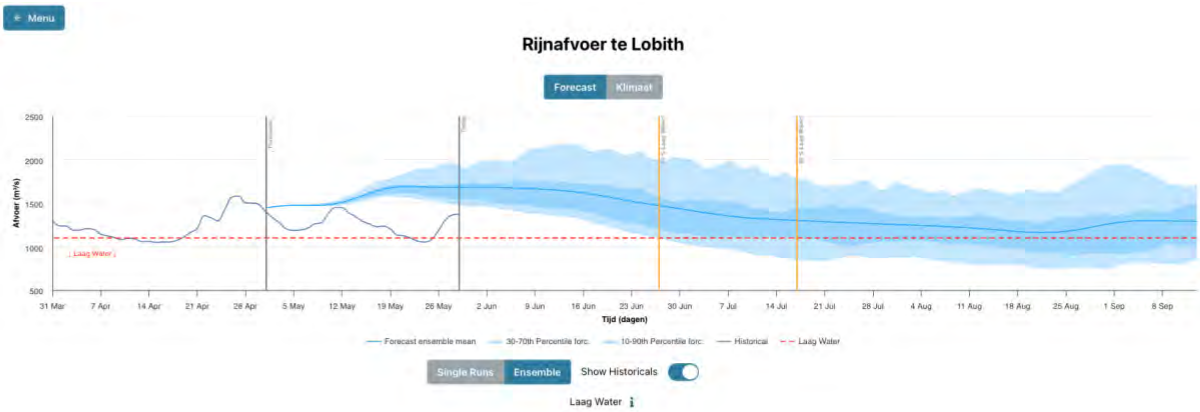

Figure 21 Screenshot of the Netherlands LL CS river discharge forecast at Lobith, displaying an ensemble forecast of river discharge out to 4 months ahead, and indicating the forecast ensemble mean, percentiles to display uncertainty, and a low water threshold. The user can toggle to show observed streamflow for the preceding month before the forecast, and any observations available since the start of the forecast. The forecast can also be displayed as individual ensemble members (a 'spaghetti' chart).

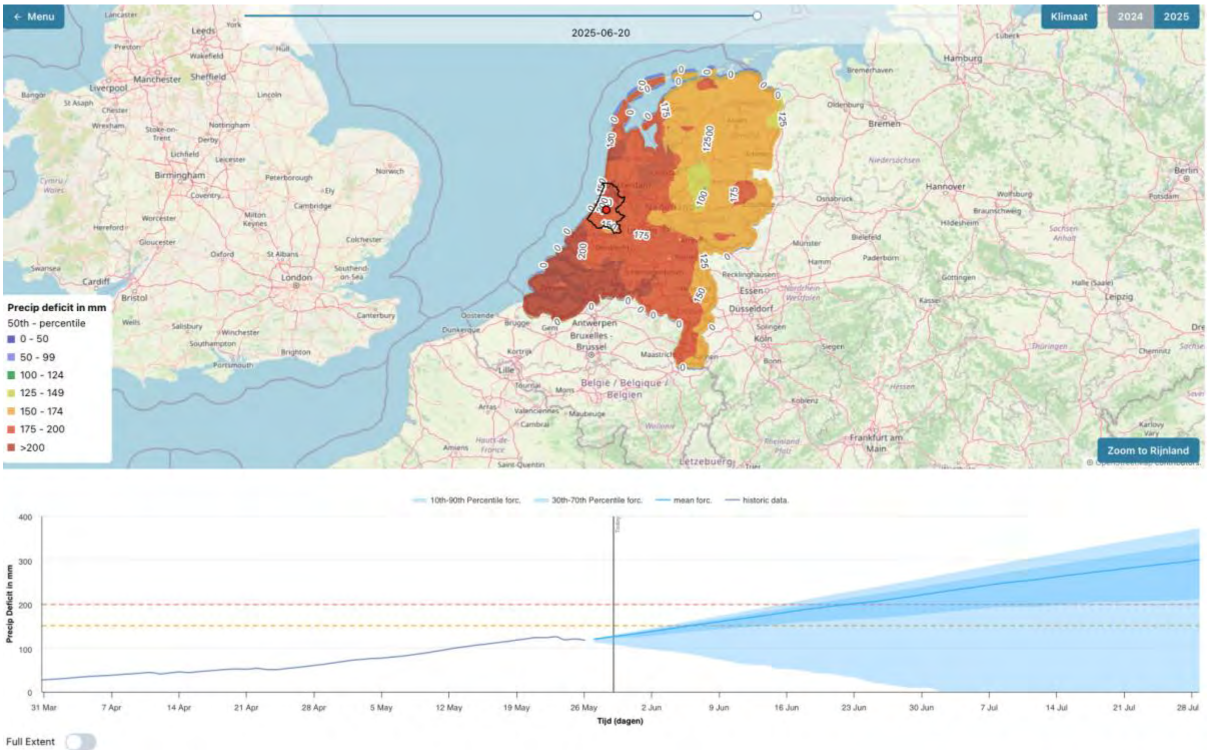

Figure 22 Screenshot of the Netherlands LL CS precipitation deficit information, indicating the predicted precipitation deficit in mm, displaying a map of the median of the forecast ensemble, and an ensemble forecast chart for the selected location.

Figure 23 Screenshot of the Netherlands LL CS weekly drought alert. Options within each dropdown guide the user to other relevant pages within the CS for more information, such as the river discharge forecast or the map of precipitation deficit forecast.

How does the new CS address the identified barriers and needs?

The key improvement this CS makes to the previous existing CS and information is the provision of longer forecast lead times for drought awareness, combined with climate change drought impact information, addressing the need for longer lead times and climate information.

The new CS also provides tailored information including new visualisations based on user needs, a weekly drought status and alert overview, and thresholds of relevance to the users.

Stakeholder engagement has also been addressed through the co-creation process of the I-CISK project, which has helped to raise awareness of CS and drought preparedness and adaptation strategies across the water management, agriculture and recreation / tourism sectors.

4.7 Spain

Figure 24 Overview of the barriers to the use of existing CS identified at the start of the project, the needs for improved CS, and how the newly-developed CS addresses these barriers and needs, for the LL in Spain.

What is the decision-making context?

In Spain, the LL is shared between the Guadalquivir and Guadiana river basins, in northern Andalusia. Within this region, Los Pedroches is the primary focus area, where key economic sectors include agriculture, livestock farming, olive groves and agro-industry, all of which are vulnerable to droughts and other climate-related hazards. A second sub-region within the LL providing a test site for CS developed as part of I-CISK, is the Sierra de Cazorla, Segura and Las Viñas Natural Park. Rainfall patterns are the preliminary interest for CS, as these impact all sectors, and there is intense pressure on water resources due to drought, alongside risks from forest fires. The LL characterisation report (Masih, Van Cauwenburgh, et al., 2022 [D1.1]) highlighted that initial interviews with stakeholders point out broad environmental impacts affecting natural areas, wildlife and agriculture due to "increased temperatures and sustained rainfall pattern disruption", with the cumulative effect of this disruption reducing resilience.

What existing CS were already in use at the start of the I-CISK project, if any?

In the Andalusia region in Spain, the network REDIAM (the Andalusian Environmental Information Network), run by the Department of Agriculture, Livestock, Fisheries and Sustainable Development of the regional government of Andalucia, is responsible for integrating and disseminating environmental information produced by various centres. They produce and update information regarding a range of environmental issues and climate change. The Department also maintains a tool, *Subsistema Clima,* for the compilation and standardisation of climate and weather information generated in the region, including 3000 meteorological observation stations (of which ~1/3 are currently active).

Initial interviews highlighted that the most-used CS in the region, for both forest and agriculture sectors, are AEMET (the State Meteorological Agency of the Spanish Government), TV, press and media channels (elTiempo.es and meteo.es are given as examples of frequently used sites), alongside traditional knowledge based on historical observations and experience. It was also considered that the 14-day forecasts available from AEMET and elTiempo.es are generally reliable, whereas longer-range predictions lack sufficient spatial and temporal resolution and are unreliable. Interviews with stakeholders also provided the opportunity to understand their experiences in more detail, with responses noting for example the types of decision made, such as when to prune olive trees based on 15-day forecasts, alongside details of some of the ancestral local knowledge that is used for decision-making. As local farmers know their land well, it was noted that they may see that weather forecasts online predict it will rain, but with the air coming from a certain direction, they are aware that based on experience, it won't rain on their land. Another example of a proverb was provided by one participant, which translated indicates that if the local river is dry at a certain time, you know which decisions to make regarding buying food or selling livestock, for example. A challenge noted here is that changes due to climate change are resulting in the invalidation of traditional local knowledge reflected in these proverbs, that no longer serve to predict upcoming conditions.

The CS available for the Spanish LL include:

- **Climatological data** such as drought indices and land use, for the 1981-2010 climatological period, provided by AEMET as statistics, extreme values, threshold exceedances, event reports and maps.
- **Seasonal forecasts** of precipitation and temperature, produced by AEMET monthly out to 3 months ahead.
- **Climate projections** for precipitation and min/max temperature out to 2100, provided by AEMET as monthly and daily data, maps and charts of regionalised projections.
- **Forest fire risk management plans and forest use restrictions** are provided as bulletins by the Andalusian Environmental Information Network (REDIAM).

- **Climate scenarios** are also provided by REDIAM for temperature, precipitation, potential evapotranspiration, hydric balance, hot days and tropical nights, for 1961 to 2099.
- **Drought monitoring** for 1961 to present is provided by the Higher Council for Scientific Research (CSIC) as maps, data and bulletins.
- **Meteorological forecasts** are provided by AEMET daily out to two weeks ahead for temperature and precipitation.
- **River basin monitoring** is provided by the Guadalquivir River Basin Authority as a geoportal, text and charts, covering reservoirs, flow rates, river levels, floods, rainfall, irrigable areas, with historical data up to the present at hourly, daily and monthly timescales, and by the Guadiana River Basin Authority covering the hydrogeological situation, water quality, ecological status and flood risk assessment.
- **Groundwater monitoring** data from two piezometers managed by the Guadiana River Basin Authority.

Additional information was provided by the stakeholders participating in the Spanish LL, outlining their role, sector, and the climate services they produce themselves and use from other organisations. This information is outlined in Table 2 below.

Table 2 Actors involved in the Spanish LL, their role, and the CS produced and used by each actor.

Actors involved	Role	Type of organization	Sector	Climate value chain	CS produced (publicly available)	CS used
Guadalquivir River Basin authority (RBA)	Water management and planning	Policy makers / water managers	Water	Provider & End-User	Hydrological and groundwater monitoring networks Monthly drought monitoring reports GIS layers	Climate services from: AEMET REDIAM Climate change impact predictions on water resources from CEH-CEDEX
Guadiana River Basin Authority (RBA)	Water management and planning	Policy makers / water managers	Water	Provider & End-User	Hydrological and groundwater monitoring networks Monthly drought monitoring reports GIS layers	Weather forecasts provided by: AEMET and REDAREX (Extremadura regional weather service) Climate change impact predictions on water resources from CEH-CEDEX
REDIAM (Environmental Information Network of Andalusia)	Environmental Information Network of Andalusia – data management and dissemination	Public entity of regional government of Andalucía	Environment	Provider Purveyor	Data gathering, processing and dissemination on environmental information: climate, weather, land use, water resources, fire risks, etc.	Information generated by other public and private institutions: AEMET, Government of Andalucía, IFAPA, RBAs, etc.
Sierra de Cardeña and Montoro Natural Park	Nature conservation park	Natural area management	Nature conservation	End-User	Not applicable	Experience INFOCA fire risk reports (bi-weekly)
CCEFC (Centro de Capacitación y Experimentación Forestal de Cazorla)	Forestry management research and training center in Cazorla natural park	Education and training	Forestry	Purveyor	Not applicable	INFOCA fire risk reports (bi-weekly) Personal experience AEMET Weather forecasts
IFAPA – Instituto de investigación y formación agraria y pesquera	Agriculture & Fisheries Research and Training centre	Research and Academia	Agriculture	Purveyor	Carbon, water and energy balances to provide information on plant water use and needs Models that relate climate with plant (oak trees and pasture) phenology and production	REDIAM data AEMET data Ventusky Rain alarm REDIAM's CLIMA network AEMET historical climate data

Actors involved	Role	Type of organization	Sector	Climate value chain	CS produced (publicly available)	CS used
					Network of meteorological stations	RIA (Red Información agroclimática de Andalucía)
ADROCHES	Local rural development association for the Pedroches region	Not for profit association	Rural development	End-User	Not applicable	CSIC drought monitor: monitordesequia.csic.es Traditional knowledge AEMET 15-day predictions
OLIPE	Olive growers cooperative (organic and conventional)	Farmer organization and food processing industry	Agriculture & agroindustry	End-User	Not applicable	Cabañuelas (traditional predictive system) Experience AEMET Weather forecasts Regional and local weather stations
COVAP	Cooperative of ranchers & farmers that produces milk and meat products	Rancher organization and food processing industry	Livestock, feed production, and agroindustry	Provider End-User	Network of meteorological stations and a network of environmental stations on livestock farms	TV and radio weather reports 15 day predictions – AEMET and eltiempo.es Traditional knowledge Data from own meteorological network
CICAP	Research and milk production quality control organization	R&D associated with COVAP	Agriculture and livestock	Provider End-User	Network of meteorological stations and a network of environmental stations on livestock farms	15 day predictions – AEMET and eltiempo.es TV and radio weather reports Traditional knowledge Data from own meteorological network
Federación Andaluza de Caza (Andalucía Hunting Federation)	Federation of small game hunters in Andalucía	Hunting not for profit association	Forestry / hunting	End user	Not applicable	TV and radio weather reports 15 day predictions – AEMET and eltiempo.es INFOCA fire risk reports Monthly drought reports from RBA

What were the barriers to using existing CS?

Dissemination and communication, tailored information

During initial interviews conducted when establishing the LL, REDIAM, who integrate and disseminate environmental information from various providers, highlighted concerns that their CS are not reaching the target audiences as desired – potentially due to a combination of lack of effective dissemination and communication, and lack of tailored information for the needs of local users. Stakeholders in the agriculture sector noted that a lack of specialised information, and slow communication regarding drought, cause challenges for decision-making. Another limitation is the inaccessibility of information from other sources, such as river basin authorities or drought reports.

Forecast uncertainty

The uncertainty of forecasts is noted as a challenge in all questionnaire/interview responses, from the forestry, agriculture and rural development sectors; some forecasts/CS are too uncertain to support decision-making processes.

Insufficient spatio-temporal resolution

While the 2-week forecasts from AEMET and elTiempo.es, for example, are considered to be generally reliable with sufficient resolution, other CS, particularly longer-range predictions, do not have spatial or temporal resolutions adequate to support decision-making.

Access to historical data

Lack of access to historical data relevant to the decision-making was also noted as a key challenge at the start of the project.

Limited knowledge of groundwater dynamics

The Pedroches aquifer system is a highly fractured low productivity aquifer but critical for extensive livestock production and the health of the *dehesa* agroforestry system. There is little information available and a sparse monitoring network. Aquifer dynamics and its relationship to surface water and climate are, however, poorly understood.

What needs were identified for improved and tailored CS?

Sector-tailored information

The climate information currently available is not tailored to stakeholders needs and the information in forecast and projections does not take impacts into consideration (e.g. expected acorn production in the coming year, or water availability under different drought scenarios). Tailored CS would help farmers adjust their plans and estimate productivity, manage water availability and plan management of activities such as livestock stocking rates or purchase of additional feed. Key variables of interest include rainfall patterns (seasonal and monthly distribution, yearly accumulations), and the start and duration of summer and winter seasons.

Improved spatio-temporal resolution

Existing forecasts are available up to 7-14 days; however, stakeholders noted that the addition of CS covering longer timescales (sub-seasonal, seasonal, annual) would be useful to make informed decisions. For example, longer-range forecasts would allow farmers to adapt (reducing numbers of livestock, when to harvest etc), and would assist in planning forest management activities. In addition, the spatial resolution of existing information from e.g. climate projections is seen as too coarse (e.g. only international information is available) to be informative at the scale of the LL, and would benefit from being downscaled to more local levels / regions given existing spatial variability.

Historical data and climatology

Easy access to historical data (such as precipitation, temperature, runoff generation, vegetation phenology etc.) would allow stakeholders to identify trends / confirm observations of trends and help them to make decisions with or without forecast information. Alongside this, information on climate and hydrological characteristics based on historical data would be useful.

Uncertainty and skill information

Questionnaire/interview responses from the forestry and agriculture sectors highlighted a need for reducing the uncertainty in the forecast information, and the response from the rural development sector indicated an interest in improved availability of uncertainty and skill information for available CS.

What information does the new CS co-created through I-CISK provide?

To address these needs, the Spanish LL has developed a 'Climate Planning Service' (https://i-cisk.dev.52north.org/living-labs/guadalquivir--es/), which has five main sub-services: 1) climate projections, 2) seasonal forecasts, 3) historical climate information, 4) an olive phenology service and 5) groundwater characterisation.

This information is designed to be tailored to the decision-makers and intended use, and as such, climate projections for monthly temperature and precipitation out to 15 years are provided at a spatial resolution of 1km, seasonal forecasts are provided monthly out to 6 months ahead for temperature and precipitation at a spatial resolution of 250 m. The olive phenology service models the impacts of climate change on olive production, using indicators of relationships between phenology of olive trees and climate. Historical data is also rendered into various formats of relevance to the end user. For example, 10-day precipitation accumulations are provided, which give a measure of possible water shortage, and the number of days on which the temperature exceeds 25°C provides information on heat stress or conditions for optimal growth of crops.

CS 1 to 4 (climate projections, subseasonal to seasonal predictions, historical data and olive phenology) make use of historical monthly values of temperature and accumulated precipitation, from AEMET, and CS 4 also uses data on olive tree production from the local cooperative OLIPE, while CS 5 (hydrogeology characterisation) uses piezometric data from two public piezometers managed by the Guadiana River Basin Authority, data gathered through five fieldwork campaigns for well measuring, as well as data from grey literature, past research projects, and local knowledge. In addition to the observed data, seasonal forecasts of temperature and precipitation from ECMWF's SEAS5 forecasting system are used for CS 2 (subseasonal to seasonal forecasts), with a bias correction methodology applied using observed meteorological data, followed by a linear regression and residual interpolation processing method to create higher-resolution (250m) maps, driven by the user needs for improved spatial resolution of information due to a limited network of meteorological stations in the Pedroches region. CS 1 (climate projections) uses climate projection data from the CODREX-EUR11 dataset, using the RCP 4.5 scenario, and the information is downscaled from 11km spatial resolution to a 1-2km spatial resolution. Detailed information on these methodologies can be found in the deliverables from Work Package 3.

How is the new information visualised and communicated?

Throughout the co-creation of the new CS for the Spanish LL, online and in person meetings and workshops were held with stakeholders, either bilaterally or in a group setting, to present the CS and discuss the visualisation. Input and feedback were gathered at each meeting to guide the development and improvement of the CS throughout the process.

The discussions and feedback covered topics such as uncertainty and how to convey and visualise it effectively, the need to ensure sustainability of the CS beyond the project, the need to homogenise the language of the CS with those used in other CS from AEMET, and the need for open data. On the topic of uncertainty, feedback from some users indicated that when there are high levels of uncertainty in the data, the information should not be presented or made available.

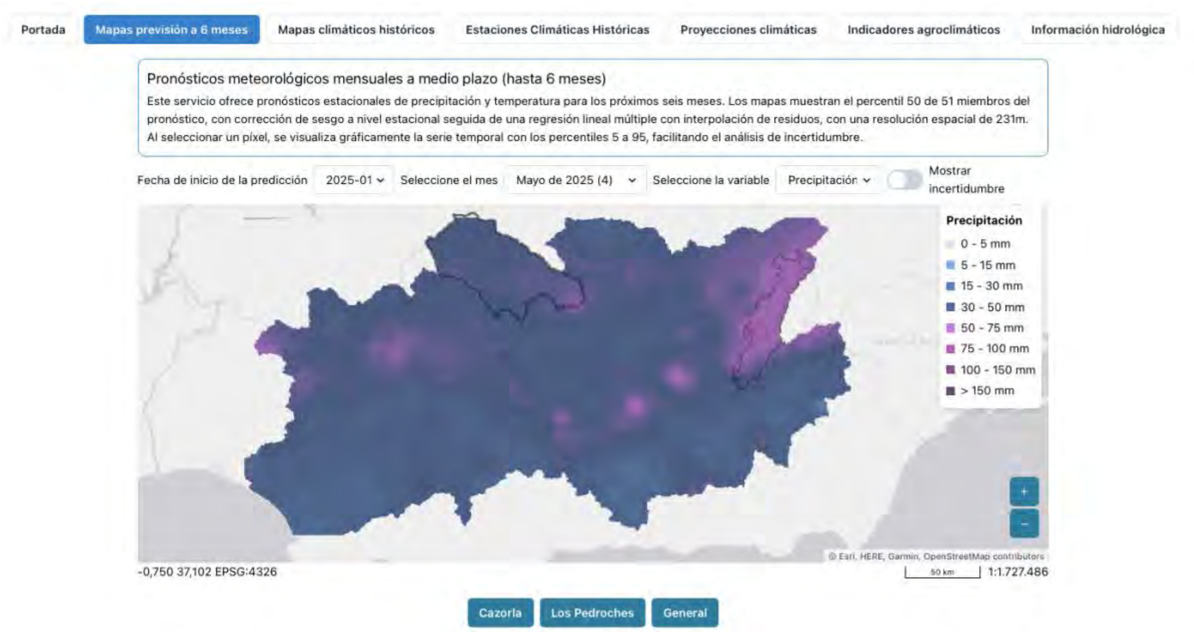

Figure 25 Screenshot of the Spain LL CS 2, showing a seasonal precipitation forecast. The map displays the median of the forecast ensemble, with seasonal bias correction and downscaling applied, showing a spatial resolution of 231m. A toggle allows the user to display the associated uncertainty (see Figure 26).

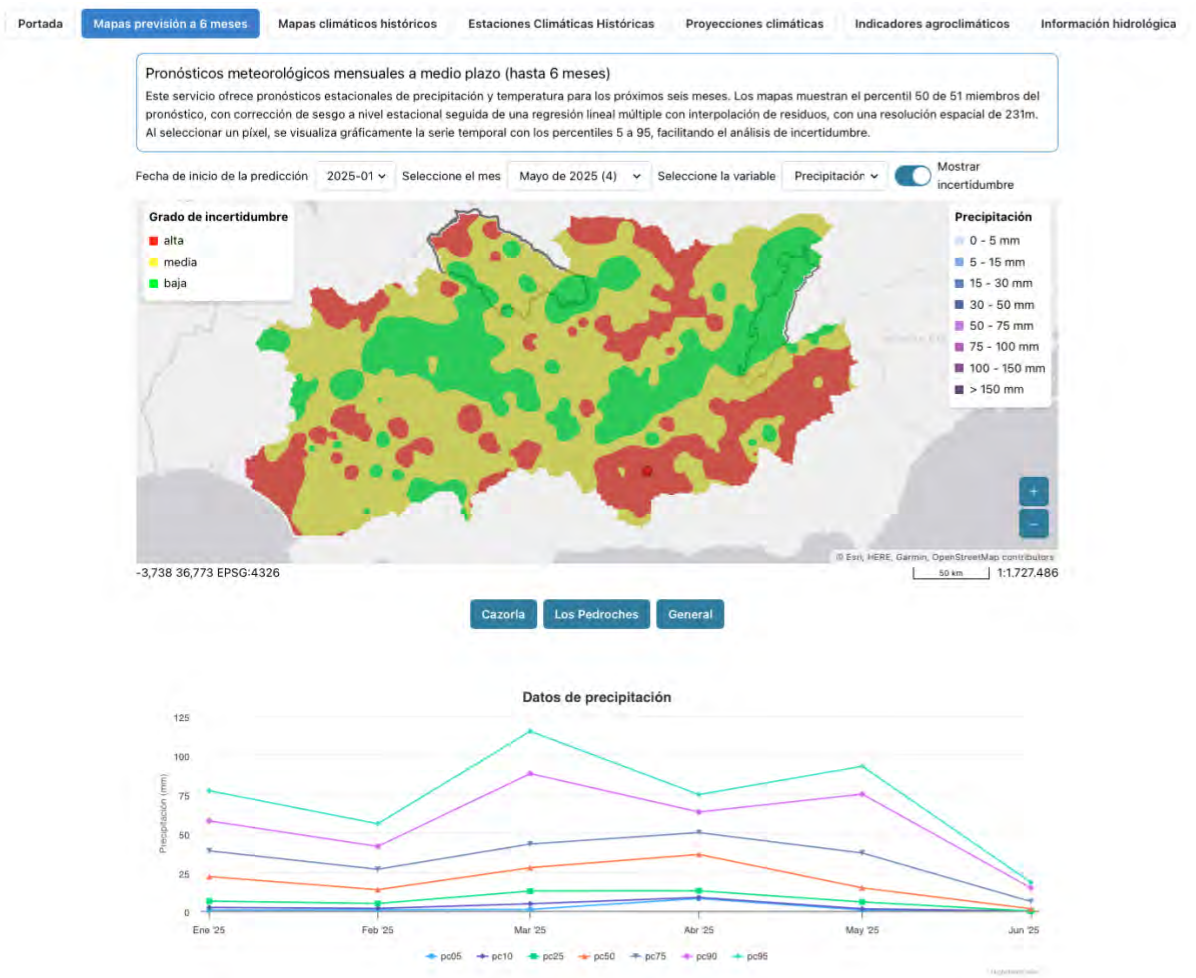

Figure 26 Screenshot of the Spain LL CS2, showing a seasonal precipitation forecast. The map displays the uncertainty in the forecast, which has been bias corrected and downscaled to a spatial resolution of 231m. Clicking on a point on the map shows the 5th to 95th percentiles of the forecast, providing an assessment of the forecast uncertainty at that location.

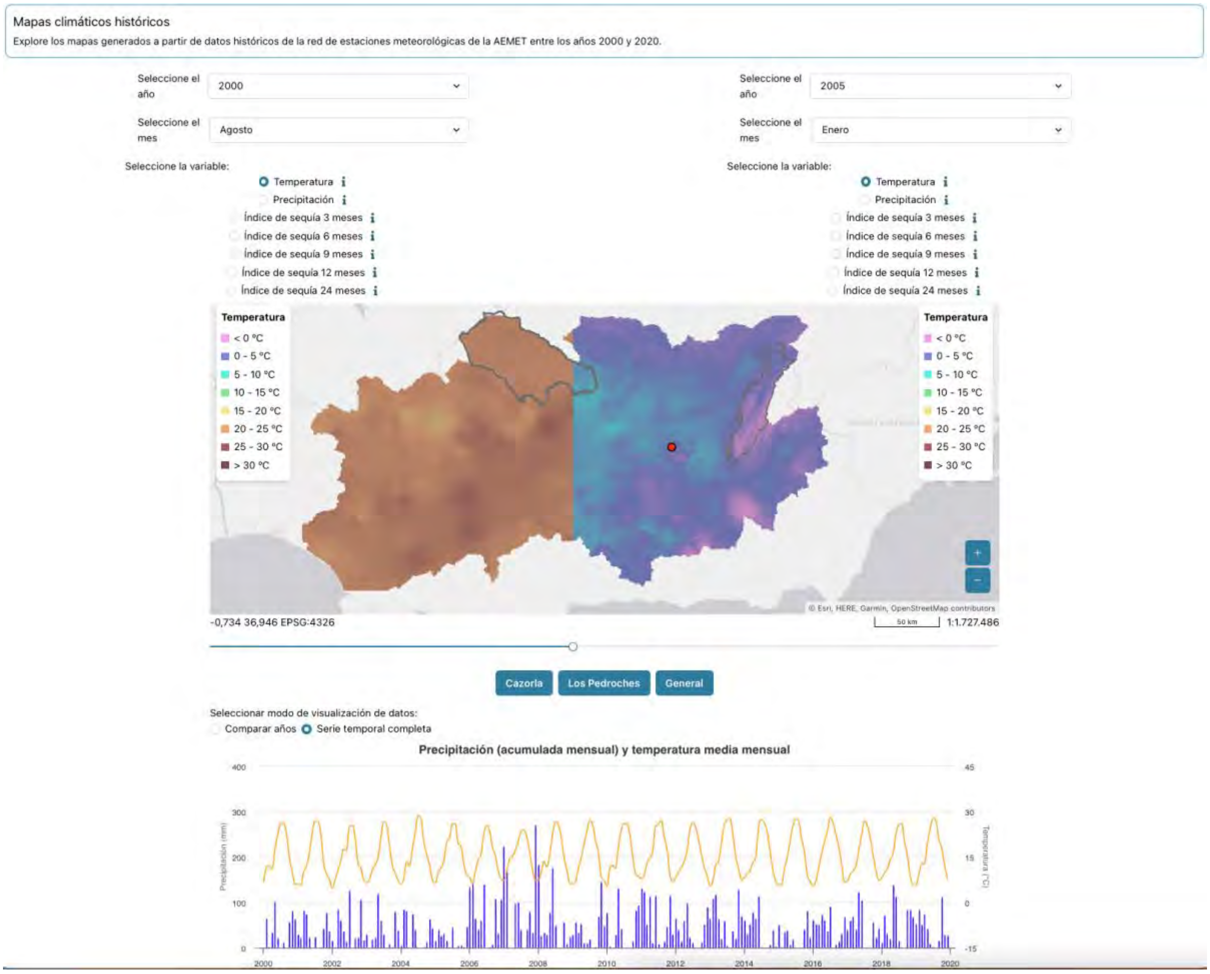

Figure 27 Screenshot of the Spain LL CS 3, showing historical climate information. The map displays temperature, precipitation or drought indices, and allows comparison of two different time periods using the dropdown menus at the top, and the slider underneath the map. Clicking on a location displays a time series of the data at that location. Another map layer provides temperature and precipitation time series data at individual stations.

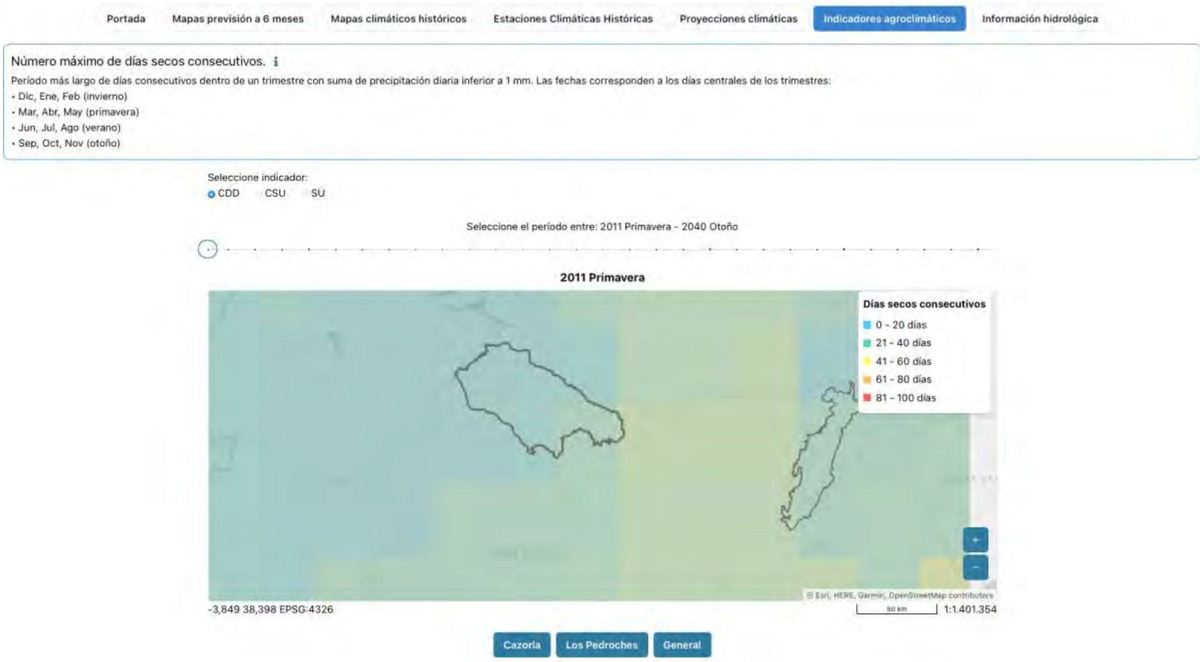

Figure 28 Screenshot of the Spain LL CS, showing agroclimatic indicators. The map displays the maximum number of consecutive dry days (<1 mm of rain) per season, for the years 2011 to 2040. This CS is still under development and the final service may be displayed differently based on the upcoming development and feedback from the stakeholders in the LL.

How does the new CS address the identified barriers and needs?

These new CS address the lack of access to information with sufficient level of detail, spatiotemporal resolution, and tailored information. It addresses the lack of access to historical data and, alongside the development of bespoke services such as olive phenology indices, linking phenological data and climate data for the region for the first time. The Los Pedroches region had limited climate information and relied on 15-day forecasts from the National Met Service (AEMET) or online weather services. These are also based on a limited number of stations in the area, so the provision of historical, extended-range forecast and climate projection data with increased resolution will address this. The service will also provide or account for forecast/projection uncertainty.

Overall, the service is expected to help reduce the impacts of climate variability/change, building resilience and reducing vulnerability by aiding evidenced based decision making and supporting sustainable management.

5 Overarching remarks

5.1 Barriers and needs

Across the seven LLs—The Netherlands, Spain, Italy, Greece, Hungary, Georgia, and Lesotho—common barriers to the effective use of **existing climate services (CS)** emerged despite the geographic, climatic, and sectoral diversity. These included:

- **Lack of sector-specific tailoring**: A predominant challenge was the provision of generic CS that did not cater to the specific needs of sectors like agriculture, water management, tourism, and health. This was noted in almost all LLs, where users found existing CS to lack actionable detail and relevant variables.
- **Limited spatial and temporal resolution**: Many stakeholders noted that forecasts were either too coarse spatially (e.g., country-level rather than regional or catchment-level) or temporally (e.g., aggregated weekly or seasonally, missing important intra-period variability).
- **Poor accessibility and usability**: CS interfaces often required technical expertise, lacked intuitive visualisation, and were not always openly accessible. Barriers such as language, absence of centralised platforms, and non-continuous service provision further hindered access, especially among local and non-expert users.
- **Lack of trust and understanding**: Trust was undermined by unclear communication of uncertainty and skill. Users struggled to interpret probabilistic forecasts or understand how CS linked to historical conditions, leading in some cases to avoidance of or scepticism towards CS.
- **Fragmentation and over-reliance on external sources**: In some contexts (e.g., Georgia, Lesotho), stakeholders relied on fragmented sources or external tools, making consistent decision-making difficult

These barriers led to the following set of overarching needs that apply to most, if not all, of the LLs, and can be considered as a list of recommendations to CS producers to consider in the creation of new CS and information to ensure relevance to decision-makers, depending on the context. The newly-developed CS would need to be:

- **Locally relevant**: Stakeholders expressed a need for CS with ***higher spatial resolutions*** for improved local relevance, and that include variables directly relevant to their decisions, such as streamflow, soil moisture, heat indices, and ***sector-relevant indicators***.
- **Multi-hazard and cross-sectoral**: There was a need to capture compounding and cascading effects of hazards (e.g., drought, heatwaves, flooding) and their cross-sectoral implications. There remain challenges associated with addressing this need, but incorporating a range of information on ***all relevant hazards in one centralised CS*** can be useful as a starting point, which also addresses the identified barrier of fragmented information from various external sources.
- **Proactive and early warning-oriented**: There was a consistent need for CS that could support a transition from reactive to anticipatory action, and often this means providing improved temporal resolution / ***more frequent and regular updates*** and relevant temporal aggregations, and ***longer lead times***.
- **Integrated with local data and workflows**: Across LLs, stakeholders stressed the need for ***integration of local observations*** and compatibility with existing planning frameworks and policies (e.g., drought management protocols).
- **Accompanied by guidance and capacity building**: Users highlighted the importance of ***documentation, training, and support*** to ensure CS usability, particularly around ***interpreting uncertainty***.

- **Clear and effective visualisation and communication: *Visualising information clearly*** and providing ***clear information on forecast uncertainty and skill*** can help users to build trust in the information through confidence in the understanding of the information presented and the benefits and limitations of the CS for the intended use. Considering ***accessibility*** and ***language*** of the information provided is also essential.

5.2 The new climate services - commonalities and differences

Table 3 Overview of information provided by the new CS co-created under the I-CISK project.

LL	Variables	Type	Temporal Resolution	Spatial Resolution	Forecast lead time	Forecast update frequency
Georgia	- Streamflow - Standardised precipitation index - Temperature - Precipitation	Historic and Forecast	Daily, monthly, bi-monthly and 3-month	Sub-catchment, point locations	Up to seasonal	Monthly
Greece	- Large range of tailored indices based on temperature, precipitation, surface water discharge and wind speed/direction	Historic and Forecast	Daily, fortnightly, monthly, 4 month	Sub-catchment, point locations, gridded	Up to climate projection	Monthly
Hungary	- Urban mapping and thermal imaging - Heat source information	Historic	N/A	Individual property level	N/A	N/A
Italy	- Streamflow	Historic and Forecast	Daily	Sub-catchment, point location	Next weeks, up to 3-month lead	Monthly to start, weekly optimal
Lesotho	- Precipitation (droughts) - Population exposed	Forecast	Seasonal (droughts)	District level	Up to 6 months	Monthly
Netherlands	- Streamflow - Temperature - Precipitation	Historic and Forecast	Daily, weekly, monthly, TBC	Point location and gridded data	Up to climate projection	Monthly
Spain	- Temperature - Precipitation - Agroclimate indicators - Groundwater (spatial description of the aquifer) and groundwater level monitoring - Olive phenology	Historic (scientific and local knowledge) and Forecast	Monthly (Temperature and Precipitation) Seasonal and 10-day (agroclimatic indicators) Yearly (olive phenology)	Point locations and gridded data (250 m for historical data and seasonal forecast, 1-2 km climate projections) 50 km (agroclimatic indicators) Groundwater modelling n/a	Up to climate projection	Monthly for forecasts

Within most LLs, end user needs are diverse and two main strategies have been employed to deal with this. Some LLs, for example Georgia, Italy and The Netherlands, focus primarily on one main information type (streamflow), and a primary end user who makes decisions that impact upon other 'downstream' beneficiaries. These 'beneficiary' users gain from a service that supports decision making by the primary user but may not use the service directly themselves. For example, better planning and management of water resources benefits users ranging from farmers to hydropower plants and recreational boaters (Table 1 and Table 3).

In other LLs, for example Greece and Spain, several bespoke indices are brought together under one 'umbrella' service for a given sector or sectors. This alternative approach to diverse needs provides streams of data that may be used directly by multiple end users. For example, data provided in the Greece LL service range from bespoke wind indices for port management through to surface runoff and reservoir storage for water management, and in the Spain LL service examples include bespoke olive phenology and agroclimate indicators, and groundwater data.

CS information provided by the Georgia and Italy LLs is very similar, and has strong parallels with the Netherlands' service (Table 4). These services also show commonality with streamflow provision in other locations and for other uses (e.g. flood forecasting), in that they provide ensemble streamflow forecasts overlaid with various thresholds of interest. This convergent evolution of services, based on consultation with different stakeholders, in some cases in different fields (e.g. flood vs. drought), suggests there may be scope for a transferable framework that others in the field, and perhaps even other fields, could utilise. However, some caution needs to be exercised to avoid influencing end user 'needs' with existing provision.

Parallels exist between the Lesotho and Spanish LLs, in terms of natural hazard and aspects of vulnerability. In both locations, there is a reliance on rainfed agriculture, which increases vulnerability to drought and rising temperatures. As a result, there may be similarities in the types of information that could be of use. However, user requirements in the two LL are different; the focus in Lesotho on preparedness for DRR and Anticipatory Action would suggest that a smaller number of main users (The Lesotho Meteorological Service, The Lesotho Red Cross Society) will make decisions that benefit downstream 'beneficiary' users. Conversely, the Spanish LL CS is more directly usable by farmers and co-operatives.

A key need for existing CS improvement identified across the LLs was the use of appropriate spatial and temporal resolutions, for both forecast and historical data. Methods of addressing this within the new CSs include downscaling of data to a more useful gridded resolution, aggregation of data over appropriate regions of interest or more useful time periods or providing increased resolution timesteps.

Another common user requirement is access to relevant historical data. Within the new CS, provision of such data not only directly addresses this, but is also one of three main methods used to incorporate, or facilitate the use of, local knowledge. Historical data is important in this respect because it allows the user to contextualise current or forecast events using their own lived experiences.

Two other methods for integrating local knowledge, demonstrated in the new CS, are the inclusion of user-defined decision/indicator thresholds (e.g. streamflow values or Early Action Protocol trigger thresholds) and provision of bespoke indicator forecasts identified by the user (such as the tourism indicators in the Crete CS). Both methods are used to indicate when events might be impactful, and therefore help users assess when they need to act.

Hazard impact forecasting is mentioned as a user requirement in the Georgia, Greece and Spain LLs, and may also be of interest in the Lesotho LL. Progression/further development of CS, perhaps beyond the I-CISK project, could include hazard impact modelling (Hemingway & Gunawan, 2018; Schroeter et al., 2021) utilising the forecast parameters and user action thresholds/indices identified to date. A benefit of such modelling is the potential to build multi-hazard or cross-sector services if a common impact framework is utilised (Hemingway & Gunawan, 2018). The Hungarian LL also focuses on impacts, through the provision of detailed risk maps for heat in urban environments. Further work in this domain could provide the opportunity to link such risk maps to climate change projections and scenarios, further aiding planning and adaptation and taking a step towards impact modelling.

Alongside the development of the CSs themselves, a key requirement identified across the LLs is around awareness, preparedness and communication. For example, in the Netherlands a highlighted need was to 'strengthen stakeholder engagement and communication', while the Greece, Hungary and Spain LLs aim to improve awareness and preparedness. The co-creation approach taken within I-CISK helps to address these needs and ensure they are incorporated into the CSs being developed. This is a key point that has been raised in the survey responses of two LLs, and in regular work package meetings of the project, and can be particularly beneficial in cases where the 'downstream' beneficiary may not necessarily use the service themselves. Through co-creation, such users are involved in the co-design of the service to ensure its usefulness. This process also increases awareness in user communities beyond those directly taking decisions based on the service.

5.3 Uncertainty and skill

Uncertainty and skill are separate properties of a forecast or climate service, and are here defined as:

Uncertainty: Representation of the inherent uncertainty present in a forecast or projection, due to, for example, the chaotic nature of the atmosphere, data quality and coverage and therefore initial condition uncertainty, and model limitations. The use of ensemble derived forecasts is a key method to account for uncertainty, which may be presented as, for example, probabilities or confidence estimates.

Skill: The performance or accuracy of the service, or any of its component parts, in the context of the user requirements (for example, how good was the model at detecting the past events of interest? Does the model /service accurately forecast decision thresholds?)

A lack of uncertainty and skill information was highlighted as a barrier to the use of existing CSs in three of the LLs (Spain, Italy and Greece), and therefore identified as a requirement for the new CSs. Indeed, of the seven LLs, six are providing some form of probabilistic or uncertainty information within the CS, although the extent of the information and the format varies. The Hungary LL is the only CS not considering any uncertainty information, as the service does not incorporate any forecasts or projections. The Lesotho LL has considered uncertainty information and does use probabilistic forecasts within the CS, with 'expert users' able to access some probability information, but at this stage the target users have a preference for not using uncertainty information, and so the forecast is converted to a binary outcome. It was highlighted in the most recent LL survey that communication around uncertainty can be challenging due to a lack of user understanding, but progress was made in this area with a variety of types of users, for example through using serious games and workshops (Georgia and Netherlands LLs). However, it was noted by the Netherlands LL that even when uncertainty was understood, it was not necessarily accepted as part of the decision making process. A lack of guidance on what probability levels should be applied to alert thresholds was also a problem for users. The use of best estimate and worse case scenarios was noted as one potential way of dealing with this that was also mentioned by the Italy LL.

Surprisingly, provision of skill information has been largely overlooked within the I-CISK CS, with only two LLs (Georgia and The Netherlands) planning to use it. The Greece LL highlighted that users have had the opportunity to use the service for the past year to understand how it performs. For Lesotho, Spain and Hungary, information will not be provided, while for Italy this has not been developed but there has been interest in this information from the users' perspective. Overall, a gap is highlighted in the need for purveyors/translators of forecast and climate information to not only communicate on the topic of uncertainty, but also on the understanding of forecast skill (performance/accuracy) and why forecasts are not always perfect, beyond the element of uncertainty.

There is a clear avenue for future work on understanding how best to include skill information in CS and promoting the importance of doing so. Failing to provide or consider relevant skill information could quickly lead to disillusioned users who were promised a service tailored to their needs, but that turns out not to be 'good enough' to support them in taking potentially costly actions. It is possible that this might be the 'gap' or 'use barrier' to some of the services developed within I-CISK. A good exercise might be to seek feedback from users on the performance of any I-CISK CS that are adopted operationally after a sustained period of use, to see whether they have proved 'good enough' or not.

5.4 Effective visualisation and communication

A critical element of designing a CS is ensuring that the visualisation and communication of the information is effective. Visualisation is not only a tool for displaying data, but acts as a bridge between complex climate and forecast information, and real-world decision-making. Here we provide an overview of key elements of the visualisation techniques used across the LLs. For more detailed information, the reader is referred to deliverable Van Andel et al., 2025 [D3.5] 'Categorisation and evaluation of visualisation practices for communicating uncertain predictions in climate services'.

A number of common visualisation types emerged as preferred or widely used during the co-design processes:

Time Series Graphs

- **Use**: Display temporal evolution of forecasts (e.g. streamflow, precipitation, temperature).
- **Strengths**: Easily understood by users already familiar with interpreting trends over time; useful for showing comparisons with historical data or thresholds.
- **Limitations**: Less intuitive for users unfamiliar with numerical axes or probabilistic information.
- **Example**: In Georgia and Italy, time series charts were used to show ensemble streamflow forecasts and to compare current conditions with climatological percentiles.

Box Plots and Percentile Ranges

- **Use**: Display uncertainty using forecast distributions (e.g. 25th–75th percentile ranges).
- **Strengths**: Communicate variability and probabilistic nature of forecasts clearly for intermediate-to-advanced users.
- **Limitations**: Can be difficult to interpret for non-technical users; often needed simplification or explanation.
- **Example**: Used in Italy for river discharge forecasts and in Greece for seasonal hydrological outlooks.

Map-Based Visualisations (Static and Interactive)

- **Use**: Show spatial patterns (e.g. temperature anomalies, drought alerts, hazard exposure).
- **Strengths**: Highly intuitive; useful for planning in many sectors.
- **Limitations**: Challenges with conveying uncertainty; can be overly simplified if not paired with graphs or metrics.
- **Example**: Every LL incorporated maps into its CS visualisation. These ranged from interactive forecast maps (e.g. rainfall, temperature, or streamflow over time), to historical and projected climate indicators, vegetation indices, or district-level risk classifications. In several cases, users could click on map regions to bring up detailed charts or impact summaries. Maps were particularly well received when they were layered with icons, thresholds, or user-relevant geographic boundaries such as catchments, administrative districts.

Traffic-Light and Colour-Coded Alert Systems

- **Use**: Indicate risk levels or alert statuses.
- **Strengths**: Rapidly understood, especially by non-expert users; reduces cognitive load.
- **Limitations**: Can oversimplify uncertainty and encourage binary thinking.
- **Example**: In Italy and Lesotho, colour-coded indicators showed thresholds exceeded for streamflow or drought triggers.

Icons and Infographics

- **Use**: Complement data with visual cues (e.g. warnings, drought status, action prompts).
- **Strengths**: Improve accessibility, especially for non-expert users.
- **Limitations**: Require thoughtful design to avoid ambiguity.
- **Example**: In Lesotho, drought risk and affected populations were communicated using symbol-based visuals layered on maps.

Forecast Summary Dashboards

- **Use**: Aggregate multiple indicators into a single screen or interface.
- **Strengths**: Allow users to explore relevant indices (e.g. Tourism Climate Index, hydrology indices) with minimal navigation.
- **Limitations**: Risk of information overload if not well-organised.
- **Example**: Greece's tourism CS used a dashboard of 12 tailored indices, including both seasonal forecasts and long-term climate projections.

5.5 User-Informed Design and Iterative Feedback

Throughout the I-CISK project, stakeholders were directly involved in **defining, testing, and refining visualisation formats**, ensuring that visual elements reflected their workflows and preferences:

- **Participatory workshops and mock-up testing**: Early concepts were co-developed and repeatedly refined based on user reactions.
- **Feedback-driven interface simplification**: Users across the LLs expressed a desire for decluttered interfaces and the ability to customise views. As a result, features such as being able to toggle layers on/off, simplified map legends, and user-selectable timeframes were integrated (e.g. Italy, Hungary, Spain, Crete).
- **Communication of uncertainty**: One of the most complex aspects of CS design, uncertainty, was addressed differently across LLs. Some used box plots and percentile ranges; others

offered "best case/worst case" scenarios or binary classification. However, it was clear that user training and accompanying explanations are essential to make this information meaningful.
- **Accessibility and inclusivity**: Some aspects of accessibility and inclusivity were considered in several of the new CS, such as font sizes, colour schemes, icons, and language choice. However, just one LL (Lesotho) mentioned that they actively considered the accessibility of the CS during the development, and there is further room for improvement in climate service development to ensure accessibility to a range of users, for example through the use of colours that are accessible to colour-blind users.
- **Capacity building through visualisation**: Visual tools also served an educational role. In Georgia, a serious game was developed to help farmers grasp probabilistic forecasts, with serious games also used in Lesotho and Hungary. In Hungary, visual heat maps also helped policymakers understand urban heat islands and plan green infrastructure investments.

5.6 Remaining Challenges and Opportunities

While the I-CISK project has made significant strides in addressing many of the barriers identified to using existing CS, and the needs for tailored CS that integrate local knowledge, several challenges and next steps remain:

Understanding and communicating uncertainty and skill

- **Improving uncertainty literacy**: Despite improvements, understanding of probabilistic information remains uneven, pointing to a continued need for training and clearer narrative framing.
- **Inclusion of skill information:** No LLs have incorporated skill information into their CS, despite its clear implications for decision making. Opportunities remain for ensuring thorough and user-driven evaluation of CS is undertaken, and the outcomes communicated to decision-makers, whether directly through the CS interface or separately.

Effective visualisation and communication

- **Balancing detail with simplicity**: Users often wanted both an overview and the ability to "drill down," requiring smart interface design that caters to both novice and expert users.
- **Visualising compound hazards**: Several LLs called for multi-hazard CS, yet visualising compound threats (e.g., heat + drought + flood) remains a methodological and communication challenge.
- **Standardising best practices**: While each LL developed context-specific solutions, there is an opportunity to consolidate lessons on effective visualisation formats into guidelines for broader CS development.

- **Visualising uncertainty and skill:** In addition to the challenge of understanding probabilistic information and the accuracy and performance (skill) of CS, the visualisation of this information in a way that is simple to understand without removing valuable information, remains a challenge.

Technical considerations

- **Spatio-temporal resolution:** While considerable efforts have been made to downscale spatial resolutions of existing data and provide information at more frequent time steps, with varying approaches taken across the LLs, there remains further opportunity to understand the effectiveness of these methods for usability of the CS and decision-making, particularly through the assessment of the skill of the downscaled data compared to the original source resolution, particularly at longer lead times.

- **Long-term sustainability:** Efforts will be required in the long-term to ensure the sustainability and operationalisation of co-developed CS, including for example to account for updates to the forecasting systems and datasets underpinning the new CS, to avoid the barriers encountered with service discontinuity and availability of existing CS. The reader is referred to deliverables D5.5 ‘business model storylines for sustainable CS exploitation in the Living Labs’ and D6.7 ‘exploitation and sustainability plan’ for more information on this topic.

Knowledge, awareness and capacity-building

- **Dissemination and capacity-building:** Through the I-CISK LLs, many stakeholders, users and decision-makers have been involved directly in the co-creation of new, tailored CS. There remains opportunities for further communicating and disseminating these new CS to other potential users, alongside increasing awareness of other potentially useful existing CS, and building capacity across stakeholders in the effective use of CS and understanding of concepts such as uncertainty and skill.

- **Integrating local and scientific knowledge:** While not in the scope of this deliverable, the I-CISK project has also explored the integration of local and scientific knowledge in CS co-creation. Knowledge on climate and adaptation from all stakeholders is relevant for the design, production, validation and effective application and use of CS, including a range of different knowledge derived either through traditional or cultural norms, personal observations, lived or occupational experiences. A broader framing of local knowledge within the CS provision process is beneficial, but challenges remain in the effective integration of such knowledge with data-driven information within CS. More information on this topic can be found in Van den Homberg, Rastogi, Hernandez-Mora Zapata, et al., 2023 [D2.2] ‘concepts and methods to characterise local and scientific knowledge’, Van den Homberg, Rastogi, et al., 2024 [D2.5] ‘user centred validation of climate risk knowledge integration - using decision timelines for collecting, understanding and integrating local knowledge’, and Baugh, Egan,met al., 2025 [D3.4] ‘assessment of existing and tailored climate services using a range of user-driven evaluation metrics’.

6 Conclusions

This deliverable has synthesised the insights gained throughout the I-CISK project regarding the use, needs, and development of climate services in seven diverse Living Labs. The work confirms that while climate services have expanded in availability and technical sophistication, significant gaps remain in usability, relevance, and accessibility particularly at the local and sectoral level.

Through iterative engagement, stakeholder participation, and co-development of new CS prototypes, I-CISK has made significant strides in addressing these gaps. The newly developed services are tailored to specific user needs, integrate local data, consider user workflows and decision contexts, and incorporate feedback on visualisation and interface design.

Key contributions of this work include:

- A systematic identification of shared and unique barriers to climate service use across multiple contexts.
- A set of concrete user-driven needs that inform the development of future-generation CS.
- Demonstrated success in applying participatory methods to co-design usable, context-sensitive, and actionable climate services.
- Valuable lessons on communicating uncertainty and supporting decision-making through fit-for-purpose visualisation.

Despite the progress made, further efforts are needed to:

- Expand the integration of uncertainty and skill metrics in ways users can understand and apply to their specific decision-making context.
- Continue capacity building and support for both providers and users to foster effective use and trust in CS.
- Establish stronger links between CS and policy/action frameworks at local and national levels.

The findings and tools developed through I-CISK provide a strong foundation for future climate service innovation, and a clear pathway to achieving more user-centred, impact-oriented, and inclusive climate adaptation solutions.

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Colophon:

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