D5.1 Rapid assessment of climate information user needs

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Executive Summary

This deliverable reports on the findings from a rapid assessment of climate information use and user information needs in Europe undertaken under the ASPECT project (Task 5.1). This task contributes to work package 5, which focuses on enhancing the usability of seasonal to decadal (S2D) climate information for effective adaptation in Europe. By accomplishing this, it directly supports the project's fifth scientific objective, *“Exploring for the first time how users can get value from considering information on seasonal / 1–5-year / 5– 30-year time-scales together to improve decision making”.* This rapid assessment included a review of published literature, an analysis of Copernicus Climate Change Service's (C3S) User Requirements Database (URDB) and User Requirements Analysis Documents (URAD), a mini-questionnaire distributed among European National Meteorological and Hydrological Services (NMHS), and an overview of preliminary project activities. The objective of this rapid assessment is to inform the development of Task 5.3 (a quantitative survey of current climate information use and unmet needs amongst organisations in Europe) and work packages 1-4 of the project.

The literature review (Section 2) was based on an assessment of over 1000 peer-reviewed articles and other reports over the last twelve years (2011-2023). We found that the application of seasonal climate forecast (SCF) information in various sectors is limited, with most organisations either not using or using it qualitatively without formal integration into operational routines. Large private companies with resources and expertise are more likely to use SCF information. In the agricultural sector, seasonal precipitation forecasts are the primary type of climate information used, while temperature forecasts are less commonly employed. Sector-specific assessments identified the limited use of climate information (all timescales) in industries such as tourism and surf-tourism. Although some organisations in the European railway sector incorporate multi-decadal climate projection information in risk assessments, its actual use in decision-making processes is limited. The literature also identified barriers to the use of climate information, such as poor communication and collaboration, limited relevance and usability, and institutional inertia. On the other hand, established stakeholder relationships, access to resources, and user-friendly interfaces were highlighted as key enablers supporting the use of climate information. Information requirements and user needs vary across sectors and organisations, with financial institutions prioritising historical weather data, climate predictions, and client-focused information; while the energy sector has specific demands for wind, solar, hydropower, and fossil fuel generation. The transport, energy, and forestry sectors seek decadal climate predictions for long-term planning; while tourism, railway, and agricultural sectors have more distinct climate information needs. Meeting these diverse requirements necessitates improved communication, guidance, and tailored climate services to address the specific needs of different sectors.

Section 3 reports an analysis of Copernicus Climate Change Service's (C3S) User Requirements Database (URDB) and User Requirements Analysis Documents (URAD) and the Prototype Service for Decadal Climate Predictions. The C3S mission is to support adaptation and mitigation policies of the European Union by providing consistent and authoritative information about climate change. C3S offers free and open access to climate data and tools based on the best available science; it listens to its users and tries to help them meet their goals in dealing with the impacts of climate change. The URDB collects user requirements from various sectors, with the coastal[1], agriculture, forestry, and disaster risk reduction (DRR) sectors demonstrating significant interest in both sectoral data (SIS data) and climate data (CDS data). The biodiversity sector expresses interest in SIS data, while the water

[1] In C3S, coastal refers to risk management, marine planning, ports, shipping routes and biodiversity.

management sector is specifically interested in CDS data. The largest user group for C3S services comprises the coastal and agriculture and forestry sectors. Considering how sensitive these sectors are to weather, it is unsurprising that they utilise climate information in their operations. Our analysis was based on 2837 responses collected from January 2018 until October 2021. Users are interested in climate projection information and reanalysis data, as well as a need for documentation, guidance, and quality assurance. The URAD and the Prototype Service for Decadal Climate Predictions (a C3S-funded project) highlighted the value of sector-specific decadal prediction products and emphasised the importance of addressing user requirements effectively and promoting user engagement throughout the development and delivery of climate services.

To strengthen the evidence base beyond the original description of work, we also distributed a mini-questionnaire among European National Meteorological and Hydrological Services (NMHS) (Section 4). This provided insights into the production and perceived use of seasonal and interannual climate forecasts. A majority of NMHSs produce their own seasonal climate forecasts, disseminated through various channels. SCFs are utilised in sectors such as transport, energy, agriculture, tourism, and insurance. Barriers to the use of SCFs include concerns about forecast accuracy and the lack of information on extreme events and longer-term climate trends. Regarding interannual climate forecasts (ICFs), a limited number of NMHSs produce them, primarily for research purposes or specific sectors. Barriers to the use of ICFs include availability, access, forecast accuracy, and the need for education and training. Section 5 highlights the progress made in the ASPECT project, focusing on in-depth interviews with superusers from the agriculture, finance, and governance sectors. The information needs of superusers across different timescales were identified, with a focus on seasonal and decadal timescales. The ASPECT project aligns with the EU Mission on adaptation to climate change and collaborates with selected regions and communities in Europe to promote climate resilience. In addition to these interviews, the first annual user forum of the ASPECT project provided valuable insights into the perspectives of almost 100 participants who identified predominantly as producers or translators of climate information. The majority reported always using climate information, citing reasons such as climate services, early warning, informed decisions, research, adaptation, and prediction. Enablers mentioned included public tools, metadata, and visualisations, while barriers included complexity, understanding, and uncertainty. Respondents expressed varied preferences for climate prediction lead times, with 10 years being the most useful, followed by 30 years, 3 months, and 5 years.

When comparing the findings from the different sources of evidence, several commonalities emerge. First, there is a widespread pattern of limited use of climate information across various sectors. Second, barriers hindering the effective utilisation of climate information are consistently identified. Finally, user requirements emphasise the need for tailored information and data. These common themes highlight the need for improved communication, customised services, and access to high-quality information that addresses the specific needs of users. Users across different sectors express a desire for currently unavailable data and variables, as well as reliable documentation and guidance to support their decision-making processes. Quality assessment, dataset comparison, and uncertainty information are also identified as important factors for users in assessing and utilising climate information effectively. However, the findings also present contradictions regarding the utilisation of climate information, with some sources indicating limited adoption while others reveal a significant demand. This suggests a complex landscape where different sectors may vary in their use and integration of climate information.

About ASPECT

ASPECT aims to set up and demonstrate a seamless climate information (SCI) system with a time horizon up to 30 years and accompanied with underlying research and using climate information for sectoral applications. The project's goal is to improve existing climate prediction systems and to merge their outputs across timescales together with climate projections to unify a SCI as a standard for sectoral decision-making.

The project focus will be on European climate information, but we will also look where there is a wider policy interest (e.g., disaster preparedness) and in regions of European interest. We will maintain a strong link with the WCRP lighthouse activities to exploit learning for explaining and predicting earth system change. To provide a bandwidth diversity of information, the SCI system will be based on multi-model climate forecasts and will build on learning from projects such as EUCP. It will align with new activities on Digital Twins within Europe, including DestinE. The SCI will combine physical science aspects with those from other disciplines to ensure the information is robust, reliable, and relevant for a range of user-driven decision cases. The information package will incorporate baseline forecasts and projections (plus uncertainty), and will explore new frontiers (e.g., extremes which are of socioeconomic high-level interest).

To ensure success, the research will encompass: an understanding and attribution of various processes along timescales (such as exploring signal-to-noise ratio) and their impact on predictability, new ways of initialisation of the prediction systems, merging predictions with projections, provision of regional SCI for Europe by downscaling (statistical methods, AI) and HighRes models (including convection-permitting models) and innovative post-processing method enhancing the skill and robustness of the climate forecasts.

1 Introduction

This document summarises our findings from a rapid assessment of European climate information use and user information needs from published literature (peer-reviewed and grey); a secondary analysis of Copernicus Climate Change Service's (C3S) User Requirements Database (URDB), User Requirements Analysis Documents (URAD) and Prototype Service for Decadal Climate Predictions. Our assessment of the project European Climate Prediction system (EUCP) and national assessments (as per the Grant Agreement) did not yield sufficiently relevant evidence to be included in this deliverable. To compensate for this, we have incorporated evidence from a mini-questionnaire distributed among European National Meteorological and Hydrological Services (NMHS), along with a summary of preliminary ASPECT project activities.

This deliverable contributes to work package 5, which aims to increase the usability of seasonal to decadal (S2D) climate information for adaptation in Europe. The primary objective of this assessment is to inform the principal WP5 activity Task 5.3 (a quantitative survey of current information use and unmet needs amongst organisations in Europe) and work packages 1-4 in the project. This approach will ensure that the survey builds on existing knowledge instead of duplicating previous efforts.

The report proceeds as follows. In Section 2 we outline our approach and findings from a review of peer-reviewed, grey literature and a call for evidence. This is followed by an analysis of C3S's URDB and URAD; a summary of work from the C3S's Prototype Service for Decadal Climate Predictions (Section 3) and findings from a mini-questionnaire circulated among European NMHSs (Section 4). Finally, we discuss some early ASPECT project work on this topic (Section 5) and synthesise the different lines of evidence in this deliverable (Section 6).

2 Literature review

2.1 Approach

This part of the assessment focuses on articles from peer-reviewed scientific journals and grey literature. We also launched a call for evidence on March 7 2023 to gather additional evidence from a diverse range of stakeholders who are either based in Europe or working in the European context. Despite extensive promotion on our website, Twitter, and LinkedIn pages as well as during the first ASPECT user forum, we did not receive any relevant information to include in this deliverable.

This part of the assessment was specifically centred around the literature addressing climate prediction information at ASPECT timescales, encompassing a time frame from a single season up to 30 years. When assessing the peer-reviewed literature, we exclusively reviewed articles containing empirical evidence derived from observations (e.g., quantitative surveys and interviews) and transparent methodologies to ensure the reliability and credibility of the studies under assessment. This deliberate choice excluded other types of publications such as reviews or commentary articles.

Given the relatively recent emergence of climate services as a concept and therefore the paucity of empirical studies on this topic, we have restricted our review to post-2011. We are particularly interested in what has been learnt during this period since it coincides with the publication of two key review papers (see Lemos et al., 2012 / Kirchhoff et al., 2013).

The review protocol for the peer reviewed literature was as follows:

1. Search Scopus: TITLE-ABS-KEY-AUTH ("climate information "OR "climate service" AND "decision making" OR adaptation OR resilience OR usability) AND (EXCLUDE PUBYEAR PRE-2012).
2. Identify thematically relevant articles (based on title and abstract only).
   - Q. Could the paper be relevant to our review (i.e., is it about future climate information use or user needs)?
     - If yes, go to step 3.
     - If not, exclude.
3. Classify by category.
   - Category 1 (European studies only).
     - Create a longlist of articles with European focus.
     - Create a shortlist of empirical articles that focus on climate information use and/or user needs.
       - Is it an empirical article?
         - If yes, review.
         - If not, is it a review article?
           - If yes, exclude but note for future publication.
           - If not, exclude.
       - Is it related to seasonal or inter-annual (up to 30 year) prediction timescale?
         - If yes, review.
         - If not, note for future publication.
     - Review article.
       - Quick scan through the whole paper to familiarise with structure, aims and context.
       - Read abstract and discussion/conclusions to identify key empirical findings.
       - Word search “use” and need” to identify any other relevant passages.
   - Category 2 (Global-level and European comparison studies only).
     - Create a longlist of papers with Global/Europe+ focus.
     - Same as category 1 thereafter.

2.2 Literature review findings

By implementing the protocol, we evaluated more than 1,000 peer-reviewed articles and reports spanning the past twelve years (2011-2023), ultimately identifying a total of 9 pertinent studies (see Annex 1). The following section provides a detailed review of these studies, organised according to four primary themes: climate information use, barriers to the use of information, enablers supporting the use of climate information and information requirements and other user needs.

2.2.1 Climate information use

Most empirical evidence relating the use of climate prediction information in Europe stems from three articles that came out of the EC FP7-funded project EUPORIAS (2012-2017) (Buontempo and Hewitt, 2018). In the first instance, Bruno Soares and Dessai (2015) conducted an elicitation workshop with 24 climate service experts and found a widespread perception of limited use of seasonal climate forecasts (SCFs) from ‘early adopters’ in energy, water, insurance, and transport sectors. According to these experts, the prominence of use varied from integrating forecast information within operational models or simply using it as additional qualitative information. Following on from this study, Bruno Soares and Dessai (2016) conducted 75 in-depth interviews with organisations from 8 sectors and 16 European countries. In line with the elicitation study, they found most organisations interviewed (n=50) were not currently using SCFs. Moreover, those using them (n=25) reported doing so qualitatively and without any formal way to integrate the information into their operational routines. A third article from the EUPORIAS project (Bruno Soares et al., 2018) explored more broadly the type of weather and climate information used across different economic sectors in Europe. Drawing from a European-wide online survey (n=462) and in-depth semi-structured stakeholder interviews (n=80) conducted between June 2013 and June 2014, they found SCFs and climate projection information most commonly used in combination with other environmental data for strategic decision-making in agriculture, energy and water sectors. However, decadal climate predictions[2] (DCPs) were less frequently used (if at all) by organisations interviewed. All three articles highlighted that the most advanced SCF users were mainly from large private companies looking for a competitive advantage and with the necessary level of resources, capacity, and expertise to be able to experiment and start applying prediction products to their specific decision-making context.

Since the EUPORIAS project, there have been several sector-specific assessments of climate (all time-scales) information use in Europe. Damm et al. (2020) used a mixed method approach (i.e., literature/market review, interviews, and a follow up stakeholder workshop) to explore the current and potential climate service market in the Austrian tourism sector. They found that, despite high vulnerability to climate variability and change, actual use of climate information is still limited to ski resort owners and operators occasionally requesting tailored services (e.g., future snow reliability studies) for strategic decision making on infrastructure investment. In another market study, Ciurana and Aguilar (2021) investigated the current use of information and potential market for climate services in the surf-tourism sector on the Iberian Peninsula. While survey respondents extensively use short-term wind and sea-state predictions, they were not aware of any SCFs for surfers or surfing companies. Lastly, Attoh et al. (2022) used a similar mixed methods approach in the context of the European railway sector and found some use of climate information. For example, ProRail in the Netherlands and Network Rail in the UK are beginning to incorporate multi-decadal climate projection information in their risk assessments for the design, construction, and maintenance of their systems. However, this study does not provide evidence of these assessments actually being used to support decision making (Attoh et al., 2022).

We only found one relevant study of climate information use globally. Born et al. (2021) analysed 41 empirical studies of climate-sensitive decision making in the agricultural sector, and seasonal precipitation forecasts were identified as the tool most commonly used by farmers world-wide. They were found to support farm-level decision making on crop choice, land preparation, conservation agriculture techniques, water conservation strategies, tillage, sowing date, and alternative livelihood choices. 10-day precipitation forecasts also support intra-seasonal decisions such as the application of fertiliser, sowing date, and harvest date. Temperature forecasts were not identified as especially useful for the agricultural sector.

2.2.2 Barriers to the use of climate information

Provision of information alone is not enough to ensure information use. Bruno Soares and Dessai (2015, 2016) identified several barriers to the uptake of SCF during the EUPORIAS project. While perceived low skill and reliability were noted as a significant barrier, many of the issues raised related to non-technical aspects such as:

- Poor communication and collaboration between actors.

[2] When we refer to decadal climate predictions, we also include interannual timescales.

- Limited relevance and usability of information in terms of their existing practices and needs.
- Poor access to information.
- Lack of awareness of available information and its potential value.
- Lack of capacity and resources from both providers and users.
- Institutional inertia and risk aversion.

A subsequent EUPORIAS study also highlighted the importance of forecast presentation, compatibility with in-house systems and trust between providers and users (Bruno Soares et al., 2018).

Drawing some parallels with Bruno Soares and Dessai (2015, 2016), Damm at al. (2020) identified a lack of risk awareness and some level of climate risk denial from Austrian tourism businesses and local authorities. Short business cycles and little financial pressure or ‘suffering’ in the sector has also resulted in a lack of urgency and low prioritisation with regards to climate change adaptation. Furthermore, they found information use within organisations restricted by limited knowledge of existing services and their potential benefits, a lack of dedicated resources and capacity to interpret scientific data as well as scepticism and distrust in climate research in general due to conflicting messages in the media.

Focusing on the usability of historical climate data from C3S in the European forestry sector, Fraccaroli et al. (2021) highlighted several ‘weaknesses’ of currently provided services. Most related to technical requirements, such as temporal and spatial resolution and uncertainty characterisation. However, interface design (e.g., user-friendliness, data accessibility) and low willingness to pay were also perceived by some forest managers to be a significant barrier to uptake. In line with the studies mentioned above, they found that the existence of C3S and its potential benefits were not widely known in the sector. Attoh et al. (2022) also highlighted poor availability and quality of climate change information at the national level as a barrier to use in the European railway sector. By comparing climate services provision across two very different agricultural contexts (Maharashtra (India) and Norway), Vedeld et al. (2020) found that information was poorly tailored to farmers’ needs, local cultures, and existing knowledge. For example, data was often spatially too coarse, unreliable in terms of accuracy and timing, and presented in scientific terms (e.g., probabilities).

The World Meteorological Organisation’s Standing Committee on Data-Processing for Applied Earth System Modelling and Prediction (WMO/SC-ESMP) recently conducted a global survey of NMHSs. As intermediary users, they reported issues around a lack of expertise/capacity to make use of certain products, limited access to software, untimely provision and poor information fit in terms of accessing forecasts of specific atmospheric variables at relevant temporal scales (WMO, 2022).

2.2.3 Enablers supporting the use of climate information

Bruno Soares and Dessai (2016) and Bruno Soares et al. (2018) have looked specifically at this topic. They found that those who already had established relationships and a long history of interactions with forecast producers were more likely to use the forecasts in their decision making. The trust and legitimacy that had built up between users and producers was identified as being particularly important in a European context given the relatively low forecast skill. Access to organisational resources, capacity and expertise were also identified as critical factors that support the use of SCF. Accordingly, large private organisations with strong commercial incentives, and access to high levels of resources, capacity and expertise were found to be more willing to experiment and adapt forecasts to fit their decision-making contexts (Bruno Soares et al., 2018).

In agricultural contexts, co-production and face-to-face interactions with farmers are essential in areas where there is limited access to the internet and technological devices.

Otherwise, the use of climate information and climate services is limited to those with access to, and an understanding of how to use, web technologies (i.e., male and wealthy farmers) (Vedeld et al., 2020).

From the grey literature, a recent report by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) identified several technical, service-oriented, and institutional factors that has determined the usability of climate information in adaptation planning in German municipalities (Frisch, 2019) (**Table 1**).

Table 1. Factors determining the usability of climate information in adaptation planning in German municipalities (adapted from Frisch, 2019).

Technical	• High spatial resolution and context-specific data. • Quality standards (e.g., scientifically sound, cutting edge).
Service-orientated	• Online access. • Low cost. • Face to face knowledge exchange events. • Provider-intermediary-user interaction. • Transparency about the knowledge production process.
Institutional	• Institutional frameworks and legal requirements. • Intermediary organisations. • Local-level capacity/know-how.

2.2.4 Information requirements and other user needs

Peer-reviewed and grey literature suggests there is a wide diversity of information requirements and other user needs between sectors and organisations in Europe. This section begins by assessing evidence from two early studies conducted in the financial and energy sectors and culminates with findings from a diverse range of other sectors and contexts.

Financial sector

An early survey of sixty financial service providers carried out by the Sustainable Business Institute (SBI) and the United Nations Environment Programme Finance Initiative (UNEP FI) aimed to determine the types of climate information required by global financial institutions (SBI and UNEP FI, 2011). The information needs and perceptions of financial institutions are examined separately for the three categories: insurers and reinsurers, lenders, and asset managers. The survey participants are aware of climate change risk and the need to extend risk assessments and its practice to explicitly cover climate change impacts. The majority rated historical weather data nearly as high in importance as climate predictions and their interpretation (5–30-year time horizon). Local and regional climate change predictions for a time horizon of 10 to 30 years are not available or reliable enough for many purposes (e.g., problematic reliability of regional climate predictions of storms and precipitation). Explanation of key uncertainties and advice on reliability of predictions is of the highest importance. Additionally, predictions and analyses will have to be customised to the type, location, and customer base of the financial institution concerned. There is great inconsistency among survey participants in the perception of the quality of data, timely availability of the data and the value-for-money factor.

Financial service providers find that available information is not in a user-friendly form (too generic) and is not focused on client sectors. Financial institutions ranked sectors which need climate information most in the following order of importance (top 5): Agriculture, Power, Buildings, Infrastructure, Renewables, while the biggest sectoral information gaps are in: Chemicals, Healthcare, Tourism, Mining, Utilities. The preferences for information of the financial sector are not in raw climate data, but in sectoral and regional analyses, databases on weather/extreme events, loss, and various project outputs (such as renewable energy projects) as well as studies on market potential for new/modified insurance products.

Energy sector
The WMO and Global Framework for Climate Services (GFCS) published an Exemplar in 2017 explaining the benefits of climate services for the energy sector (WMO, 2017). This document is a result of cooperation between WMO, relevant energy agencies (e.g., International Energy Agency, International Renewable Energy Agency, the World Energy Council etc.) and academia, and conclusions from private sector partnership forums and conferences like the North Atlantic Treaty Organisation's Advanced Research Workshop on Weather/Climate Risk Management for the Energy Sector and the International Conference Energy and Meteorology. Although the specific methodologies used to assess needs in this report may lack clarity, which introduces some uncertainty regarding the robustness of the evidence obtained, the following paragraphs outline some key requirements for electricity production.

Historical (and possibly projected) wind climate information is critical for identifying economic value and sustainability of a wind power plant. Coarse horizontal and temporal resolution of available data leads to an erroneous negative bias in estimating wind resources. The frequency and intensity of wind gusts, i.e., wind speeds exceeding a certain threshold for time durations of a few seconds, are also of major concern to protect the machines from heavy loading.

Requirements for solar power production, in addition to solar irradiance, depend on air temperature, wind speed and humidity. Various factors, such as humidity, thermal cycling, high-temperature operation, damp heat, strong winds, hail, and snow coverage, can all have an impact on the solar PV infrastructure. Operation of solar farms relies heavily on forecasts at various timescales while financial institutions evaluate the risk associated with uncertainty in solar resource data in terms of exceedance probabilities (e.g., P50 or P90).

Electricity generation from hydropower depends on the season, with periods of high/low flows, but it is also affected by interannual variability. Hydropower generation management requires river flow forecasts at the different timescales at which power systems are operated: yearly, quarterly, monthly, weekly, daily, and intra-daily. The current practice is to use weather forecasts of up to one or two weeks. For longer timescales, some companies use intra-seasonal to seasonal climate forecasts. To better plan future assets and to reduce risk and investment costs, the long-term seasonal variations of the hydrological cycle and the changes in extreme events need to be assessed.

Exploration, extraction, and transport of fossil fuels are also dependent on climate conditions, both onshore (mines can be flooded) and offshore (e.g., oil drilling platforms are exposed to storms and hurricanes). Thermal conversion efficiency depends on the ambient air temperature while the efficiency of cooling systems depends on water temperature (ocean and rivers), river flow (especially drought periods, but also floods) and air temperature and humidity. Short-term to seasonal climate forecasts of sea state (wave heights), surface winds, extreme winds and storms, floods, and heatwave risks (air and water temperature forecasts) are needed to optimise operation and maintenance as well as operational decisions. Long-term timescales (multidecadal to centennial) are needed for site selection and dimensioning or plant adaptation. Risks from changes in sea level, wave heights, storm surges, and high air and water temperature extremes as well as flood and drought risks may have to be reassessed to provide inputs for adaptation of existing power plants. The relevant spatial scales range from global to local, with a strong need for downscaling methods and uncertainty analysis.

Evidence from other sectors and contexts

As part of the EUPORIAS project, Bruno Soares et al., (2018) found clear interest in the use of DCPs for long-term planning and strategic decision making particularly in the transport, energy, and forestry sectors. However, this study also suggested limited understanding of the term 'decadal climate prediction', their added value as tools, and associated uncertainties. This highlights the need for improved communication and guidance on how these potentially useful tools can be applied in a decision-making context.

Subsequent studies have investigated the potential market for climate services in the tourism sector. Damm et al. (2020) found limited market demand in the Austrian Alpine tourism sector. However, some businesses expressed interest in "simple and compact" summer and winter forecasts to help make investment decisions and provide activity recommendations for tourists. Regarding the Iberian surf-tourism sector, Ciurana and Aguilar (2021) found clear interest in seasonal wind and sea-state forecasts to help surfing companies plan their expenditure and manage personnel months ahead of time.

Fraccaroli et al. (2021) assessed climate information needs for the European forestry sector and found that the forest risk management sector is particularly interested in SCFs for anticipating forest disturbances (e.g., drought induced mortality, wildfires, avalanches, landslides, tree falls) and the development of emergency warning systems. Precipitation, temperature, wind, humidity, frost days, heatwave days, snow cover and forest fires were also found to be the most salient variables/indicators for the European forest sector.

European railway organisations differ in their experience and approach to dealing with the impacts of climate variability and change. Some organisations want to use climate projection information for risk assessments to guide infrastructure decision making and formulate design and operational standards (Attoh et al. 2022). They are particularly interested in changes in seasonal precipitation (e.g., summer / winter); extremes in temperature and precipitation (or lack of); wind gusts; using exceedance thresholds e.g., number of days exceeding x mm of rainfall; and frequency-intensity statistics for future climate. Data currently available from the Copernicus Data Store was deemed too coarse to be used by railway companies for risk analysis. This study identified a clear need (especially in countries with inexperienced railway organisations and limited nationally sourced information) for more comprehensive, downscaled and bias-corrected datasets that can then be tailored to local geographies and needs (Attoh et al. 2022).

Born et al. (2021) found that farmers are more likely to be interested in using raw precipitation, temperature, soil moisture, soil temperature and wind data at seasonal, 10-day, and daily timescales. The distribution of these variables before, during and after the start of the planting and harvesting season is crucial for farmers. Aside from this study, there is little evidence found in the globally focused literature that specifies the needs or climate information requirements of climate service users. Most studies that focus on information needs do so from a process perspective (i.e., exploring how to elicit the needs of a potential climate service user), rather than reporting climate variables needed by a particular type of user or sector.

The WMO/SC-ESMP recently conducted a global survey of WMO members[3] data and product requirements. Regarding long-range (seasonal) forecasts, the majority of respondents considered the current specifications of mandatory products (2m temperature, sea surface temperature, total precipitation) sufficient, and only a relatively small number of respondents specified their requests on the mandatory products, including higher spatial resolution of the data (0.25° to 1.5°; for sectoral applications and microclimate analysis); longer forecast ranges up to 6, 12, or 16 months ahead; higher temporal resolution up to daily forecast; and more

[3] Survey respondents would therefore have been employed by National Meteorological and Hydrological Services.

frequent outputs (two updates per month). Additional product(s), not currently covered as mandatory, included among others: wind (zonal and meridional) at 850, 700 and 200 hPa, relative humidity at 850 hPa, geopotential height at 700 hPa, temperature at 200 hPa, 2m maximum and minimum temperatures, surface winds and its anomalies, soil moisture, teleconnection patterns, ocean waves characteristics and ocean currents.

The review of national legislation and strategic documents in The West Balkans[4] revealed that the importance of climate change is recognised in national policies. When analysing the impacts of climate change on various sectors (e.g., agriculture, water management, forestry, tourism, health), different climate change scenarios are used. Strengthening early warning systems for extreme weather events, including further development of forecasts, with the aim of disaster risk reduction is foreseen in many national Strategies and can be considered as the need on the governmental level. National strategies and action plans for their implementation are usually being prepared for the next 5-10 years meaning that national development planning could also use interannual to decadal prediction information in addition to the climate projection information currently used.

2.3 Summary

This literature review reveals several key findings. First, the use of SCFs in various sectors is limited, with many organisations not currently utilising SCFs or using them qualitatively without formal integration into operational routines. Large private companies with access to extensive resources and expertise are adopting SCFs to enhance their competitive advantage. In the agricultural sector globally, seasonal precipitation forecasts are commonly used to support farm-level decision making, while temperature forecasts are deemed less useful. Second, there are sector-specific assessments that highlight the limited use of climate information (at all times-scales) in industries such as tourism and surf-tourism. Although some organisations in the European railway sector are beginning to incorporate multi-decadal climate projection information within risk assessments, there is limited evidence of its actual use in decision-making processes.

The review also identifies barriers to the use of climate information in general. These barriers include poor communication and collaboration between actors, limited relevance and usability of information, poor access to information, limited capacity and resources, and institutional inertia and risk aversion. Other barriers include a lack of risk awareness, limited knowledge of available services and their benefits, and technical weaknesses in climate information services, such as interface design and low willingness to pay.

Several enablers for climate information use are identified. These include established relationships and trust between users and forecast producers, access to organisational resources and expertise, and co-production and face-to-face interactions in agricultural contexts. Additionally, the usability of climate information can be improved through better tailoring to specific user needs and local cultures, as well as addressing technical requirements and enhancing user-friendliness.

Information requirements and user needs vary across sectors and organisations. Financial institutions are most interested in historical weather data and climate predictions, while expressing the need for customised and client-focused information. The energy sector has specific requirements for wind, solar, hydropower, and fossil fuel generation, including forecasts of wind resources, wind gusts, solar irradiance, river flows, and extreme weather events. DCPs are of interest for long-term planning and decision-making in the transport, energy, and forestry sectors. The tourism industry seeks SCFs to aid investment decisions and activity recommendations, while the forestry sector focuses on anticipating forest disturbances

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[4] Albania, Bosnia and Herzegovina, Croatia, Kosovo, Montenegro, North Macedonia, and Serbia.

and developing emergency warning systems. Railway organisations require downscaled and bias-corrected climate datasets for infrastructure decision-making, while farmers are interested in precipitation, temperature, soil moisture, and wind data for planting and harvesting seasons. The global survey of WMO members' data and product requirements identified requests for higher spatial and temporal resolutions, longer forecast ranges, and additional variables for sectoral applications. National policies in the West Balkan region recognize the importance of climate change and highlight the need for strengthening early warning systems and disaster risk reduction. Overall, there is a demand for improved communication, guidance on use, and tailored climate services to meet the diverse information requirements and user needs across sectors and regions.

3 Secondary analysis of C3S user work

The C3S is the climate change information service of Copernicus, the European Union's Earth observation programme. The C3S provides data, tools and information and implements continuous activities on evaluation and quality control of its services (Buontempo et al., 2022). This section reports evidence of information use and information requirements gathered from C3S's URDB, URAD and Prototype Service for Decadal Climate Predictions.

3.1 C3S's User Requirements Database (URDB)

C3S collects and analyses user requirements to trigger new research and development towards the evolution of the service. During the period from 01/01/2018 to 25/10/2021, 2837 responses were collected for C3S URDB. Responses from C3S users are collected through workshops, user surveys, interviews, and the online service support tool: Copernicus User Support (CUS) globally. The analysis was carried out by identifying commonly occurring phrases or word clusters, mainly from open-text responses, and conducting a frequency analysis.

User requirement data are collected for all C3S topics, including Climate Data Store (CDS) General, CDS Data, CDS Toolbox, Sectoral Information System (SIS) General, SIS Data, and C3S Other. However, users exhibit a greater interest in data, specifically from CDS and SIS datasets, rather than products from other parts of C3S.

When user requirements are categorised by sectors, the coastal, agriculture, forestry, and disaster risk reduction (DRR) sectors exhibit the highest interest in both SIS data and CDS data. Additionally, the biodiversity sector shows interest in SIS data, while the water management sector is interested in CDS data. Overall, the coastal and agriculture and forestry sectors form the largest user group for C3S services. It should also be noted that some users represent multiple user sectors, while nearly half of the users haven't stated which sector they represent.

Different sectors need information for a variety of reasons; these can be summarised as:

- Agriculture and forestry: water resources (management and safety), agricultural production and food security in different parts of the world.
- Disaster risk reduction: climate change mitigation and adaptation planning, planning, and designing urban areas.
- Energy: power blackouts, revenue calculation and planning, budget allocation and planning, energy generation calculation, planning and turbine design.
- Health: climate change mitigation and adaptation planning, impacts of heat and cold waves, health, food, and water security.
- Infrastructure: climate change mitigation and adaptation planning, planning, and designing urban areas, decision making.

- Tourism: algal blooms and biodiversity of tropical ecosystems, investment planning, management of the touristic flows and their transport.
- Transport: navigation on-board the vessel or ashore by the fleet management or chartering/operation department, road, and river transport (shipping), voyages planning.
- Water management: climate change mitigation and adaptation, water resources and security, river transport.

3.1.1 Information requirements

Users are mostly interested in information related to long term climate: climate projections and reanalysis. The least interest is in in-situ observations. However, 60% of users haven't specified the type of data they use. If the data categories are divided by defined sectors, climate projections are mostly used by the coastal sector. Agriculture and forestry, and biodiversity are sectors mostly interested in reanalysis. SCFs were not highly represented amongst user requirements, except for the tourism, agriculture, forestry, and water management sectors.

Datasets used for end user applications are all datasets from ERA5 reanalysis, while precipitation is the most commonly needed variable. Other frequent variables or datasets/indicators include among others: ERSEM (European Regional Seas Ecosystem Model), SS-DBEM (Size Spectra – Dynamic Bioclimate Envelope Model) and unspecified Climate Impact Indicators (CIIs), datasets from SCFs and climate projections, and variables temperature and wind speed.

User requirements are specified in terms of Essential Climate Variables (ECV) as well. Unfortunately, this information is declared only by 17% of the total number of users. As expected, the most used climate variables are precipitation and surface air temperature. The top six most used variables also include sea level, surface wind speed and direction, land cover and soil moisture. Precipitation and surface air temperature are variables used by all sectors. The other most used variables by the two largest user sectors are:

1. Coastal: sea level, river discharge and surface wind speed and direction.
2. Agriculture and forestry: land cover, soil moisture and surface wind speed and direction.

Required output is predominantly in the form of datasets, as well as maps, graphs and tables, and these outputs are important to all sectors. A significant number of responses were for the 'Other' option. Other outputs include maps and graph/plots at various integration/aggregation time and spatial scales, daily data, bar charts, confidence intervals, early warning system, summary statistics, time series, raster and shape files, spreadsheets, or csv files (ASCII files), etc.

How often the requested item should be updated (frequency of update) and how quickly the update should be made available (timeliness) depends on product type as well as in which sector information will be implemented. Frequency of update for projections should be every 5-7 years (IPCC reporting cycle), for re-analysis at least annually, while SCFs should be updated monthly or at least several times per year. Updates should be done as soon as possible and regularly. Annual updates should be available a year or several weeks in advance, while weekly updates should be available several weeks in advance.

Horizontal resolution of the outputs needed by the users ranges from 0.125° to 0.5°, i.e., from 1 m/100 m to 10 km/30 km, or just for specific locations. Looking at the vertical resolution, mainly surface or sea level data are requested. Other vertical resolutions needed are: 50 m, 100 m, 150 m i.e., levels of wind turbines or 19 levels in the troposphere.

Horizontal spatial coverage of the output requirements is primarily local scales (small parcel/areas, extension of land less than 10 hectares, stand level or resort site). Other coverage includes European scale, Spain and Mediterranean. Global coverage is required on a significantly smaller scale. Vertical coverage doesn't have much diversity since most users need surface data. Nevertheless, requirements for vertical coverage for atmospheric variables is up to 180 m including altitude levels, while for ocean variables it is the whole water column.

Required temporal resolution i.e., frequency of data points in the datasets is daily, monthly, or annually, and it goes up to 10 min as the highest resolution demanded by the coastal sector. Required output should cover the period up to 1950 in the past and the next 100 years in the future. Information for the upcoming season as well as the next year or the next 10 to 30 years are highlighted as significant. In addition, seamless information from a season to centuries is mentioned from the coastal sector.

3.1.2 Quality of information

For the characterisation of uncertainty, some users requested multiple ensemble members, mean and standard deviation as well as different climate scenarios with ideally a range of ensemble time series for each scenario to allow uncertainty prediction. Additionally, confidence intervals and percentiles are also requisite for uncertainty assessment. Users prefer the data to be provided by a quality-assured authoritative body (cf. Yang et al., 2022; Lacagnina et al., 2022), to be as accurate as possible, highly skilled, preferably bias-corrected and provided with supporting information and uncertainty representation including skill maps. Some users consider SCFs needs to be communicated alongside details about the uncertainty in the data. Greater numbers of users are interested in validation of the risk calculations under different climate change scenarios. As validation, many users ask for comparison of reanalysis with observations to estimate skill and to analyse expected changes in the future. Furthermore, it is expected that validation is done by data providers, the process of validation is transparent, and proof of validation published. It is highlighted that metadata should follow already defined metadata standards (ISO or INSPIRE[5]). The metadata should contain a description of the indicator (definition), units used, data format, dataset coverage, temporal resolution, time period covered, spatial resolution, coordinate system, complete description of the data sources, tools and thresholds used to produce indicator, data quality/validation, usage (licence restrictions). Regarding stability, maximal consistency, service sustainability and regular updates are top priority. Likewise, users would like to see a distinction between 'provisional' and 'final' data, with frequent updates of climate data confusing for users. Ensuring consistency in format across different data sources is important, too. Stability is crucial for operational practice.

3.2 User Requirements Analysis Document (URAD)

User Requirements Analysis Document (URAD) reported the user requirements regarding the CDS Data component collected until March 3rd, 2021 (C3S, 2021a). Engaging with users worldwide was done through Focus group webinars, Copernicus hackathon, the Copernicus workshop on regional reanalysis, online training events, Interviews, Toolbox user surveys and case studies, and more. These requirements mainly relate to requests for new variables and datasets and documentation/guidance.

New data requests for SCFs include soil moisture data, u- and v-component of wind at 925 hPa, Total Column Water Vapour, better prediction of alpine snow melt, earlier releases of the forecasts and to provide updates on forecasts as the seasons progress. For climate projections there were requests to include additional variables like vertical velocity, v-wind component, humidity, agri-climatic indicators, dust, and other aerosol parameters in the outputs, and to include more regional climate model results for Europe and beyond.

5 https://inspire.ec.europa.eu/about-inspire/563

Additionally, there were requests to include bias adjustment in the climate projections and that data should be supplied in the latitude and longitude coordinate system. Documentation on the model and processes applied to produce the product (e.g., the model system and the dataset version, which ECVs are covered, more information about resolution, ensemble members, what kind of aggregations or operations are done for each variable for monthly statistics) and Guidance on which model and data to use for a certain question are requested by the users as well.

General requirements were that units of measures for the same variables should be homogenised across different datasets, all data to be available in NetCDF format as well as in .csv format, to include vulnerability impact models, socioeconomic indicators and to provide data on climate extremes. The need for dataset comparison across dataset categories, with a focus on observations and reanalysis, is rising. Also, there is a request to expand the Quality Assessment information especially for climate projections, giving higher relevance to the *key strengths and limitations*.

The user requirements for the SIS component (SIS General and SIS Data) of C3S originate from the various user engagement activities that have taken place until autumn 2021 (C3S, 2021b). The type of user engagement event varied, from high level introductions to C3S, to sector-specific workshops and regional cross-sectoral workshops, interviews, and questionnaires. The SIS Data related requirements concerning the forestry, disaster risk reduction, and energy sectors, while the SIS General requirements referred to water management. In the analysis, separate clusters of requirements are reviewed: data, applications, and guidance.

Most SIS requirements concerned new data requests regarding variables and indices/indicators. Data requests for future time periods include seasonal and decadal climate predictions with high horizontal resolution (less than 100 m) or data for one “point” or small regions. Daily, weekly, and monthly time resolutions for data output were frequently required. The most popular variables are air temperature and precipitation accumulation and related indicators. Other relevant variables are snow, wind, humidity and soil moisture and related indicators. Extreme events of these variables and their return periods are used for understanding the impacts within a particular sector.

Information on uncertainty in connection with datasets should be available. Different formats across datasets are mentioned as a barrier to calculating climate indices. Metadata should be provided for each dataset and should include information on data reliability and skill for forecast and uncertainty for projections.

Derived outputs should be provided in the form of maps or graphs, as well as statistics and time series. It should be considered how to provide an integration of skill and uncertainty information on maps. Quality related information on uncertainty is important to users and guidance on how to deal with it should be provided.

3.3 C3S Prototype Service for Decadal Climate Predictions

During the first phase of Copernicus (i.e., 2014-2021) the C3S funded a demonstrator of decadal predictions: C3S_34c Prototype Service for Decadal Climate Predictions. The aim of this initiative was to explore the value of sector-specific decadal prediction products to users in four different sectors: agriculture, energy, infrastructure, and insurance. Predictions on the decadal timescale (1-10 years) can be used for long-term planning and potentially facilitate the adaptation of different sectors to climate variability and change.

Despite showing skills for several variables over the European territory their use was (and still is) very limited. Part of the barrier in the adoption of this new technology is linked to the way in which the large-scale predictable signal is harvested to inform specific decisions. To evaluate the quality or skill of the predictions, hindcast runs were compared with actual observations. Decadal predictions that more accurately match the past observations have a higher skill score and are more 'skilful'. Such measurement of skills was then presented back to the users to assess the value these predictions could have had in their operations.

An important lesson learnt through the exercise was that the sequential approach where the outputs of a model are provided as inputs to the next (e.g., GCM→ RCM → bias-adjustment → impact model → decision) may not necessarily provide the best way of using the information available. The example of energy which focussed on hydropower, for example, used a statistical relationship linking the prediction of the NAO to the energy output of a specific plan. This provided sufficient skill to inform long term decisions (O'Kane et al., 2023).

As is common when adopting new technologies, one of the challenges is the documentation of failures. This is normally less appealing, but arguably more important, than documenting successes. The C3S_34c highlights the importance of identifying the right balance between the perceived priorities of the target users and the optimal ways of extracting value for climate projections. Being too direct in addressing the user requirement may result in a suboptimal product for the very user it targets. Including a level of abstraction in between the collection of user requirements and the elaboration of a product and iterating with the target users throughout the lifecycle of the product are two important, albeit indirect, conclusions drawn from the exercise.

3.4 Summary

This section presents evidence from C3S's URDB, URAD, and the Prototype Service for Decadal Climate Predictions. Our assessment of the URDB was based on 2837 responses collected through various channels from January 2018 until October 2021. The coastal, agriculture, forestry, biodiversity, and disaster risk reduction sectors are the largest user groups. The main user requests revolve around new data, usability, user satisfaction, and guidance. Users are particularly interested in long-term climate information, climate projections, and reanalysis data.

The URAD focuses on user requirements for CDS Data, with requests for new variables and datasets, documentation/guidance, and the inclusion of vulnerability impact models and socioeconomic indicators. Quality assessment, dataset comparison, and uncertainty information are also important to users. The SIS component of C3S gathers requirements related to forestry, disaster risk reduction, energy, and water management, with a focus on new data requests, applications, and guidance.

The Prototype Service for Decadal Climate Predictions explored the value of sector-specific decadal prediction products in agriculture, energy, infrastructure, and insurance. Adoption of these predictions remains very limited, and there is a need to improve the way large-scale predictable signals are utilised for decision-making. Lessons learned include the importance of documenting failures, striking the right balance between user priorities and product optimisation, and maintaining an iterative process with target users throughout the product life cycle.

Overall, these assessments provide insights into user needs for climate information, highlighting the demand for specific data, documentation, guidance, and quality assurance, while emphasising the importance of addressing user requirements effectively and promoting user engagement throughout the development and delivery of climate services.

Funded by the European Union

4 European National Meteorological and Hydrological Services (NMHSs) mini-questionnaire

An online mini-questionnaire was shared among European NMHSs in March 2023, leveraging contacts of the ASPECT project partners. The survey consisted of 17 short-answer questions regarding the production, dissemination, data source, usability of seasonal and interannual climate forecasts in Europe (see **Annex 2** for protocol). The mini-questionnaire was answered by 31 individuals from 16 different European NMHS.

4.1 Seasonal climate forecast production and dissemination

13 out of the 16 NMHSs that responded produce their own SCFs (Austria, Ireland, Serbia, Croatia, Sweden, UK, France, Switzerland, Portugal, Germany, Georgia, Spain, and Ukraine), although only 10 of them make it available to the general public (Serbia, Croatia, UK, France, Switzerland, Germany, Georgia, Spain, Sweden and Ukraine) (**Figure 1**). The dissemination of the SCFs is either channelled through the websites of the NMHS, the C3S, the WMO Lead Center for the Long-Range Forecast Multi Model Ensemble, media channels and through direct request from the public. Most of the respondents reported using ECMWF SCFs as inputs for their products or downscaling procedures (Serbia, Croatia, Sweden, Portugal, Ireland, Switzerland, France, Ukraine, and Spain). The UK Met Office, on the other hand, uses their own GloSea forecast system, and Germany uses their global forecast system: GCFS (Fröhlich et al., 2022).

Figure 1. Map of seasonal climate forecast production and availability in Europe as per responses from NMHS.

4.2 Seasonal climate forecast use

15 out of the 16 countries surveyed believe that their SCFs are being used in different sectors including transport, energy, public administration, water supply, agriculture, tourism, civil protection, environment management and insurance. In Germany, the El Nino Southern Oscillation Index has increasingly received attention from the public and there is *"increased demand"* for this type of product. Furthermore, German authorities that manage gas imports into the country are very interested in the temperature forecasts in winter. During the summer, there is significant interest in the prediction of heat and drought.

In France, the '*hydrology sector'*[6] uses SCF of temperature and precipitation as inputs to impact models for river flow and groundwater level forecasts (either in-house models or tailored outputs of hydrology models which use SCF data as input). Some users in hydrology use both SCFs and past climatology as input data for their models and decide on the preferred scenario depending on an assessment of uncertainty of SCFs for the upcoming season. Several ministries use SCFs in early warning systems and to anticipate water restrictions, mitigate the risk of shortages in the energy and agricultural sectors. The agriculture sector also uses SCFs to model crop yield and to anticipate demand for certain consumer goods.

In Sweden, SCFs are used by the hydropower sector for resource planning and reservoir regulations. The government authority responsible for drinking water is also interested in these forecasts during the summer season.

4.3 Barriers to seasonal climate forecast use

Most barriers identified by the NMHSs pivot between issues related to the quality of the forecasts, and issues related to the user experience (see **Table 2**). In addition, there is also a lack of information on extreme events and how the climate may evolve over a certain period:

"In order to achieve a good prediction (high skill), we currently integrate over quite long periods (3 months). This is too rough for many questions. Our offer is also still quite limited. We do not yet have any automated information on extreme events and no narratives on climate developments. (Respondent 21)

Table 2. Barriers to seasonal climate forecast use.

Forecast quality	• Lack of reliability. • Lack of accuracy. • Lack of predictive skill/poor skill. • Low verification scores and low confidence. • Low spatial resolution. • The integration of 3 months data has limited use. • Lack of capacity to incorporate the long-timescale probabilistic data into existing decision-making processes, e.g., processes that are designed for week-to-week analysis (based on weather forecasts) can be hard to extend to use a seasonal mean.
User experience	• The interpretation of the products can be difficult to understand for novice users. • Users do not know how to use probabilistic forecasts. • Users distrust the forecasts. • Difficult to explain the forecasts to users. • Products not tailored to the users' needs. • Unaware of forecast availability and value. • Economic value of the forecasts is not assessed yet.

[6] This term is taken directly from the respondent; we take this to mean the management of water resources, supply and sanitation.

4.4 Interannual climate forecast production and dissemination

Four out of sixteen NMHS produce ICFs (Sweden, the UK, Germany, and Portugal), while only two of them (the UK and Germany) make it publicly available (**Figure 2**). Sweden uses an EC-Earth global climate model. Previously, they utilised anomaly initialisation for their climate predictions (at standard and high resolutions of the model), but then they developed a data assimilation approach to produce initial conditions for decadal climate hindcasts and forecasts. The UK produces them through dynamical ensemble forecasts using the DePreSys system at the Met Office. UK ICFs are available to the public through the Met Office website and via CMIP database for hindcasts and the WMO Lead Centre for annual to decadal predictions for forecasts. In Germany, they compute global forecasts with GCFS and publish the ICFs on their website.

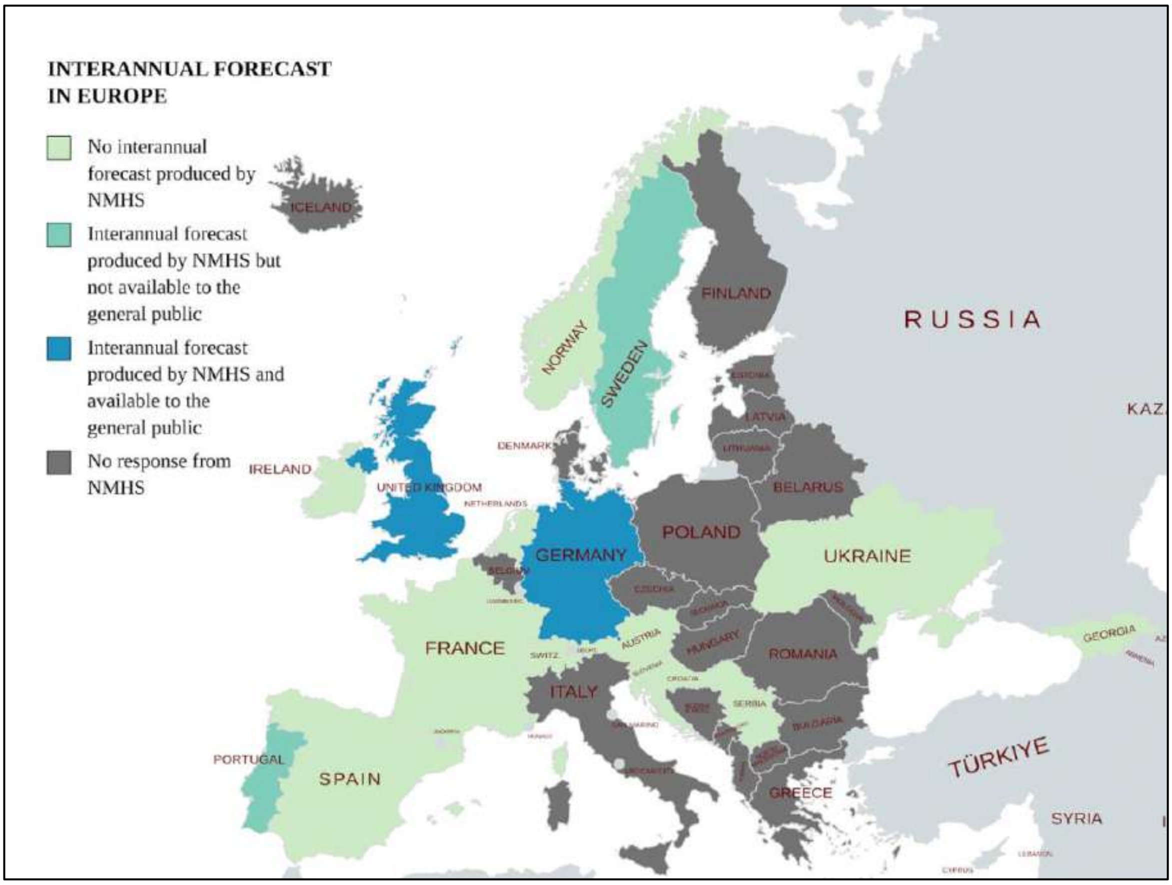

Figure 2. Map of interannual climate forecast production and availability in Europe as per responses from NMHS.

4.5 Interannual climate forecast use and demand

Three respondents from the UK Met Office are aware of the ICFs that they disseminate being used in the UK. The government is particularly interested in the occurrences of 1.5° C exceedance, and the energy sector is interested in evaluating the risks of investments like wind farms in the next decades. In addition to ICFs, the energy sector is also interested in standard terms for interannual variability of annual mean wind speed, to better understand future change. An inevitably higher uncertainty would feed through as a higher cost of project finance, and higher cost of energy to the consumer. There is a belief in the energy sector that:

"A skilful intra-decadal model would alleviate some of this risk." (Respondent 13)

In Germany, on the other hand, the use of this sort of forecast has more of an academic purpose, being used by research centres interested in forestry or groundwater. In Sweden, the demand for this type of product is relevant to sectors such as agriculture, water management, energy, and hydropower production.

4.6 Barriers to interannual climate forecast use

The main barriers identified by the respondents are related to the characteristics of the ICF itself (i.e., availability, access, and accuracy of the forecast). Most respondents identify the lack of skill in this type of product as a major problem:

"Forecast skill is even lower than for seasonal forecasts." (Respondent 17)

The lack of understanding, expertise, and capability to calibrate these forecasts to extract useful information was also mentioned as a main concern. Furthermore, one respondent also mentioned the lack of education and training of users on how to extract maximum value from these forecasts and how to integrate them with climate projection information on longer timescales. The lack of knowledge and lack of trust from the users also impacts their demand. One respondent mentioned the small number of organisations that make concrete plans on interannual-to-decadal timescales as a barrier to convince users of the practical usefulness of these types of forecasts.

4.7 Summary

The findings from the online questionnaire indicate that a majority of the European NMHSs produce their own SCFs, with 10 of the 16 respondents making them available to the general public. The dissemination of these forecasts occurs through various channels, including NMHS websites, the C3S, the WMO Lead Center for Long Range Forecast Multi Model Ensemble, media channels, and direct public requests. Most respondents rely on ECMWF SCFs as inputs or for downscaling procedures, while the UK Met Office uses their own GloSea forecast system, and Germany uses their GCFS forecast system.

The questionnaire also revealed that SCFs are utilised in various sectors such as transport, energy, public administration, water supply, agriculture, tourism, civil protection, environmental management, and insurance. For example, the hydrology sector in France uses SCFs for temperature and precipitation inputs in impact models for river flow and groundwater level forecasts. In Sweden, the hydropower sector employs SCFs for resource planning and reservoir regulations. The main barriers to the societal use of SCFs identified by NMHSs revolve around issues related to forecast quality and user experience. These include concerns about the accuracy and skill of the forecasts, as well as the lack of information on extreme events and the long-term climate 'narrative'.

Regarding ICFs, four NMHSs produce them, but only two make them publicly available. Sweden uses the EC-Earth global climate model and has developed a data assimilation approach for initial conditions. The UK produces ICFs through dynamical ensemble forecasts using the DePreSys system, and Germany computes global forecasts with their GCFS system. The use and demand for ICFs varies across countries and sectors. In the UK, the government and energy sector are interested in assessing risks and making long-term investments, such as wind farms. In Germany, ICFs are primarily used for academic purposes, such as forestry and groundwater research. Sweden sees relevance in sectors like agriculture, water management, energy, and hydropower production. The main barriers to the use of ICFs are related to their characteristics, including availability, access, and forecast accuracy. Respondents also expressed concerns about the skill level of these forecasts, lack of understanding and expertise in calibrating and extracting useful information, as well as the need for education and training to maximise their value and integrate them with longer-term climate projections. Additionally, the lack of knowledge and trust from users affects the demand for ICFs.

5 Early work of ASPECT

5.1 Provision of requirements of first cohort of superusers to work packages 1, 2 & 3

In WP4 (co-developing case studies with superusers and exploring the benefits), the initial interaction through in-depth interviews with superusers from the three case studies defined in the ASPECT project has been carried out. These case studies focus on the agriculture (grape/wine), finance (pensions) and governance sectors (EU Mission on Climate Adaptation). Their aim is to understand the superusers' decision-making context and to identify their information requirements for timescales ranging from the next season up to 30 years.

The ASPECT superuser for the **agriculture sector** is Codorniu-Raventós, which is the oldest wine company in Spain, and one of the largest vineyard owners in Europe. The intention of this company is not to maximise the quantity of grapes/wine, but to reach the appropriate quality and see which variety they can use for that. To control the quality of the wine they apply precision viticulture which is intended to monitor the level of stress affecting the plants.

This superuser already explored seasonal predictions of environmental climate variables such as temperature and precipitation to support operational decisions such as pruning, crop forcing, soil management (cover crops or tillage) and irrigation. Additionally, they have experience on how to deal with probabilistic climate predictions and their potential to inform specific decision-making processes. However, their knowledge of DCPs and climate projections is still limited. They expect seasonal predictions to be a valuable tool for them to improve growth cycle management, decadal predictions to identify where they should put their focus in terms of investments or research and climate projections to take business strategic decisions.

In general, the needs of the grape/wine sector are mainly related to seasonal and decadal timescales since the grapevine has a lifetime of around 25 years. They could explore the potential usefulness of seasonal and inter-annual predictions for lead times of up to 24 months which are updated every 6 months. The main climate-related impacts on grapes/wine are frost and hail, temperature/solar radiation, heatwaves, and drought.

The financial sector case study focuses on the **pensions sector** as a specific type of user who makes financial investments over different timescales. These investments are typically diverse in terms of sector (built environment, agriculture, transport, infrastructure, manufacturing etc) and geographically diverse – pension funds invest globally. Investments will be exposed and vulnerable to a range of risks, including those from climate variability and change. There is a need to assess and manage risks within the current portfolios and assess the inherent risks (climate and otherwise) of investments they hold currently as well as new investments pension funds are asked to make.

The sector is currently at a very early stage in its understanding of climate change risks. ASPECT is using two mediators to help engage with the pensions sector to understand their requirements, a member of the Centre for Greening Financial Investments (a UK centre established to accelerate the adoption and use of climate and environmental data and analytics by financial institutions internationally) and the company ClearGlass Analytics. ClearGlass Analytics is an independent data company and technology platform that was created to help asset owners (i.e., pension funds) assess value for money delivered by their asset managers.

Using state-of-the-art seasonal prediction and climate projection information, WP4 will develop useful and useful predictions of climate risk for case study examples in the pensions sector, focussing on key climate hazards which have historically resulted in substantial economic losses such as flooding and heatwaves, including consideration of compound events. Key primary variables are likely to include daily maximum, minimum and mean temperature, rainfall and other contributing variables to wildfire, health, and asset damage such as wind and humidity.

The EU Framework Programme for Research and Innovation 2021-2027 (Horizon Europe) established five research and innovation-oriented Missions, one of which is the EU Mission on adaptation to climate change (Mission Adaptation), WP4 case study for the **governance sector**. Local and regional communities are exposed to various climate risks and lack the necessary information, data, and skills to identify and prioritise climate risks, assess their vulnerability, and develop strategies to manage them. This is due to a range of factors such as limited financial resources, technology, or skilled professionals, weak institutional capacity, and political or social barriers. The primary objective of the Mission is to enable at least 150 European regions and communities to become climate-resilient by 2030, while also delivering a minimum of 75 large-scale demonstrations of systemic transformations towards climate resilience.

The ASPECT consortium aims to actively support the Mission Adaptation by closely collaborating with communities and regions enrolled in the Mission. The Regional Agency for Environmental Protection and Energy (ARPAE), a public research institute operating in the field of environmental protection and energy within the Emilia-Romagna region of Italy, has been chosen as a superuser for the governance sector in ASPECT.

5.2 Real-time survey results from the 1st ASPECT annual user forum

As described in the Deliverable 5.2, the first annual user forum was organised as part of the Climateurope2 Webstival on March 24th, 2023. From the 99 participants, 85 of them engaged in a Mentimeter survey. Questions regarding enablers, barriers and prediction lead times were asked to better understand the audience perspective, their needs and understand how ASPECT can support climate information needs. **Figure 3** outlines the type of participants that attended the first ASPECT forum (as self-reported by participants). Most participants deemed themselves either producers or translators of climate information (70%).

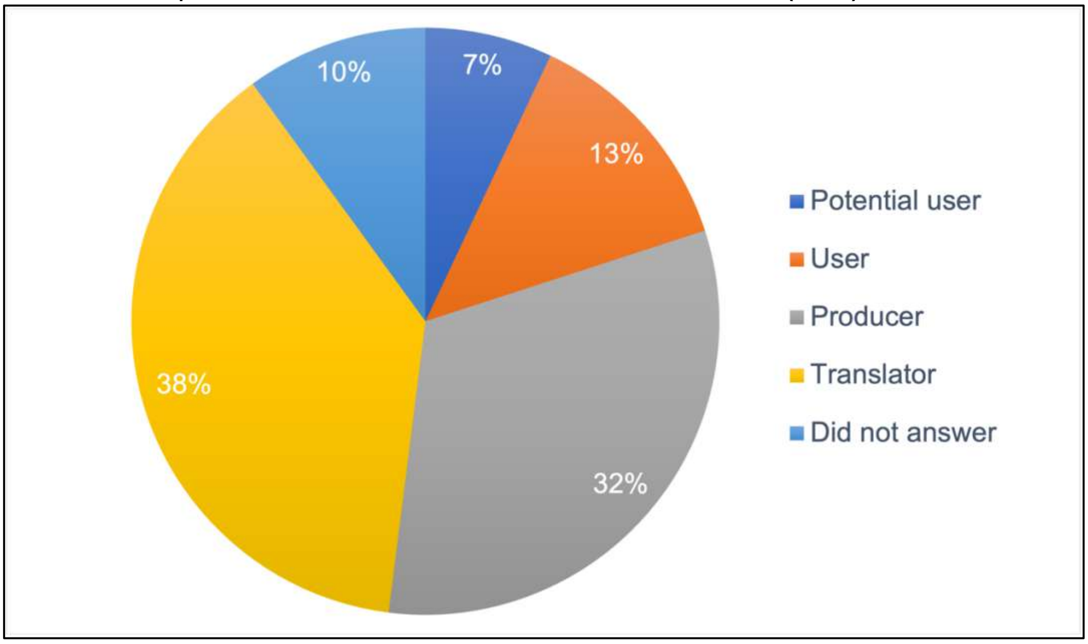

Figure 3. Self-reported type of participants at the first ASPECT forum.

57% of respondents indicated that they or their organisations always use climate information, followed by those who use it sometimes with 29% of responses. 11% of the participants answered not applicable and 2% indicated either never or I do not know. The most popular answers when asked why they use climate information in their organisation were climate services, early warning, informed decisions, research, adaptation, and prediction.

Regarding enablers and barriers to using climate information within their organisations, responses varied widely. The top three most reported enablers were *public tools, metadata, and visualisations;* and for barriers, *complexity, understanding and uncertainty*. When asked what climate prediction lead times would be most useful to their organisations, there was a wide spread of responses. The most useful was 10 years (18%) followed by 30 years (16%), 3 months (13%), and 5 years (13%) (see **Figure 4**).

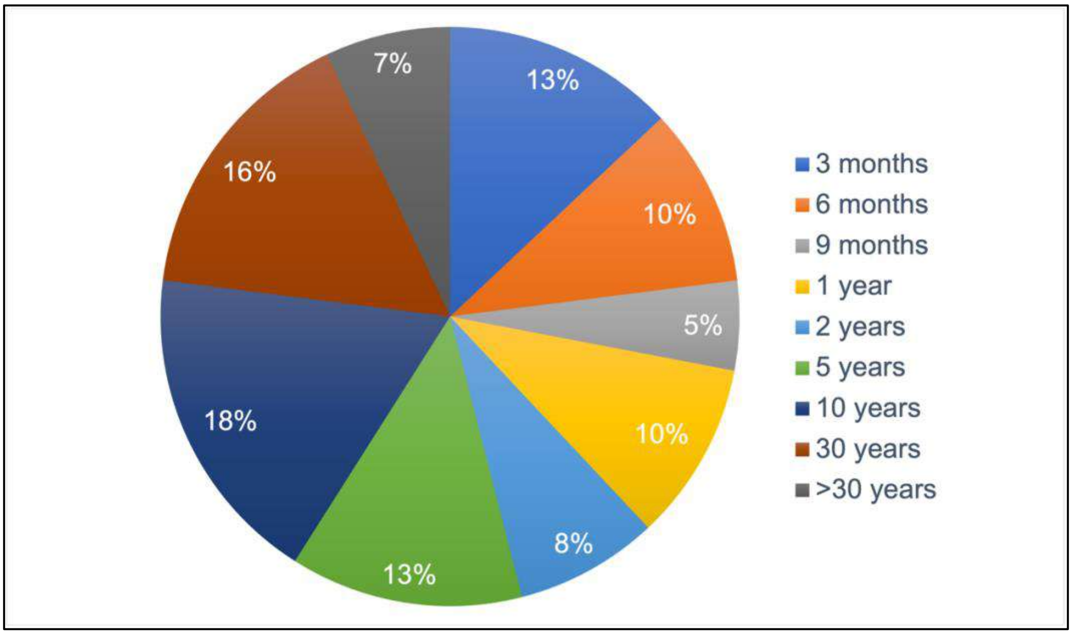

Figure 4. Most useful prediction lead times as reported by user forum participants.

5.3 Summary

The section highlights the progress made in the ASPECT project so far. In-depth interviews were conducted with superusers from three case studies focusing on the agriculture (grape/wine), finance (pensions), and governance (EU Mission on Climate Adaptation) sectors. The goal was to understand the decision-making context of superusers and identify their information requirements across different timescales, ranging from the next season to 30 years.

The superuser for the agriculture sector is Codorniu-Raventós, a renowned wine company in Spain and one of the largest vineyard owners in Europe. Their focus is on achieving appropriate wine quality rather than maximising quantity. Precision viticulture is employed to monitor plant stress levels and maintain wine quality. The company has already explored seasonal predictions for temperature and precipitation to support operational decisions such as pruning, crop forcing, soil management, and irrigation. They are familiar with probabilistic climate predictions but have limited knowledge of DCPs and climate projections. They anticipate that seasonal predictions will be valuable for growth cycle management, decadal predictions for investment and research focus, and climate projections for strategic business decisions. The grape/wine sector's needs mainly revolve around seasonal and decadal timescales, given the vine's lifespan of approximately 25 years.

The financial case study focuses on the pensions sector, which involves making financial investments over various timescales and diverse sectors globally. ASPECT engages with the pensions sector through mediators from the Centre for Greening Financial Investments and ClearGlass Analytics, an independent data company and technology platform. The sector is in the early stages of understanding climate change risks. ASPECT aims to develop useful predictions of climate risk, focusing on hazards like flooding and heatwaves, considering multiple hazards and key variables such as temperature, rainfall, wind, and humidity.

The ASPECT project aligns with the EU Mission on adaptation to climate change, one of the missions under the EU Framework Programme for Research and Innovation 2021-2027 (Horizon Europe). The mission aims to support 150 European regions and communities in becoming climate-resilient by 2030, with at least 75 large-scale demonstrations of systemic transformations towards climate resilience. The Regional Agency for Environmental Protection and Energy (ARPAE), a public research institute operating in the field of environmental protection and energy within the Emilia-Romagna region of Italy, has been chosen as a superuser for the governance sector in ASPECT.

The first annual user forum of the ASPECT project was held during the Climateurope2 Webstival. Almost all forum participants (n=99) responded to a Mentimeter survey, and most participants identified themselves as producers or translators of climate information. 57% reported 'always' using climate information, while 29% indicated 'occasional' use. The reasons for using climate information included climate services, early warning, informed decisions, research, adaptation, and prediction. Enablers mentioned were public tools, metadata, and visualisations, while barriers included complexity, understanding, and uncertainty. Respondents expressed varied preferences for climate prediction lead times, with 10 years being the most useful, followed by 30 years, 3 months, and 5 years.

6 Synthesis

The various sources of evidence summarised above provide insights into climate information use, information requirements, and user needs in Europe. There are commonalities in terms of the limited use of climate information, barriers to its effective utilisation, and diversity of user requirements and needs. These common themes highlight the need for improved communication, customised services, and access to high-quality information that addresses the specific needs of users. Users from diverse sectors are interested in data types and variables that are currently unavailable, as well as having access to dependable documentation and guidance to support their decision-making processes. Quality assessment, dataset comparison, and uncertainty information are also identified as important factors for users in assessing and utilising climate information effectively. In fact, our assessment would indicate that uncertainties play a substantial role in shaping the perception, acceptance, and utilisation of climate information.

However, our findings also present some contradictions regarding the use of climate information in Europe. The literature review suggests limited utilisation of SCFs and multi-decadal climate projection information across various sectors, while the C3S analysis reveals a significant demand for long-term climate information and reanalysis data. Additionally, the NMHS mini-questionnaire highlights the utilisation of SCFs in sectors such as transport, energy, agriculture, and tourism, albeit with some barriers and limitations. These differences indicate a complex landscape where some sectors may be actively using climate information, while others have limited adoption or face challenges in its integration into decision-making processes.

Responding to and implementing the information requirements and user needs outlined in this report will vary in difficulty. Traditionally, within climate services, the easier aspects include providing historical climate data, weather forecasts, and basic climate information. On the other hand, more challenging elements involve offering climate change projections, impact assessments, tailored services, and early warning systems. The complexity arises from factors such as data analysis, modelling, uncertainties, sector-specific considerations, and the need for deep interdisciplinary collaboration.

Due to the diverse nature and varying quality of evidence incorporated in this report, synthesising a comprehensive overview becomes challenging. Notably, the presence of different methodological biases in each evidence source could potentially impact the representation of various sectors. Consequently, we cannot claim to be comprehensive; for example, we are aware that climate purveyors have significant expert knowledge about this topic, but the rapid nature of this task/assessment didn't enable us to elicit this relevant knowledge (e.g., through expert elicitation). However, it does establish a robust knowledge foundation for WP5 to build upon in T5.3 (Analysis of how climate information and knowledge can help organisations prepare for the physical risks of a changing climate).

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Annex 1: Peer-reviewed articles selected from our review protocol

Category 1 (European studies only)	Attoh, E. M., Goosen, H., van Selm, M., Boon, E., & Ludwig, F. (2022). Climate services for the railway sector: A synthesis of adaptation information needs in Europe. *Frontiers in Climate*, *4*. Boqué Ciurana, A., & Aguilar, E. (2021). Which Meteorological and Climatological Information Is Requested for Better Surfing Experiences? A Survey-Based Analysis. *Atmosphere*, *12*(3), 293. Bruno Soares, M. & Dessai, S. (2015). Exploring the use of seasonal climate forecasts in Europe through expert elicitation. *Climate Risk Management*, *10*, 8-16. Bruno Soares, M., & Dessai, S. (2016). Barriers and enablers to the use of seasonal climate forecasts amongst organisations in Europe. *Climatic Change*, *137*, 89-103. Bruno Soares, M., Alexander, M., & Dessai, S. (2018). Sectoral use of climate information in Europe: A synoptic overview. *Climate Services*, *9*, 5-20. Damm, A., Köberl, J., Stegmaier, P., Alonso, E. J., & Harjanne, A. (2020). The market for climate services in the tourism sector–An analysis of Austrian stakeholders' perceptions. *Climate Services*, *17*, 100094. Fraccaroli, C., Govigli, V.M., Briers, S., Cerezo, N.P., Jimenez, J.P., Romero, M., Lindner, M. & de Arano, I.M. (2021). Climate data for the European forestry sector: From end-user needs to opportunities for climate resilience. *Climate Services*, *23*, 100247.
Category 2 (Global-level and European comparison studies only)	Born, L., Prager, S., Ramirez-Villegas, J., & Imbach, P. (2021). A global meta-analysis of climate services and decision-making in agriculture. *Climate Services*, *22*, 100231. Vedeld, T., Hofstad, H., Mathur, M., Büker, P., & Stordal, F. (2020). Reaching out? Governing weather and climate services (WCS) for farmers. *Environmental Science & Policy*, *104*, 208-216.

Annex 2: NMHS mini-questionnaire protocol

Name, organisation, email (Optional)

Seasonal climate information

1. Does your NMHS produce seasonal climate forecasts?
    a. If so, how?
2. Does your NMHS make seasonal climate forecasts available?
    a. If so, how?
    b. What is your data source?
3. Do you think seasonal climate forecasts are currently being used in your country?
    a. If so, by whom and briefly explain how you think it's being used?
4. What do you think are the barriers to using seasonal climate forecasts in your country?

Interannual climate information

5. Does your NMHS produce interannual climate forecasts (1-10 years)?
    a. If so, how?
6. Does your NMHS make interannual climate forecasts (1-10 years) available?
    b. If so, how?
    c. What is your data source?
7. Do you think interannual climate forecasts are currently being used in your country?
    d. If so, by whom and briefly explain how you think they're being used?
8. What do you think are the barriers to using interannual climate forecasts in your country?

Links

9. Please provide links to any documents on these topics (in any language).