Updated recommendations for assessment and increase of CS impact, catalogue of best practices and malpractices; foresight of demand evolutions and market development

Deliverable 4.6

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Glossary

Abbreviation	Explanation
AI	Artificial Intelligence
CBA	Cost-Benefit-Analysis
CE2	Climateurope2
CMCC	Euro-Mediterranean Centre on Climate Change
CS	Climate Service(s)
CSRD	Corporate Sustainability Reporting Directive
CV	Contingent Value
DTU	Technical University of Denmark
ECMWF	European Centre for Mid-Range Weather Forecasts
ERA4CS	European Research Area for Climate Services
FGDs	Focus Group Discussions
GEM	General Equilibrium Models
GFCS	Global Framework for Climate Services
IQR	Interquartile Range
M&E	Monitoring & Evaluation
RHMZ	Republic Hydrometeorological Service of Serbia
SD	Standard Deviation
TCFD	Task Force on Climate-related Financial Disclosures
ToC	Theory of Change
WMO	World Meteorological Association
WTP	Willingness to Pay

About Climateurope2

Timely delivery and effective use of climate information is fundamental for a green recovery and a resilient, climate neutral Europe, in response to climate change and variability. Climate Services (CS) address this through the provision of climate information for use in decision-making to manage risks and realise opportunities.

The market and needs for climate information have seen impressive progress in recent years and is expected to grow in the foreseeable future. However, the communities involved in the development and provision of CS are often unaware of each other and lack interdisciplinary and transdisciplinary knowledge. In addition, quality assurance, relevant standards, and other forms of assurance (such as guidelines, and good practices) for CS are lagging behind. These are needed to ensure the saliency, credibility, legitimacy, and authoritativeness of CS, and build two-way trust between supply and demand.

Climateurope2 aims to develop future equitable and quality-assured CS to all sectors of society by:

- Developing standardisation procedures for CS
- Supporting an equitable European CS community
- Enhancing the uptake of quality-assured CS to support adaptation and mitigation to climate change and variability

The project will identify the support and standardisation needs of CS, including criteria for certification and labelling, as well as the user-driven criteria needed to support climate action. This information will be used to propose a taxonomy of CS, suggest community-based good practices and guidelines, and propose standards where possible. A large variety of activities to support the communities involved in European CS will also be organised.

Executive Summary

Deliverable 4.6 of the Climateurope2 project presents updated recommendations for assessing and increasing the impact of Climate Services (CS), alongside a refined and ranked catalogue of best practices and malpractices, and a foresight analysis of demand evolutions and market developments. This report builds on the findings of Deliverable 4.3 and contributes to Work Package 4 (WP4) on Market Development, with a focus on Task 4.2.

The report is built on an eDelphi study, a structured expert consensus technique, to identify and rank beneficial best practices and detrimental malpractices influencing the CS market. A total of 38 stakeholders—including users, providers, and market experts—participated in the survey. The results show strong consensus around several best practices, such as promoting internal upskilling, linking local data with climate models, and fostering cross-sector collaboration. Conversely, detrimental malpractices include misleading data presentation, poor science communication, and lack of user-provider feedback mechanisms. Based on these findings, a set of expert-backed recommended best practices for the success of the CS market is issued in this report.

In parallel, the report provides a comprehensive literature review on impact assessment methodologies for CS. It distinguishes between value, benefits, and impact, and outlines both quantitative (e.g., cost-benefit analysis, econometric models) and qualitative (e.g., case studies, participatory approaches) methods. A six-step process for conducting impact assessments is proposed, emphasising the importance of co-production, baseline definition, and scalability.

Based on findings from the relevant peer-reviewed and grey literature, the report includes a set of actionable recommendations:
- For impact assessment: adopt flexible, user-oriented frameworks; embed evaluation early; and promote participatory methods.
- For impact enhancement: prioritise co-production; align services with operational needs; invest in communication and capacity building; and leverage innovation to reach underserved users.

The market foresight section identifies key sectors driving CS demand, including agriculture, urban planning, and disaster risk reduction. It highlights emerging market trends such as the rise of digital platforms, the influence of regulatory frameworks (e.g., CSRD, TCFD), and the growing role of market-stimulating services in the face of more frequent and impactful climate hazard events.

These insights and recommendations published in this report aim to support the development of equitable, quality-assured CS across Europe and beyond, contributing to climate resilience and informed decision-making, and the stated goals of the Climateurope2 project. The findings will be further refined in the final iteration of this deliverable series (D4.9), due in June 2026.

Keywords

Market Development, Market Foresight, Best Practices, Malpractices, Climate Service Impact, Impact Assessment

1. Introduction

The Climateurope2 (CE2) project aims to develop quality-assured and equitable Climate Services to all areas of society, where the term *Climate Services* (CS) describes the provision of climate information such that decision-making is facilitated, including engagement between users and providers, while based on scientifically credible information and expertise, and with an effective mechanism that responds to user needs.

The overall goal of the CE2 project is reinforced in three main pillars: developing standardisation procedures for CS, supporting an equitable European CS community, and enhancing the uptake of quality-assured CS to support adaptation and mitigation to climate change and variability (Fig. 1).
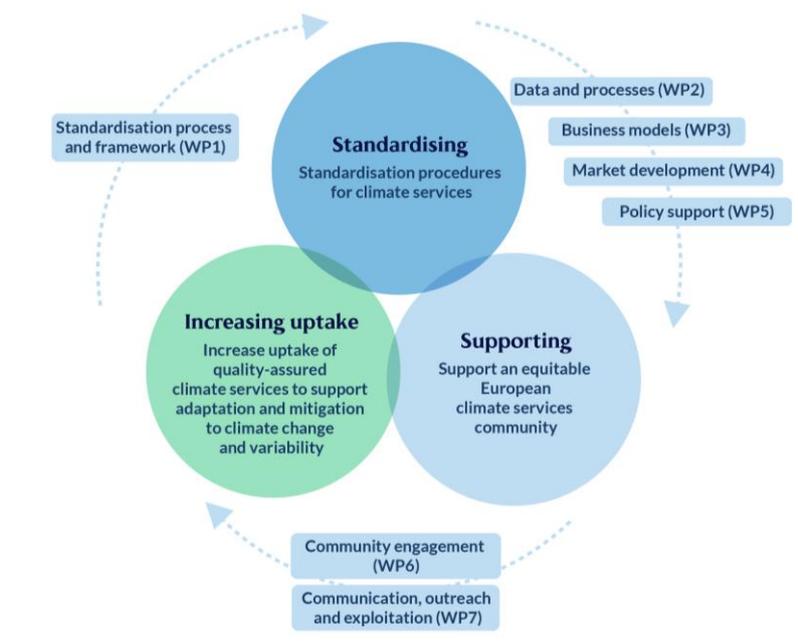
Figure 1: The goals of the Climateurope2 project

Within the project, and specifically to support the goals and Standardising and Supporting, work is being carried out to understand the development of the CS market. As part of these efforts, this document summarises initial recommendations on how to assess and increase the impacts of the use of CS. These recommendations will be based primarily on findings from interviews with stakeholders regarding best practices and malpractices. They will also include stakeholder perceptions on the development of the CS market, including key drivers and trends in future CS demand and supply. The recommendations will be reviewed, contrasted, and updated twice more as the project evolves.

2. Scope

This deliverable report D4.6 builds on the results obtained in D 4.3 report by Matthies and Ramirez (2024). These reports are part of a series of three deliverable reports that use different methodologies to achieve their common goal of understanding the CS market by engaging with market actors (i.e. users of CS, providers of CS, and experts on the CS market). The focus of the reports is threefold:

1. Creating, refining, and consolidating a catalogue of best practices and malpractices that influence the CS market
2. Providing recommendations for assessments and increase of CS impact
3. Providing a foresight of demand evolutions and market developments

2.1 Scope 1: Best practices and malpractices

The first point, related to best practices and malpractices that influence the CS market, follows an internal logic and structure throughout these three deliverable reports that is outlined in the below Figure 2.

Figure 2: The internal logic between the three consecutive deliverables on climate service best practices and malpractices

2.2 Scope 2: Providing recommendations for assessments and increase of CS impact

Scope 2 of this document provides an in-depth discussion on the assessment of climate services and explores ways to enhance their impact, drawing on insights from the literature.

2.3 Scope 3: Providing a foresight of demand evolutions and market developments

Scope 3 draws on an initial literature review to examine demand evolutions in climate services and related market development. A more comprehensive market analysis will be provided in the final version of this deliverable.

3. Methodology

3.1 Applying the eDelphi method

Deliverable 4.6 of the Climateurope2 project aims to update the catalogue of best practices and malpractices in the CS market, building on the findings of Deliverable 4.3. To achieve this, the project employs the eDelphi method—a structured, iterative survey technique designed to elicit expert consensus on complex or uncertain topics (Boon *et al.*, 2024; Khodyakov, 2023; Fink-Hafner *et al.*, 2019). This method is particularly well-suited for refining qualitative insights into actionable, ranked priorities, making it ideal for the Climateurope2 objective of identifying and validating key best practices and malpractices that shape the CS market.

The eDelphi method was selected for its ability to systematically gather and synthesize expert opinions in a transparent and replicable manner (Khodyakov, 2023). As noted by Fink-Hafner *et al.* (2019), the Delphi technique is especially useful when knowledge is incomplete or fragmented—conditions that characterize the evolving and diverse field of CS. The method allows for anonymous input from a diverse panel of stakeholders (Boon *et al.*, 2024), reducing the influence of dominant voices and 'groupthink', while enabling iterative refinement of opinions through controlled feedback.

In the context of Climateurope2, the eDelphi method serves three key purposes:

1. **Validation:** It builds on the qualitative findings from stakeholder interviews in D4.3 by testing their relevance and importance across a broader expert base.

2. **Prioritisation:** Experts are asked to rank best practices and malpractices on a 1–10 scale, enabling the identification of those most critical to the CS market.

3. **Consensus building:** Through multiple rounds, the method fosters convergence of expert opinion, enhancing the legitimacy and utility of the final catalogue.

3.2 How the eDelphi method works

The eDelphi process involves at least two rounds of surveys distributed to a panel of pre-qualified experts. In the first round, participants rank a predefined list of best practices and malpractices. In the second round, they are shown anonymized statistical summaries of the group's responses and invited to revise their rankings if desired. This feedback loop encourages reflection and convergence without coercion (Khodyakov, 2023 and Boon *et al.*, 2024). Experts are selected based on their demonstrated experience in CS, either through academic research or practical implementation as users or providers of CS. Anonymity is maintained throughout to ensure impartiality, as per the established four key characteristics of the Delphi method (Khodyakov, 2023):

1. Anonymity;
2. Iterative data collection;
3. Participant feedback; and
4. Statistical determination of group response.

The process is conducted entirely online, which increases accessibility and reduces logistical constraints.

Statistical evaluation of consensus

To assess the level of agreement among experts in the eDelphi process, a combination of statistical measures is typically employed to ensure robustness and transparency. In line with best practices outlined by Fink-Hafner *et al.* (2019) and Boon *et al.* (2024), the Climateurope2 project will apply the following threefold approach:

I. **Standard Deviation (SD)**
SD is used to measure the dispersion of expert ratings. A lower SD indicates a tighter clustering of responses, suggesting stronger consensus. Most often, an SD of less than 1.5 was considered indicative of agreement

II. **Interquartile Range (IQR)**
IQR captures the middle 50% of responses and is less sensitive to outliers than SD. An IQR below 2.5 is typically used as a threshold for consensus. This metric complements SD by providing a more nuanced view of the distribution

III. **Agreement Around the Mean**
This measure assesses whether at least 75% of expert responses fall within ±2 points of the mean score on a 10-point Likert scale. This criterion helps confirm that the central tendency reflects a shared view among participants

Together, these metrics provide a triangulated approach to evaluating consensus, balancing sensitivity to variation with robustness against skewed distributions. The eDelphi methodology was successfully applied in the 2024 Boon *et al.* global Delphi study on CS, reflecting the usefulness of this method for understanding the CS market.

3.3 Implementation of the eDelphi survey

At the start of the survey, the participants were asked "Which category do you best fit in?" with the options being: 1) User of Climate Services; 2) Provider of Climate Services; and 3) Expert with knowledge of the Climate Services market (Mainly from academia).
Beyond that, the survey was divided into two sections:

Best Practices
- Participants were asked: "How important is the listed Best Practice for the success of a Climate Service?"
- Each item was rated on a 10-point Likert scale, where:
  - o 1 = "Not important"
  - o 10 = "Very important"
- Best Practices included:
  - o Promoting internal upskilling or having technically skilled staff
  - o Linking local/in situ data with large climate models
  - o Knowledge sharing and cross-sector collaboration
  - o Integrating user feedback throughout CS development
  - o Making CS user-friendly for non-technical users
  - o Following or using standards to generate trust

Malpractices

- Participants were asked: "How detrimental are the listed Malpractices to the success of a Climate Service?"
- Each item was rated on the same 10-point Likert scale, where:
  - 1 = "Not detrimental"
  - 10 = "Very detrimental"
- Malpractices included:
  - Datasets too large or complex to process
  - Misleading data presentation
  - Lack of common understanding of CS and their value
  - Perception that CS investment is not justified
  - Poor communication or feedback between users and providers
  - Inadequate science communication
  - Lack of user-centric design
  - Reluctance to pay for standards

These best practices and malpractices were identified through stakeholder interviews conducted for Deliverable D4.3 in 2024. The outcomes are summarised in Figure 3.
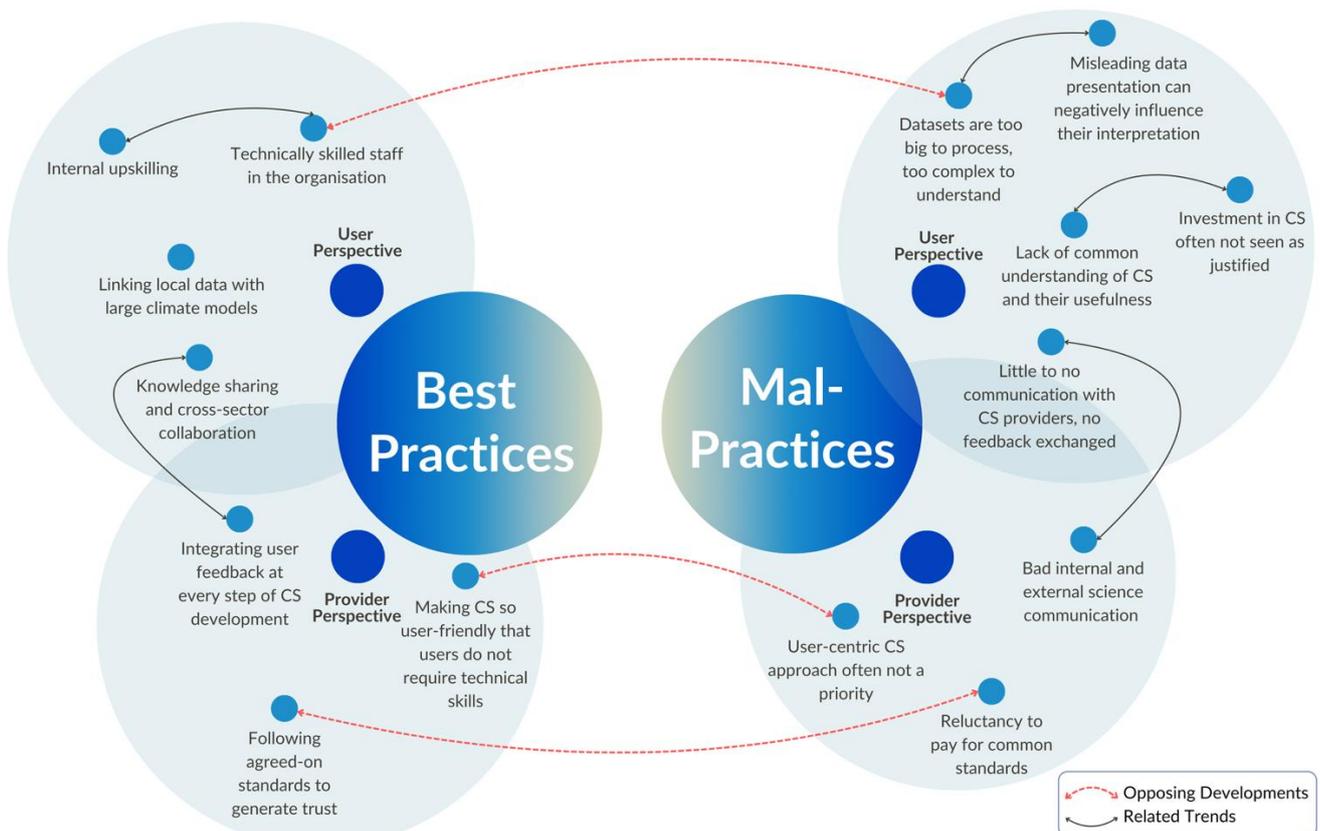
Figure 3: Overview of best Practices and malpractices identified through stakeholder interviews for Deliverable D4.3 (Matthies and Ramirez, 2024)

The survey was distributed to the stakeholders who participated in the D4.3 interviews, the consortia of climate service users and providers of the VALORADA and PCP WISE projects, as well as through the Mip4Adapt Climate Services network. The survey was conducted anonymously to encourage honest responses. Participants were also asked not to consult external resources before giving their responses.

In total, 38 stakeholders participated in the survey, representing CS experts, users, and providers (see Figure 4). Beyond the three stated categories, there were three participants who selected "other" and specified their background as 1) Public buyer with some knowledge of Climate Services; 2) Working on engagement activities for C3S; and 3) Climate (service) researcher. All of these backgrounds are relevant for participating in the survey.

The participants are relatively evenly distributed (Figure 4), and having slightly more CS users than providers is beneficial as the user perspective is often underrepresented in CS studies and assessments Rigby et al. (2023). Statistical evaluation will include measures such as standard deviation, interquartile range, and agreement around the mean to assess consensus levels (see above). This structured approach ensures that the updated catalogue reflects a broad and validated expert consensus on what drives or hinders success in the CS market.

eDelphi Participants
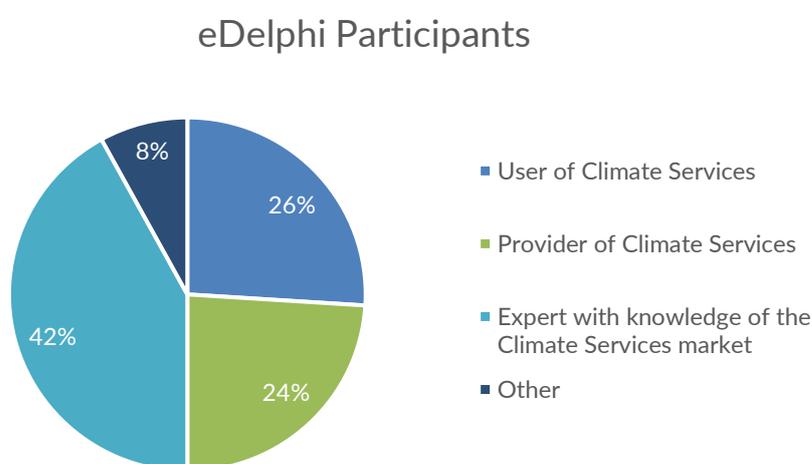
Figure 4: Categories of stakeholders who responded to the eDelphi survey

3.4 Limitations of the eDelphi method

While the eDelphi method offers a structured and inclusive approach to the engagement of diverse stakeholder Boon *et al.* (2024), several limitations should be acknowledged when applying it to update the catalogue of best practices and malpractices in the Climateurope2 project.

1. **Participant dropout and fatigue**
   Delphi studies typically require multiple rounds of participation, which can lead to attrition and reduced response rates over time. Although Boon *et al.* (2024) reported relatively stable participation across three rounds, they also noted that maintaining engagement required proactive communication and reminders. This risk is particularly relevant when expert availability is constrained or when the topic is perceived as abstract or time-consuming. This risk was not an issue for D4.6, as only one round of eDelphi was conducted.

2. **Ambiguity in defining consensus**
   There is no universally accepted threshold for what constitutes consensus in Delphi studies.

Boon *et al.* (2024) addressed this by applying a combination of statistical measures (e.g. percentage of high ratings) but acknowledged that these thresholds are somewhat arbitrary and context dependent. This ambiguity can affect the interpretation of results, especially when expert opinions are diverse or polarised.

3. **Limited depth of qualitative insight**

   The eDelphi method prioritizes breadth and convergence over deep exploration of individual perspectives. While it is effective for ranking and prioritizing items, it may not fully capture the nuanced reasoning behind expert judgments. Boon *et al.* (2024) noted that the lack of real-time interaction may limit opportunities for learning and creativity.

4. **Potential bias in expert selection**

   Ensuring a diverse and representative expert panel is critical. Boon *et al.* (2024) highlighted challenges in achieving geographic and disciplinary balance, particularly in recruiting experts from highly climate-vulnerable regions. This imbalance can skew results and reduce the generalizability of findings. In the context of the eDelphi survey conducted for this deliverable, respondents were not asked to provide information on their geographical location or disciplinary background. This decision was deliberate, as the primary objective of the exercise was to elicit expert judgement on the thematic issues under investigation rather than to characterise the respondent pool. The omission of such metadata helped to streamline the survey, reduce respondent burden, and maintain focus on the substantive content of the enquiry. A consequence of this approach, however, is that it is not possible to assess the extent of potential biases in the results arising from uneven geographical or disciplinary representation.

5. **Exclusion of end-users**

   Although the method is designed for expert input, Boon *et al.* (2024) noted that excluding end-users—such as decision-makers or community stakeholders—may limit the relevance of the outcomes. In the context of CS, where user-cantered design is essential, this exclusion could overlook practical implementation challenges or user-specific needs. This was not an issue with the eDelphi survey conducted for this deliverable, as 26% of the respondents were end-users, and the user community was thus well represented.

6. **Risk of over-simplification**

   The ranking process may lead to the exclusion of context-specific or minority viewpoints that are nonetheless important, as observed by Boon *et al.* (2024). This shortcoming may have affected the eDelphi survey conducted for this deliverable, as the best practices and malpractices the respondents were asked to rank had already been summarised based on the findings of D4.3 and therefore potentially over-simplified.

Despite these limitations, the eDelphi method remains a valuable tool for structured stakeholder engagement, particularly when combined with complementary methods such as interviews or case studies. In the context of the Climateurope2 project and this deliverable report, its use is justified by the need for consensus on complex and evolving issues in the CS market.

3.5 Literature review for the assessment and increase of climate service impact

The literature review underpinning this work was conducted collaboratively by Climate KIC together with three partners: the Euro-Mediterranean Centre on Climate Change (CMCC), the Technical

University of Denmark (DTU), and the Republic Hydrometeorological Service of Serbia (RHMZ). The review addressed three guiding questions: (i) how to define impact in the context of CS, (ii) how to assess the impact of CS, and (iii) what processes can be used to structure such assessments.

In line with the principles of a conventional literature review, the process involved systematically identifying, selecting, and synthesising peer-reviewed and grey literature relevant to CS impact evaluation. This included a structured search of academic databases and project reports, followed by screening and categorisation of studies according to their conceptual, methodological, or applied contributions. Attention was paid not only to established frameworks but also to emerging approaches and case studies across different sectors and geographies.
The details of the methodology, including search strategies, inclusion and exclusion criteria, and the synthesis should be documented in the methodology section of this report to ensure transparency and reproducibility.

3.6 Preliminary literature review for the foresight of demand evolutions and market developments

The work on providing insights to the topic of foresight of demand evolutions and market developments was carried out as a preliminary research exercise, undertaken jointly with the project partner LGI. The objective was not to conduct a full literature review, but rather to map existing evidence and highlight emerging trends, opportunities, and challenges in the CS market, while also identifying areas requiring deeper investigation.

The process involved a targeted scan of academic publications, policy reports, and market analyses relevant to CS demand and market development. Sources were selected for their contribution to understanding sectoral dynamics, user needs, business models, and governance frameworks. The emphasis was on capturing early signals, illustrative examples, and knowledge gaps that could inform subsequent, more detailed analysis.

The insights presented here represent an initial evidence base, which will be expanded through a more comprehensive market study to be delivered in the final version of this report.

4. Recommendations for the assessment and increase of climate service impact

As the impacts of climate change intensify, the need for actionable, user-centred CS has never been more pressing. CS aim to deliver climate information and knowledge that support decision-making across a wide range of sectors, including agriculture, energy, urban planning, and coastal management (Hewitt, Allis, *et al.*, 2020; Hewitt & Stone, 2021). Yet despite the rapid growth in demand, a persistent gap remains between the supply of climate information and its actual uptake and integration into policy and everyday practice (Antwi-Agyei *et al.*, 2021; Jacobs & Street, 2020; Swart *et al.*, 2021; Vaughan *et al.*, 2019). Recent evidence underscores that producing more or better data alone is not enough; meaningful climate action hinges on whether services are designed and delivered in ways that users can understand, trust, and apply (Di Napoli *et al.*, 2023; Hewitt *et al.*, 2021; Webber, 2019 and Schuck-Zöller et al., 2022).

Studies consistently show that traditional supply-driven models, where providers concentrate on producing high-quality datasets and forecasts, often fall short in driving real-world decisions (Antwi-Agyei *et al.*, 2021; Daniels *et al.*, 2020; Findlater *et al.*, 2021; Jacobs & Street, 2020). Many users struggle to interpret and translate technical information into actions that fit their specific contexts (Clifford *et al.*, 2020; Hewitt, Golding, *et al.*, 2020; Raaphorst *et al.*, 2020; Visman *et al.*, 2022). This tension between product-oriented delivery and more process-oriented, participatory approaches highlights an important shift: effective CS depend not only on what is produced but also on how they are co-developed with those who use them (Daniels *et al.*, 2020; Findlater *et al.*, 2021; Perrels, 2020; Vaughan *et al.*, 2019; Vincent *et al.*, 2020; Vollstedt *et al.*, 2021).

As CS expand into new sectors, including the private sector and finance (Cortekar *et al.*, 2020; Larosa & Mysiak, 2020; Fiedler *et al.*, 2021; Tart *et al.*, 2020; Visscher *et al.*, 2020), they face barriers such as unclear value propositions, trust gaps, and limited evaluation of their real-world impact (Bamzai-Dodson & McPherson, 2022; Brasseur & Gallardo, 2016; Soares & Buontempo, 2019; Vaughan & Dessai, 2014). In agriculture, for example, whether farmers adopt CS depends on trust, local relevance, and whether information aligns actual decision-making windows—yet adoption remains uneven and often poorly tracked (Born *et al.*, 2021; Dinku *et al.*, 2022; Toreti *et al.*, 2022; Vaughan *et al.*, 2019; Warner *et al.*, 2022).

4.1 Defining impact in the context of climate services

In the context of CS, *impact* refers to the tangible and intangible effects that the use of climate information has on decision-making processes, behaviours, and outcomes across multiple sectors. Rather than focusing solely on the delivery of data or products, the emphasis lies on how such information is co-created interpreted and applied to enable positive change such as enhanced preparedness, adaptive action, policy development, or socio-economic resilience. This perspective aligns with the definition provided by the IPCC, which states that CS support "decision-making in relation to adaptation, mitigation, and risk management" by delivering actionable climate information tailored to user needs (IPCC, 2022). The World Meteorological Organization (WMO) similarly highlights that CS are co-produced knowledge systems that inform decisions across climate-sensitive sectors, embedding climate data into operational, strategic, and policy contexts (WMO, 2014).

Evaluations of CS further distinguish between **process** (e.g. co-creation of CS pr), **outputs** (e.g. forecasts delivered), **outcomes** (e.g. behaviour changes) and **impacts** (e.g. long-term benefits to livelihoods or resilience), illustrating how climate information must be developed and used—not merely accessed—to generate value (Vaughan & Dessai, 2014; Tall et al., 2018, Schuck-Zoeller et al.,2022).

Building on this, it is useful to clarify the related but distinct concepts of **value, benefits**, and **impact**. Values represent the socio-economic potential that users can derive from CS; benefits are the measurable economic or social gains observed through monitoring; and impact refers to broader, systemic changes in well-being, livelihoods, or institutional resilience that typically emerge over longer timescales (Watkiss & Hunt, 2021; OECD, 2010). Differentiating these concepts is important not only for evaluation but also for the design of services, as each requires different methodological approaches. Table 1 summarises these distinctions and the common methods used to assess them. So, while benefits may be captured through short-term metrics such as avoided losses or improved yields, impact assessment refers to measuring the deeper and longer-term consequences of CS—changes that are harder to attribute, often unfold over decades, and demand robust methods to establish causality.

Table 1: Distinction among value, benefits and impact

Concept	Definition	Nature	Methods

Value	The perceived or potential worth of a CS often considered before or during implementation	Perceived/potential	Ex-ante assessments, surveys (e.g., willingness to pay) expert elicitation
Benefits	The realised positive outcomes (tangible or intangible) from CS use, often short or medium term	Realised gains	Case studies, cost-benefit analysis (CBA) observational data
Impact	Long-term systemic changes resulting from CS including social, economic, environmental or institutional shifts	Structured change	Ex-post evaluation, impact pathway analysis, counterfactual or control-group studies

This distinction between value, benefits, and impact provides an essential foundation for understanding how CS contribute to change. While value highlights potential usefulness and benefits capture realised short- to medium-term gains, impact reflects the broader, systemic transformations that CS can enable. These transformations are multi-dimensional, spanning social, economic, environmental, behavioural, and policy domains, each of which illustrates how climate information moves beyond technical outputs to shape resilience and adaptive capacity in practice.

The impacts of climate services can be categorised across multiple dimensions, as illustrated in Figure 5. These categories help highlight the broad-reaching benefits that climate information can have on various sectors. Some of the main elements include:

- Social impacts include improved public safety, enhanced awareness, community empowerment, and better health outcomes through early warnings or seasonal forecasts (Vaughan & Dessai, 2014).
- Economic impacts involve cost savings, avoided losses, or increased productivity, such as optimised agricultural planning or reduced weather-related disruptions (Soares, Alexander, & Dessai, 2018).
- Environmental impacts arise from the implementation of nature-based and climate-smart practices and solutions informed by climate information for example, ecosystem-based adaptation enhances biodiversity and resilience, while climate-smart agriculture improves soil health and reduces emissions (IPCC, 2022; Souza et al., 2025).
- Behavioural impacts refer to shifts in practices or attitudes driven by climate information, such as farmers adjusting planting calendars or urban planners incorporating future climate risks into zoning decisions (Vaughan & Dessai, 2014; Ziervogel et al., 2010).
- Policy related impacts involve the uptake of climate information into regulations, strategic planning, and governance frameworks e.g., mainstreaming climate risks into national adaptation plans (Street, 2016).

IMPACTS OF CLIMATE SERVICES

Social impacts
Safety, awareness and empowerment

Economic impacts
Savings, productivity and resilience

Policy impacts
Regulation, strategy and governance

Environmental impacts
Biodiversity, soil, and emissions

Behavioural impacts
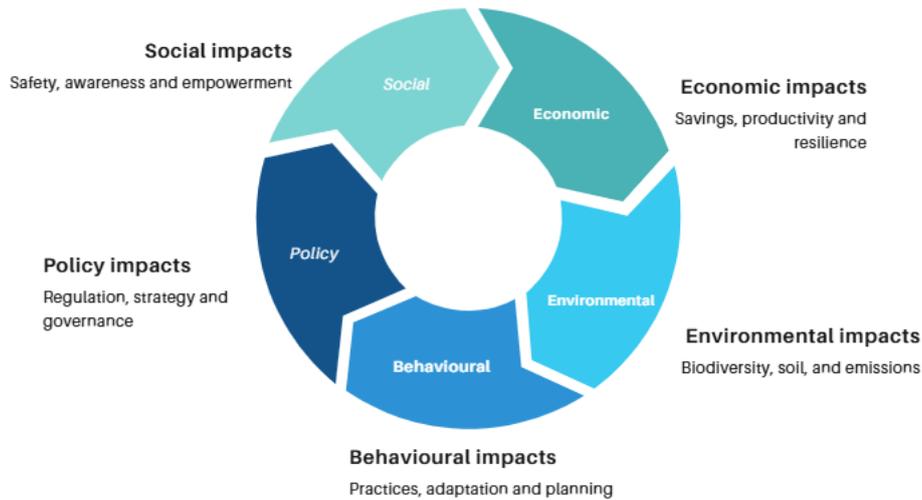Practices, adaptation and planning

Figure 5: Different impacts of climate services

The application of CS can have **direct impacts**, such as a city revising flood risk plans using seasonal projections. **Indirect impacts**, by contrast, are mediated over time and space, such as cultural shifts in how communities perceive climate risks, second-order benefits in supply chains and ecosystems, or cross-sectoral spillovers into health, education, and migration policies.

The application of climate services (CS) can have direct impacts, such as a city adjusting emergency response protocols based on seasonal climate forecasts. While these short-term projections support operational decisions, robust flood risk planning typically relies on long-term statistics of extreme event frequency and intensity derived from climate change projections. Indirect impacts, by contrast, are mediated over time and space—such as cultural shifts in how communities perceive climate risks, second-order benefits in supply chains and ecosystems, or cross-sectoral spillovers into health, education, and migration policies.

Capturing the full value of climate services (CS) therefore requires systems thinking and **comprehensive** evaluations—that is, assessments conducted over extended periods—to understand how interventions produce cascading and distributed effects across time, sectors, and social groups (Chapagain et al., 2023; Vaughan & Dessai, 2014; Soares et al., 2018; IPCC, 2022).

A useful example of impact evaluation is provided by Pérez-Terán *et al.* (2015), who conducted a quantitative assessment of a radio-based intervention aimed at improving climate knowledge in a local community in the Congo Basin. The study applied a structured, multi-step framework designed to trace the causal pathway from activities to outcomes. The framework followed four stages: (i) contextual analysis and intervention design, which ensured that the radiogramming—defined here as the strategic development and delivery of radio-based messaging tailored to local socio-cultural and informational needs—was appropriately customized; (ii) implementation and outputs, focusing on broadcast delivery and listener engagement mechanisms; (iii) short-term outcomes, measured through changes in knowledge levels; and (iv) longer-term impacts, particularly behavioural change and increased community participation in climate-related practices.

The evaluation employed a quasi-experimental design with treatment and control groups, based on 60 baseline observations and follow-up surveys to track changes over time. To address potential biases, the analysis combined propensity score matching—to construct a statistically comparable control

group—with an instrumental variable approach, mitigating concerns over self-selection into the programme.

The econometric results indicated a statistically significant 22.3% increase in climate knowledge among individuals exposed to the radio programming compared to the control group. Beyond knowledge gains, the study also observed behavioural changes, including greater involvement in local conservation initiatives and shifts in natural resource management practices.

4.2 Assessing the impact of climate services

Introduction and framing

Assessing the impact of CS has become increasingly important to ensure their effectiveness, relevance, and sustainability in supporting climate resilience, adaptation, and mitigation goals. The methodologies used in this field reflect the diversity of CS and the evolving understanding of how to capture their value across different contexts and scales.

Assessing the impact of CS remains challenging. To date, many evaluations rely on conventional scientific measures rather than evidence of changes in policy, practice, or behaviour (Bamzai-Dodson & McPherson, 2022; Tall *et al.*, 2018). Calls for more robust, multi-level frameworks are growing louder, with researchers urging the integration of qualitative and quantitative methods from the earliest stages of service design (Boon *et al.*, 2022; Englund *et al.*, 2022; Jahan *et al.*, 2023; Tall *et al.*, 2018; Vaughan & Dessai, 2014).

Emerging approaches in the literature

Promising approaches include using detailed case studies to capture tangible outcomes such as yield improvements or financial risk reduction (Delpiazzo *et al.*, 2022; Halsnæs *et al.*, 2021; Toreti *et al.*, 2022). Other methods, like Social Network Analysis, help map how information moves among stakeholders and identifies key intermediaries or knowledge brokers (Giordano et al., 2020; Simon et al., 2021). By visualising relational structures, SNA can reveal clusters of actors, patterns of collaboration, and potential gaps or bottlenecks in communication flows. This allows for a better understanding of power dynamics and influence in climate service networks, highlighting where interventions might enhance connectivity, inclusivity, and the effective uptake of knowledge. Some studies apply Constructive Technology Assessment or typologies that classify services to better align supply with the diverse needs of different user groups (Bisaro *et al.*, 2021; Raaphorst *et al.*, 2020; Visscher *et al.*, 2020).

Intermediate-scale evaluations that bridge in-depth case studies and large-scale surveys can also assess how usable, transparent, and decision-relevant online climate tools really are (Jahan *et al.*, 2023; Vollstedt *et al.*, 2021) . Importantly, several contributions stress that good performance metrics should capture not only potential benefits but also the trade-offs and risks that climate service use may involve (Boon *et al.*, 2024; Lusk, 2022; Toreti *et al.*, 2022; Webber, 2019).

What emerges from the literature is that there are several approaches for identifying the impacts of CS, which could be classified according to quantitative and qualitative methods, mixed-method approaches, as well as ex-ante, formative and ex-post methods (Tall *et al.*, 2018).

4.2.1 Quantitative approaches

Cost-benefit analysis (CBA) remains one of the most widely used quantitative methods for assessing the economic value of CS. It compares the benefits derived from using climate information against the cost of producing and delivering it. For example, a study by Tall *et al.* (2014) found that seasonal climate forecasts in West Africa yielded economic returns of up to 4:1 for farmers who used the information to adjust their planting strategies.

Performance metrics such as accuracy, lead time, spatial resolution, and skill scores are also essential for evaluating technical effectiveness. These metrics often serve as proxies for value, particularly in weather and seasonal forecasting services. More recently, **impact indicators** (e.g., yield changes, disaster loss reduction, or improved resource efficiency) have been employed to quantify user-level benefits, especially in agriculture, water, and disaster risk reduction sectors (Vaughan & Dessai, 2014).

Based on this, Ferrari *et al.* (2024) show that tangible benefits from CS could be quantified in economic or numerical terms following two commonly used conceptual frameworks: the cost-loss approach and the cost-benefit analysis. The former assumes that the user can translate the information provided by a climate service into quantifiable impacts in terms of costs and cost savings, which can then be used to estimate the value of the climate service.

The latter instead makes a comparison of benefits and costs associated with the climate service used. Soares *et al.* (2018) additionally provide further methodologies to evaluate the impact of CS value: the General Equilibrium Models (GEM) and the Contingent Value (CV). The first refers to a quantitative model which compares scenarios with and without CS to estimate net benefits and trade-offs across sectors. The second is used to assess the perceived value of climate information by asking users their willingness to pay for it. This helps estimate the direct benefits users attribute to improved forecasts or early warnings. The results inform cost-benefit analyses and justify investment in CS. Other methods could include econometric regression analysis as well (Orlove et al., 2004; Patt et al., 2005). Such approaches enable a quantitative assessment of the relationships between the provision or use of climate services and measurable outcomes, such as changes in decision-making, productivity, or risk reduction. By statistically controlling for confounding variables, econometric models can help to isolate the specific contribution of climate services to observed impacts. This makes them particularly valuable for generating evidence of effectiveness and cost–benefit performance, which is often required to justify investment and scaling of climate services.

4.2.2 Qualitative approaches

User feedback is central to qualitative assessments and can provide insights into user satisfaction, trust, enhancement of applicability, transparency, professionalism, perceived usefulness, and barriers to uptake. Methods include surveys, interviews, and focus groups. Qualitative data are especially useful for understanding the context of use and social dimensions of impact.

Case studies enable an in-depth examination of how CS are implemented and utilised in specific settings. For instance, Buontempo *et al.* (2018) illustrate case-based learning from the Copernicus Climate Change Service (C3S), showing how stakeholder engagement shaped the tailoring of services.

The theory of change (ToC) framework is gaining prominence in CS impact evaluation. It helps mapping how inputs and activities are expected to lead to activities, outputs, outcomes, and long-term impacts. This structured approach aids in identifying key assumptions and indicators at each stage and is often used in donor-funded projects to assess value for money and strategic alignment (Vogel, 2012).

There has been a growing trend in recent years towards using qualitative approaches to understand the impact of CS, often relying on descriptive evaluations such as participatory approaches, case studies, descriptive statistics, and tools such as focus group discussions, key informant interviews, and structured surveys with the goal to capture and describe the changes users experience from using climate information services (Soares *et al.*, 2018; Roudier *et al.*, 2014; Tall *et al.*, 2018).

4.2.3 Mixed-methods and adaptive approaches

Mixed-methods evaluations combine the robustness of quantitative data with the depth of qualitative insights. These are particularly useful when evaluating complex, multi-stakeholder CS. An example is the Global Framework for Climate Services (GFCS), which recommends integrated approaches to capture both technical and societal dimensions of impact (WMO, 2016).

Adaptive evaluation frameworks acknowledge that the effectiveness of CS can change over time due to evolving climate risks, user needs, or policy contexts. These frameworks emphasise iterative learning, regular feedback loops, and co-design principles. For instance, the European Research Area for Climate Services (ERA4CS) promoted reflexive monitoring as part of project evaluation, enabling real-time adjustments to better meet stakeholder needs (Harjanne *et al.*, 2021).

4.2.4 Ex-Ante vs. Ex-Post distinction

An interim distinction between ex-ante and ex-post evaluations is essential for understanding how climate services evolve throughout their implementation. While ex-ante assessments focus on anticipated outcomes and planning assumptions, and ex-post evaluations measure final impacts and effectiveness, formative or process-oriented evaluation occupies the critical space in between. This approach enables continuous reflection and adaptation during the project lifecycle, allowing co-creation processes to be restructured in response to emerging insights. Grounded in literature review and user feedback, formative evaluation enhances responsiveness and inclusivity, ensuring that climate services remain contextually relevant and socially attuned as they unfold.

An **ex-ante approach** is prospective and assesses the potential value of a climate service before its implementation, often using historical data, simulations, or models (Meza *et al.*, 2008). This method is more common in quantitative analyses and is especially useful for exploring the likely impacts of a climate service on specific activities, which supports better resource allocation and investment decisions. It can also be applied to examine how improvements to an existing climate service could enhance economic returns and user benefits.

In contrast, an **ex-post approach** is retrospective and focuses on the actual benefits that have emerged after a CS has been delivered (Meza *et al.*, 2008). Typically, more common in qualitative analyses, this method draws on observed data, user feedback, and measurable outcomes, though it does not always quantify economic value directly. Because it involves users and real-world experiences, an ex-post approach provides valuable insights into how CS influence decision-making and can help illustrate impacts and guide future improvements.

4.2.5 Synthesis

Each approach has its own strengths and weaknesses, which differ in terms of data requirements, expertise, time, and resources. While quantitative approaches provide measurable indicators of economic and technical value, qualitative and participatory approaches shed light on contextual, behavioural, and social impacts.

Increasingly, studies highlight the importance of combining methods and adopting iterative evaluation frameworks. This reflects the growing recognition that comprehensive and context-sensitive assessments are needed to capture the diverse impacts of CS. Table 2 provides a detailed summary of the methodologies used.

Table 2: Summary of main methodological approaches used for valuing CS

Method	Type	Primary use	Key strengths	Key limitations
Cost-Loss Models	Quantitative / Ex-ante	Forecasting use cases	Simple to apply; decision-oriented & user-focused.	Ignores broader social & environmental impacts.
Simulation-Based Models	Quantitative / Ex-ante	Scenario analysis	Useful for assessing potential outcomes over time; flexible.	Requires detailed data inputs.
Cost-Benefit Analysis (CBA)	Quantitative / Both	Economic evaluation	Standardised, widely accepted, & suitable for policy.	Requires reliable data; undervalues intangible benefits.
Willingness-to-Pay (WTP)	Quantitative / Ex-ante	Valuing preferences	Reveals user preferences & perceived value.	Subject to hypothetical bias; costly to survey.
Econometric Approaches	Quantitative / Ex-post	Impact assessment	Can control for multiple variables.	Requires statistical knowledge & data.
General Equilibrium Models	Quantitative / Both	Policy evaluation	Captures systemic interactions; useful for large-scale analysis.	Highly data-intensive with complex assumptions.
Case Studies	Qualitative / Ex-post	Evaluating impact	Provides in-depth, rich insights into specific contexts.	Difficult to generalise; time intensive.
Interviews	Qualitative / Both	Stakeholder feedback	Provides nuanced, context-rich data; flexible.	Subjective, not easily generalisable, & requires skilled facilitation.

Source: (Gonzalez Romero *et al.*, 2025)

4.3 Challenges in measuring the impact of climate services

Measuring the impact of CS remains a complex task due to a variety of methodological and practical challenges. These challenges hinder robust evaluation and complicate efforts to demonstrate the added value of climate information in decision-making contexts. Despite growing recognition of the importance of evidence-based assessments, current evaluation practices often fall short of capturing the diverse and multi-dimensional nature of climate service outcomes.
A closer look at the literature reveals several interrelated obstacles that explain why measuring impact is so difficult.

Attribution issues are a central concern. CS often operate as one input among many in complex decision-making environments. As such, isolating their specific contribution to observed outcomes—such as reduced losses from extreme events or improved agricultural productivity—is rarely straightforward. This challenge is compounded when climate information is embedded in broader advisory systems or policy frameworks (Vaughan & Dessai, 2014).

The absence of standardised indicators or benchmarks further complicates evaluation efforts. While some domains, such as disaster risk reduction, may have established metrics (e.g. number of people reached by early warnings), many other sectors lack agreed methodologies to assess whether and how climate information leads to meaningful change (Tall *et al.*, 2018). Without such standards, evidence remains fragmented and often incomparable across projects and regions, limiting the ability to build a cumulative knowledge base.

Variability across sectors, geographies, and user groups also restricts the transferability of evaluation approaches. CS are inherently context-specific, shaped by sectoral needs, institutional settings, and user capacities. What constitutes success for a coastal planner may differ significantly from what a farmer or public health official requires. This diversity underscores the need for tailored approaches, often combining mixed-methods and participatory evaluation to reflect the realities of different decision contexts (Soares & Buontempo, 2019).

Data limitations and weak feedback mechanisms present another barrier. Reliable information on usage, behavioural responses, or socio-economic benefits is often unavailable or difficult to access. Moreover, the absence of structured feedback loops between users and providers hampers learning and the adaptive improvement of services (Soares *et al.*, 2018).

Finally, time delays between service delivery and observable results can obscure impact detection. While some outcomes—such as emergency-response activation—may occur rapidly, others, such as ecosystem restoration or enhanced institutional resilience, unfold over years or decades. This temporal lag highlights the importance of long-term monitoring frameworks and systems-thinking approaches to evaluation (Tuler *et al.*, 2020).

Taken together, these challenges demonstrate that robust assessment of CS requires more than technical accuracy or performance metrics. It calls for sustained investment in impact research, stronger co-evaluation mechanisms, and consistent guidance to support monitoring and learning across the CS landscape. These challenges also mirror some of the malpractices collected in D4.3 and ranked in this report (see Chapter 5).

4.4 Process to assess the impact of a climate service

Impact assessment is not a single tool or methodology; rather, it represents a broader evaluative process that can be implemented through a variety of tools, methods, and approaches. What fundamentally distinguishes impact assessment from other forms of monitoring and evaluation (e.g. value and benefits evaluation) is its exclusive focus on change and the pathways leading to that change. The study by Tall *et al.* (2018) applied to the agriculture contexts offers one of the most comprehensive overviews of how to evaluate the impacts of CS. Based on their insights, we derived some steps to conduct an impact assessment of CS.

4.4.1 Step 1: Define the evaluation purpose and scope

As Tall *et al.* (2018) emphasise, clarifying the purpose of an evaluation is a critical first step in conducting an impact assessment, as it directly shapes the choice of appropriate methods. Defining this purpose provides the foundation for a coherent and rigorous evaluation approach.

What distinguishes impact assessment from routine monitoring and evaluation (M&E) lies precisely in this framing. Whereas M&E typically concentrates on tracking activities, outputs, and immediate

results, impact assessment focuses on pathways of change and seeks to capture the deeper, often longer-term transformations triggered by an intervention.

Guiding questions at this stage include:

- What has changed as a result of the implementation of the climate service (CS)?
- Which groups were affected—or not affected—and in what ways?
- How significant and enduring were these changes?
- How can impacts across economic, social, and environmental domains be systematically assessed?

PRACTICAL EXAMPLE

Agro-climatic Advisory Services in Niger
(Seydou et al., 2023)

Objective: To asses whether farmers using agro-climatic advisories adopt different land-use or planting strategies.

Unit of Analysis: Smallholder farmers.

Domain of Impact: Economic (yield, income), behavioral (practice change).

Figure 6: **Practical example of how to establish objectives, unit of analysis, and impact domain for an impact assessment of CS**

Addressing these questions requires attention to three core components: the objective of the evaluation, the unit of analysis, and the impact domain. Establishing these elements from the outset ensures methodological coherence, enhances analytical rigour, and strengthens the credibility of the assessment (Figure 6).

4.4.2 Step 2: Develop an impact pathway as part of project design

The second step involves the selection and definition of metrics for outputs, outcomes, and impacts. According to Tall *et al.* (2018), distinguishing these levels is essential to trace the causal chain from service delivery to ultimate societal effects. While outputs reflect direct products of the intervention (e.g., number of forecasts disseminated or training sessions held), outcomes relate to behavioural or cognitive changes among users (e.g., improved planning decisions, altered agricultural practices).

Impacts represent the most distal and complex changes—economic, social, or environmental—that result from sustained use of CS (Figure 7).
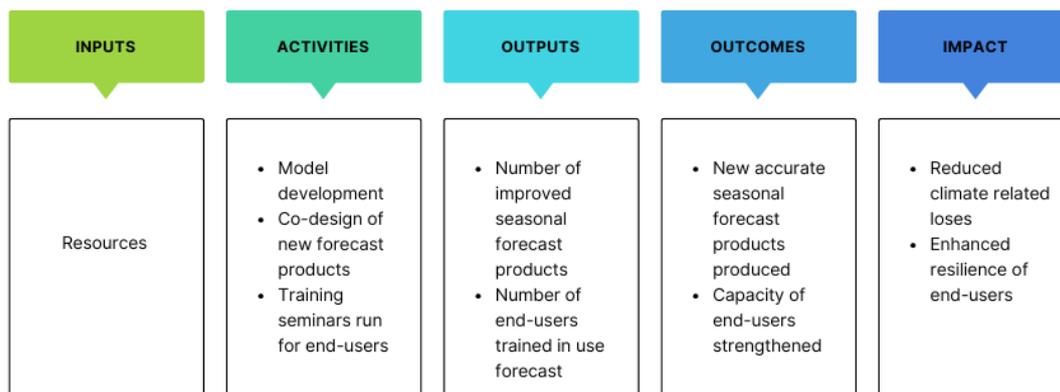
Figure 7: Metrics for Impact evaluation. Source: Watkiss and Hunt, 2021

Metrics must be tailored to the specific domain of impact and enable evaluators to capture both intended and unintended effects. Tall *et al.* (2018) emphasise that insufficient attention to outcomes often produces misleading conclusions about programme success: high levels of output do not necessarily translate into meaningful change without evidence of user uptake or behavioural shifts. To address this, metrics should combine quantitative indicators (e.g., yield increase, household income) with qualitative ones (e.g., user trust, institutional legitimacy) and ideally be measured at multiple time intervals to reflect the temporal dynamics of change.

This leads to tools that help visualise and logically structure the changes expected during a project's implementation. Two models are particularly relevant for CS impact assessment, as they provide a framework for articulating assumptions, causal links, and intended outcomes: the **Theory of Change (ToC)** and the **Impact Pathway**. Both encourage systematic reasoning and offer guidance for assessing how and why change is expected to occur.

As introduced earlier, the theory **of change (ToC)** framework provides a structured way of linking inputs, activities, outputs, and long-term impacts in CS evaluation. Beyond this technical function, ToC can also be understood as a flexible, dual-purpose approach. On the one hand, it serves as a methodological tool that visualises causal sequences and identifies assumptions, risks, and external factors influencing results. On the other hand, it operates as a reflective and iterative process—often co-produced with stakeholders—that encourages critical examination of values, contextual conditions, and pathways of change. This dual role makes ToC valuable not only for evaluation but also for planning, adaptation, and learning throughout the project lifecycle (Vogel, 2012).

An **impact pathway** is a more granular version of a ToC. It focuses on the causal chain linking activities, outputs to outcomes and impacts, often including specific actors, interventions, behavioural responses, and feedback loops (Alvarez *et al.*, 2010). It is particularly useful for tracking attribution and identifying where in the chain a service might succeed or fail. By using ToC or Impact Pathway tools, evaluators can systematise the logic of change, identify critical indicators, and design data collection strategies aligned with different stages of the results chain.

4.4.3 Step 3: Define a baseline

Defining a baseline is a critical step in the evaluation of CS, as it establishes the reference conditions against which the effects of an intervention can be assessed. According to Lazo *et al.* (2008), the baseline represents the status quo in the absence of CS and should include data on key outcome indicators prior to the intervention's deployment. This pre-intervention data provides the necessary

foundation for identifying measurable changes over time and facilitates the construction of a counterfactual scenario.

4.4.4 Step 4: Select the appropriate evaluation methodology

The choice of evaluation methodology should be directly informed by the type of evidence needed and the nature of the expected changes. As noted by Tall *et al.* (2018), a comprehensive impact evaluation of CS requires combining **quantitative** and **qualitative** methods to capture both the measurable and contextual dimensions of change.

Quantitative methods, such as randomised control trials, difference-in-difference estimations, or regression-based impact models, allow for causal inference and the estimation of treatment effects. These approaches are particularly effective in identifying behavioural outcomes and welfare impacts (e.g., changes in income, yield, or risk exposure), provided that a reliable counterfactual can be constructed.

Qualitative methods, including key informant interviews, focus groups, and case studies, contribute by revealing how and why certain changes occur, capturing user perceptions, institutional dynamics, and context-dependent meanings of value and use. These are particularly crucial when assessing intangible benefits or institutional impacts that are difficult to quantify.

Insights from the Climateurope2 Deliverable D3.1 confirm the added value of mixed-methods approaches in the evaluation of CS. Although the deliverable primarily focuses on assessing the value and benefits of such services, it highlights that few studies effectively integrate both qualitative and quantitative methods. This lack of integration limits the scope of evaluation, whereas a combined approach can provide a more comprehensive understanding of the multifaceted value of CS. For instance, qualitative assessments are crucial for tracing how users perceive, interpret, and incorporate CS into their decision-making processes and reveal intangible benefits created. In contrast, quantitative methods evaluate whether these decisions translate into measurable outcomes and enable the assignment of monetary values to the observed benefits. The synergy between these approaches allows for more robust impact evaluations.

It is not our intention to provide an exhaustive review of all possible quantitative and qualitative methodologies, as numerous other works offer comprehensive overviews. Instead, we present a comparative table highlighting a selection of methods with strong potential for application in CS impact assessments (Table 3).

Table 3: Potential methods for impact assessment of CS

Method type	Method	Purpose	Strengths	Limitations
Quantitative	Randomised controlled trials (RCTs)	Estimate causal impact by comparing treatment and control groups randomly assigned	High internal validity	Practical constraints; costly and time-consuming
Quantitative	Difference-in-Difference (DiD)	Compare changes over time between treatment and control group	Controls for time invariant unobserved heterogeneity	Requires pre-and-post data; assumptions about parallel trends

Quantitative	Matching methods	Creative statistically comparable groups from non-randomised data	Address selection bias	Dependent on quality of matching variables
Quantitative	Instrumental variables	Use external instruments to isolate variation unrelated to confounding variables	Helps deal with endogeneity and omitted variables bias	Identification of valid instruments can be difficult
Qualitative	Focus group	Explore group perspectives, perceptions and shared experiences	Contextual depth; captures group dynamics and perceptions	Not generalisable
Qualitative	Interviews	Gather expert or insider insights on implementation and impact	Reveals institutional processes and decision rationales	Subject to bias; depends on information selection
Qualitative	Ethnographic analysis	Understand cultural, social, and contextual dynamics of intervention	Rich contextual insights; captures tacit knowledge and long-term social dynamics	Time-intensive; limited generalisability; requires high researcher immersion

It is important to emphasise that impact assessments greatly benefit from the use and careful construction of a counterfactual. A counterfactual explains what would have happened in the absence of the intervention, making it a cornerstone of causal impact evaluation. By providing this benchmark, evaluators can attribute observed changes specifically to the CS, rather than to external or confounding factors.

As Gertler *et al.* (2011) note, building a credible counterfactual requires careful attention to issues such as selection bias, measurement timing, and the comparability of groups. The strength of an impact assessment depends largely on how convincingly it can rule out alternative explanations for the observed changes.

4.4.5 Step 5: Account for attribution and confounding factors

Impact evaluation must also address the problem of attribution, namely, identifying the extent to which observed outcomes and impacts are due to the CS intervention itself, rather than other external influences. This requires explicit attention to confounding variables, which are factors outside the intervention that may influence the same outcomes, such as economic trends, weather variability, concurrent policies, or access to other services.
To isolate the contribution of the intervention, evaluators should identify and include control variables in their analysis. Control variables are characteristics that are statistically accounted for to prevent them from biasing the estimate of the intervention effect. For example, in evaluating the impact of CS on crop yields, variables such as soil type, rainfall, and household assets should be controlled for in the analysis. Failure to control for confounders can result in over- or underestimation of the intervention's effect.

4.4.6 Step 6: Reflect on external validity and scalability

The final step involves assessing the external validity and scalability of the intervention. External validity refers to the extent to which the findings of an evaluation can be generalised beyond the specific context in which it was conducted. A pilot project that demonstrates strong local impact may not yield the same results when scaled across regions with different socio-political, ecological, or institutional conditions.

Reflecting on scalability also requires a critical assessment of contextual dependencies that may condition the success of CS. Tall *et al.* (2018) note that impact evaluations are most feasible and rigorous in pilot settings, where it is easier to isolate effects. However, these settings may not reflect the complexity or diversity of broader implementation environments.

Therefore, reflection in Step 6 should address:

- What conditions enabled success in the evaluated setting?
- Are these replicable elsewhere?
- What institutional adaptations are needed for broader uptake?
- How might the service evolve over time in response to changing needs?

This final step serves both as a feedback loop for programme design and a contribution to the broader knowledge base on CS effectiveness. It ensures that evaluations are not only informative but also transformative, by linking evidence to adaptive learning and future decision-making.

4.5 Challenges in increasing the impact of climate services

A review of methodologies used to assess climate services (CS) in the literature highlights a widely discussed point: the potential of CS is most fully realized when they are co-produced through continuous, trust-based cooperation among developers, intermediaries, and end-users (Hewitt, Golding, et al., 2020; Hewitt & Stone, 2021; Pimentel et al., 2022; Rubio-Martin et al., 2023; Vincent et al., 2020). While this principle is strongly supported in academic discourse, its practical implementation varies across providers. For instance, even well-established services such as Copernicus Climate Change Service (C3S) may not fully meet this ideal, reflecting the challenges and trade-offs involved in operationalizing co-production at scale.

Effective co-production starts early and continues throughout the service lifecycle, with users helping to define the problems, **co-develop** prototypes, and refine outputs in iterative cycles (Hewitt, Golding, *et al.*, 2020; Perrels, 2020; Rubio-Martin *et al.*, 2023; Steynor *et al.*, 2020; Vollstedt *et al.*, 2021).

This approach not only helps build trust but also ensures relevance and strengthens local capacity to interpret and act on climate information (Daniels *et al.*, 2020; Findlater *et al.*, 2021; Lawrence *et al.*, 2021; Vincent *et al.*, 2020). Emerging place-based methods increasingly integrate perspectives from the humanities, broadening problem framings and embedding climate science within local narratives and cultural memory (Krauß, 2020). Intermediaries play a particularly critical role in this process: local extension officers, trusted community leaders, and other knowledge brokers translate complex climate information into accessible language and practical formats that diverse user groups can readily understand and apply (Buontempo *et al.*, 2020; Simon *et al.*, 2021; Swart *et al.*, 2021).

In agriculture, for example, the use of multiple communication channels and gender-sensitive outreach can help overcome social and cultural barriers and encourage adoption (Vaughan *et al.*, 2019; Warner *et al.*, 2022). Boosting the impact of CS also depends on business models and supportive institutions that enable their long-term sustainability. Innovative models that blend public and private incentives, co-create value with users, and link CS to broader sustainability goals can help expand adoption and impact (Cortekar *et al.*, 2020; Larosa & Mysiak, 2020; Fiedler *et al.*, 2021; Tart *et al.*, 2020; Visscher *et al.*, 2020) .

Strong governance frameworks and coordination across scales and sectors are equally important, especially in regions where technical and institutional capacities remain limited (Antwi-Agyei *et al.*, 2021; Bernardini, 2022; Soares & Buontempo, 2019; Escada *et al.*, 2021; Giorgi, 2019; Lawrence *et al.*, 2021; Meque *et al.*, 2021) . For instance, initiatives like ENACTS demonstrate how partnerships can enhance data availability and usability in Africa, addressing persistent data gaps (Dinku *et al.*, 2022). Equally, CS must integrate new areas such as health impacts (Di Napoli *et al.*, 2023) and biodiversity and ecosystem changes (Telo Da Gama, 2023; Wani & Sahoo, 2020, 2020; Williams *et al.*, 2020) to broaden their relevance. As evidence shows, robust climate observations, modelling, and tailored research are essential to develop services that inform adaptation and resilience strategies (Hewitt *et al.*, 2021; Wani & Sahoo, 2020; Weiskopf *et al.*, 2020; Williams *et al.*, 2020).

Taken together, a strand of literature points to several priorities for improving and enhancing the real-world impact of CS (Jahan *et al.*, 2023).

First, robust evaluation needs to be embedded throughout the service development process, using mixed methods that connect climate information to actual decision outcomes (Bamzai-Dodson & McPherson, 2022; Boon *et al.*, 2022; Englund *et al.*, 2022; Jahan *et al.*, 2023; Tall *et al.*, 2018; Vaughan & Dessai, 2014). Indeed, mix methods that combine quantitative impact indicators with qualitative insights, together with adaptive and developmental evaluation approaches that capture the dynamic and context-specific nature of climate service use (Boon *et al.*, 2022; Englund *et al.*, 2022), could be beneficial. This could move beyond output-based metrics to track real-world outcomes, such as behaviour change, policy uptake, or risk reduction (Bamzai-Dodson & McPherson, 2022; Englund *et al.*, 2022; Jahan *et al.*, 2023; Tall *et al.*, 2018; Vaughan & Dessai, 2014) .

Second, co-production and user-centred design must become the norm rather than the exception, ensuring that services respond to local contexts and changing needs (Daniels *et al.*, 2020; Findlater *et al.*, 2021; Hewitt, Golding, *et al.*, 2020; Perrels, 2020; Rubio-Martin *et al.*, 2023; Vincent *et al.*, 2020; Vollstedt *et al.*, 2021). Indeed, end-users, intermediaries, and stakeholders should be involved to identify problems, select relevant metrics, and co-design tools (Findlater *et al.*, 2021; Hewitt, Golding, *et al.*, 2020; Perrels, 2020; Rubio-Martin *et al.*, 2023; Vincent *et al.*, 2020; Vollstedt *et al.*, 2021) from the beginning. In this context participatory workshops and interviews, may help to map and tailor information to local contexts and values (Vaughan *et al.*, 2019; Vincent *et al.*, 2020).

Additionally, along with hard sciences, humanities and social sciences should be integrated to expand how climate risks and solutions are framed (Krauß, 2020).

Third, strengthening the networks and capacities of intermediaries is vital for bridging the gap between data producers and diverse user groups (Buontempo *et al.*, 2020; Simon *et al.*, 2021; Swart *et al.*, 2021).

To make climate information truly useful, it's vital to empower the people who bring it to communities — extension agents, local leaders, NGOs, and other trusted intermediaries (Buontempo *et al.*, 2020; Simon *et al.*, 2021; Swart *et al.*, 2021) . They need ongoing training and support to share knowledge in ways that make sense for different audiences. Building lasting connections between those who

produce climate information and those who rely on it requires practical tools, training, and clear incentives to keep the relationships strong over time. It's equally important to break down social and cultural barriers by ensuring outreach efforts are inclusive and sensitive to gender and other forms of diversity, so that no group is left out of the conversation (Vaughan *et al.*, 2019; Warner *et al.*, 2022) .

Fourth, innovative business models and public-private partnerships can help unlock new markets and make CS more viable in practice (Soares & Buontempo, 2019; Cortekar *et al.*, 2020; Larosa & Mysiak, 2020; Fiedler *et al.*, 2021; Tart *et al.*, 2020; Visscher *et al.*, 2020). To ensure climate information drives real action, it must be clear, accessible, and directly useful for decision-making. This means using simple language, clear visualizations, and formats that help people understand what it means for their choices (Bisaro *et al.*, 2021; Clifford *et al.*, 2020; Raaphorst *et al.*, 2020; Visman *et al.*, 2022) .

Information should also be tailored to the timing and scale that matter most for each user — whether it's a farmer planning a planting season, a financial institution assessing risk, or a health official preparing for climate-related impacts (Born *et al.*, 2021; Di Napoli *et al.*, 2023; Fiedler *et al.*, 2021; Toreti *et al.*, 2022; Warner *et al.*, 2022). Closing data gaps is equally crucial. Supporting open-source tools and initiatives, like ENACTS in Africa (Dinku *et al.*, 2022), helps communities access reliable local data and adapt to changing conditions with confidence.

Fifth, building trust and encouraging adoption requires transparent communication, meaningful community engagement, and sustained capacity building, particularly in vulnerable regions (Dinku *et al.*, 2022; Escada *et al.*, 2021; Solaraju-Murali *et al.*, 2022; Vaughan *et al.*, 2019; Warner *et al.*, 2022; Malakar *et al.*, 2024). This could be done thanks to public funding with private incentives to co-create value propositions that align with users' financial and operational needs (Cortekar *et al.*, 2020; Larosa & Mysiak, 2020; Fiedler *et al.*, 2021; Tart *et al.*, 2020; Visscher *et al.*, 2020).

Finally, CS need to be integrated into policies and governance arrangements that enable coordinated, multi-level adaptation and resilience actions, while critically reflecting on their social, political, and ethical implications (Antwi-Agyei *et al.*, 2021; Bernardini, 2022; Giorgi, 2019; Lawrence *et al.*, 2021; Lusk, 2022; Webber, 2019). For CS to have real impact, they need to be woven into wider policy and planning processes at every level — from local communities to national governments and regional bodies (Antwi-Agyei *et al.*, 2021; Bernardini, 2022; Escada *et al.*, 2021; Giorgi, 2019; Lawrence *et al.*, 2021; Meque *et al.*, 2021). Better coordination among data providers, researchers, and the people who use this information helps avoid duplication and makes services more effective (Soares & Buontempo, 2019; Hewitt *et al.*, 2021). Just as important is ensuring that everyone has fair access to information and that ethical considerations are front and centre (Lusk, 2022; Webber, 2019). This builds trust and makes CS more credible, equitable, and useful for the communities they are meant to serve.

Ultimately, CS have enormous potential to help societies navigate both the risks and the opportunities that come with a changing climate. But turning this potential into lasting impact calls for an ongoing commitment to learning, true co-production with users, and careful, context-aware evaluation. One important step is to expand what CS cover. This means looking beyond traditional areas to address emerging challenges like shifting biodiversity (Telo Da Gama, 2023; Wani & Sahoo, 2020; Weiskopf *et al.*, 2020; Williams *et al.*, 2020), health risks (Di Napoli *et al.*, 2023), and soil sustainability (Telo Da Gama, 2023) — all of which matter deeply to different communities and sectors. Supporting this wider scope will require strong investment in interdisciplinary research, better data, and advanced modelling to make sure these new services are grounded in solid science and practical insight (Hewitt *et al.*, 2021; Meque *et al.*, 2021; Wani & Sahoo, 2020; Weiskopf *et al.*, 2020).

4.5.1 Barriers to increasing the impact of climate services

While the literature highlights promising practices for strengthening the design, governance, and sustainability of CS, it also underscores persistent barriers that limit their real-world effectiveness. These challenges are not only technical but also social and institutional, arising from how services are conceived, communicated, and embedded in decision-making processes. A closer look at recurring issues—including gaps in co-creation, misalignment with user needs, institutional fragmentation, weak integration into policy frameworks, and communication barriers—helps to explain why many CS remain underutilised despite growing investment and sophistication. These barriers also reflect some of the malpractices identified in D4.3 and ranked in this report (see Chapter 5).

Lack of co-creation and user engagement

Many climate services are still developed in a top-down manner, with limited involvement of end-users in their design, implementation, and evaluation (Hewitt, Mason, & Walland, 2012; Dilling & Lemos, 2011). This lack of co-creation reduces the relevance and legitimacy of services, often resulting in low uptake and trust (Soares *et al.*, 2018). Moreover, the absence of structured feedback loops between users and providers weakens learning and adaptive improvement of services (Soares *et al.*, 2018). Evidence from urban climate governance also shows that co-creation strategies require institutional support and leadership to be effective (Hofstad & Sørensen, 2021).

Misalignment with user needs or decision-making processes

CS frequently fail to align with the specific temporal, spatial, and operational needs of decision-makers. This misalignment—often referred to as the "usability gap"—means that even scientifically robust information may not be actionable or timely for users (Vaughan & Dessai, 2014). Services that do not consider users' planning cycles, risk tolerances, or institutional mandates are less likely to support or influence decision-making processes (Cash *et al.*, 2003).

Institutional fragmentation and siloed approaches

The governance of CS is often fragmented across sectors, disciplines, and administrative levels. This institutional fragmentation leads to duplication of efforts, inconsistent messaging, and missed opportunities for integration (Soares & Buontempo, 2019). Siloed approaches also hinder the development of cross-sectoral services that address interconnected challenges such as water-energy-food security.

Limited integration into policy and planning frameworks

Despite international efforts to mainstream climate information, many services remain peripheral to formal policy and planning processes. Barriers include a lack of institutional mandates, insufficient technical capacity, and competing political priorities (Tall *et al.*, 2018). Integration is further complicated by the disconnect between scientific outputs and the policy formats and timescales required by decision-makers (Vaughan & Dessai, 2014).

Communication gaps and accessibility issues

Climate information is often communicated in technical language or formats that are inaccessible to non-specialists. This creates barriers for communities, local authorities, and small businesses who may lack the capacity to interpret complex data (Vaughan & Dessai, 2014). Moreover, services frequently overlook the needs of marginalized groups, reinforcing existing inequalities in access to climate knowledge and adaptive capacity (Tall *et al.*, 2018).

4.6 Recommendations for enhancing climate services impact

Despite increased investment and institutional support, many CS still struggle to achieve sustained and measurable impact. Challenges such as limited user uptake, weak alignment with decision-making processes, and fragmented evaluation efforts often hinder their effectiveness.

Addressing these limitations requires a strategic shift toward user-centric design, long-term engagement, and continuous learning. The following recommendations outline key areas where interventions can strengthen the relevance, usability, and influence of CS, ultimately contributing to more climate-resilient societies. These insights draw on current literature, evaluation studies, and emerging practices from across sectors and regions.

The first set of recommendations focuses on improving the way impact is assessed and understood.

4.6.1 Recommendations for assessing the impact of climate services

Robust evaluation is widely recognised as the foundation for improving both the design and the uptake of CS. Yet, as highlighted in the previous sections, current practices often fall short of capturing the complex, context-specific ways in which services influence decisions and outcomes. To address this gap, recommendations for assessment need to prioritise methods that are adaptable, inclusive, and grounded in real-world decision contexts.

Promote flexible, user-oriented evaluation frameworks

Impact assessment in CS should adopt flexible and user-centred evaluation frameworks that are responsive to different contexts and types of services. Widespread used top-down approaches often fail to capture the nuances of how climate information is interpreted and applied by different users.

Instead, evaluation frameworks should reflect the co-production process, diversity of user needs, and local decision contexts. As Vaughan and Dessai (2014) note, frameworks that integrate institutional, social, and behavioural dimensions of service use are more effective in identifying barriers and enablers of impact. Furthermore, Englund *et al.* (2022) argue for the importance of adapting evaluation models over time, as relationships evolve and service use matures, supporting iterative learning and long-term relevance.

Encourage adoption of standard yet adaptable indicators

To support consistent and credible assessment across services, it is important to define core indicators while allowing for contextual adaptation. These indicators can be grouped into categories such as process quality, relevance, uptake, behavioural change, and observed outcomes. However, overly rigid metrics may fail to capture non-linear or indirect impacts, especially in complex decision-making environments. Wall, Meadow, and Horganic (2017) recommend balancing standardisation with the flexibility to incorporate sector-specific or place-based indicators. A modular approach to indicator development allows for comparability across services while ensuring that unique aspects of a programme's design and delivery are properly reflected.

Embed evaluation mechanisms from the early design stages

Integrating evaluation from the outset of a climate service initiative helps ensure that data on impact pathways is collected systematically and that the service is built with accountability and learning in

mind. When evaluation is treated as an afterthought, opportunities to document progress, identify bottlenecks, or adapt to feedback are often missed. Bamzai-Dodson *et al.* (2022) stress the value of planning for impact assessment during the service design phase, including stakeholder consultations to co-define success criteria and anticipated outcomes. Embedding evaluation also facilitates the use of baseline data, counterfactual comparisons, and the early identification of unintended effects.

Use participatory methods to capture user experience and value

Participatory evaluation approaches are essential to understand how users perceive and engage with CS. These methods provide qualitative insights into perceived usefulness, trust, relevance, and the enabling or constraining factors influencing uptake. Tools such as outcome mapping, Most Significant Change, and participatory scenario analysis allow service developers and users to reflect jointly on what has changed and why. As Englund *et al.* (2022) highlight, participatory methods also strengthen accountability and ownership, particularly in contexts where formal data is limited or where service use is highly context-dependent. These approaches are especially important for capturing intangible or long-term value, such as enhanced decision confidence or strengthened networks.

Share results and lessons learned openly across the sector

Creating a culture of openness and shared learning is critical to advancing CS as a field. Evaluation findings—whether positive, negative, or mixed—should be made accessible through peer-reviewed publications, grey literature, and practitioner networks. This openness can prevent duplication of effort, inform new initiatives, and support capacity-building. Visman *et al.* (2022) argue that sharing monitoring and evaluation approaches is just as important as sharing outcomes, as it fosters methodological innovation and coherence. Knowledge-sharing mechanisms such as online repositories, policy briefs, and cross-institutional learning events can help disseminate good practices and strengthen impact across the sector.

Recommendations for assessing the impact of Climate Services

- *Promote flexible, user-oriented evaluation frameworks*
- *Encourage adoption of standard yet adaptable indicators*
- *Embed evaluation mechanisms from the early design stages*
- *Use participatory methods to capture user experience and value*
- *Share results and lessons learned openly across the sector*

Figure 8: Summary of Recommendations for assessing the impact of Climate Service

4.6.2 Recommendations for increasing the impact of climate services

Enhancing the impact of CS goes beyond improving how they are assessed; it requires ensuring that services are genuinely usable and embedded in decision-making processes. Even the most advanced tools will have limited effect if they are not co-created with users, aligned with policy priorities, or communicated in ways that support practical action. Strengthening impact therefore calls for approaches that build trust, foster collaboration, and translate scientific insights into decisions that matter. The recommendations below outline key strategies to achieve this.

Prioritise co-production and long-term stakeholder engagement

Co-production, involving stakeholders from the earliest stages through to implementation, is fundamental for creating CS that truly meet user needs. Long-term engagement builds trust, ensures relevance, and fosters mutual learning. As Kruk *et al.* (2017) highlight, sustained interaction supports iterative refinement of climate products, making them more actionable and usable. Furthermore, Tall *et al.* (2010) emphasise that engagement beyond one-off consultations promotes stronger institutional relationships and enhances service legitimacy.

Ensure services align with operational and policy needs

CS should be designed with clear understanding of the operational contexts and policy frameworks they intend to support. Alignment with decision-making processes ensures that outputs are actionable and timely. Vaughan and Dessai (2014) argue that tailoring services to end-users' workflows increases their integration into planning and response activities, thereby enhancing impact. This requires ongoing dialogue with both technical users and policymakers to translate scientific data into usable formats.

Invest in communication, visualisation, and capacity building

Effective communication and visualisation tools are crucial to bridge the gap between complex climate data and decision-makers' needs. As Daron *et al.* (2015) demonstrate, appropriately designed graphs and charts can significantly improve users' comprehension and confidence in interpreting climate information. Additionally, capacity building through training and co-learning workshops empowers users to interpret and apply data effectively, which is vital for sustained impact (Dilling *et al.*, 2015).

Foster institutional coordination and system integration

Fragmentation among climate service providers and related institutions can undermine service delivery. Coordinated efforts that integrate data, expertise, and resources across agencies and sectors help create coherent service ecosystems. According to Hulme (2011), system integration enhances efficiency and reduces duplication, while institutional coordination supports shared goals and governance structures necessary for scaling impact.

Leverage innovation and technology to reach under-served users

Adopting innovative technologies such as mobile platforms, cloud computing, and AI-driven analytics can expand the reach and accessibility of CS, especially to under-served and remote communities. This approach aligns with the recommendations by Buontempo *et al.* (2019), who emphasize the potential of emerging technologies to tailor services for diverse user groups and improve responsiveness. Technology-enabled feedback loops also facilitate real-time user engagement and continuous improvement.

Recommendations for increasing the impact of Climate Services

- *Prioritise co-production and long-term stakeholder engagement*
- *Ensure services align with operational and policy needs*
- *Invest in communication, visualisation, and capacity building*
- *Foster institutional coordination and system integration*
- *Leverage innovation and technology to reach under-served users*

Figure 9: Summary of Recommendations for increasing the impact of Climate Services

This section has examined how to assess and increase the impact of CS, underscoring the central role of user engagement, flexible evaluation, and institutional alignment. A key insight emerging from the literature is the need to move beyond simply measuring outputs to understanding how climate information is interpreted, applied, and embedded in decision-making processes that drive adaptation, resilience, and mitigation outcomes.

CS create value when they inform or influence real-world decisions—whether by shifting behaviours, guiding investments, improving policy frameworks, or reducing climate-related losses. As such, impact should be understood as multidimensional and context-dependent, encompassing social, economic, environmental, behavioural, and policy-related change. Impacts also differ across timescales and geographies: while some effects (e.g. improved disaster response) are immediate and observable, others (e.g. ecosystem restoration or institutional learning) unfold over longer periods and require sustained monitoring.

A recurring theme throughout this section is the need for a **dual focus on robust assessment and meaningful improvement**. Measuring impact is essential for accountability, learning, and strategic alignment—but without a parallel effort to enhance the relevance, usability, and uptake of services, evaluation alone is insufficient. Similarly, improving CS without understanding what works, for whom, and under what conditions risks producing technically sound but underutilised outputs.

Robust impact assessment requires a mix of methods, including both quantitative indicators (e.g. avoided costs, improved yields) and qualitative insights (e.g. user trust, perceived usefulness). However, current practices often fall short due to methodological complexity, attribution difficulties, data gaps, and the absence of standardised indicators. To address these limitations, there is a need for adaptive, user-centred evaluation frameworks that capture both direct and indirect effects, as well as tangible and intangible outcomes.

Equally important is the process of **increasing impact through co-production, stakeholder engagement, and institutional alignment.** CS designed in collaboration with users are more likely to be trusted, actionable, and sustained. Ensuring that services align with policy cycles, decision-making contexts, and communication needs enhances their salience and integration. Strategic investments in communication tools, capacity building, and institutional coordination are key enablers of impact—particularly when targeting under-served communities or complex multi-sector challenges.

Ultimately, building a **shared understanding of impact** across the CS community is critical. This requires a cultural shift towards open sharing of evaluation methods and results, embracing both successes and limitations. Such transparency will support collective learning, strengthen credibility, and guide future

innovation in the field. By recognising impact as both a process and an outcome, the CS community can more effectively demonstrate its value and contribute to a more climate-resilient society.

5. Refined and ranked catalogue of best practices and malpractices

5.1 eDelphi Results

The statistical evaluation of the eDelphi survey on best practices and malpractices is shown in the below Tables 1 and 2. The green shaded cells indicate where consensus among experts was reached, as defined in section 3.2. All best practices and malpractices achieve 75% agreement around the mean, indicating a generally good consensus among stakeholders. Almost all of them achieved the other statistical goals of standard deviation (SD <1.5) or interquartile range (IQR <2.5), which impacts the ranking of best practices and malpractices. All but one achieved the goal of a mean of 8 or higher (Boon *et al.*, 2024).

Table 4: Statistical evaluation of eDelphi on most beneficial best practices

	Promoting internal upskilling of staff and/or having technically skilled staff in the organisation	Linking local/in situ data with large climate models	Knowledge sharing and cross-sector collaboration	Integrating user feedback at every step of CS development	Making CS so user-friendly that users do not require technical skills to use them	Following/using standards to generate trust
Standard Deviation (goal <1.5)	1.30	1.20	1.10	1.60	1.74	1.48
Mean (goal >8)	9	8	9	8	8	8
Median	9	8	9	9	9	9
Agreement around mean (goal >75%)	83%	93%	90%	93%	86%	86%
Q3	10	9	10	10	10	10
Q1	8	8	8	8	7	8
IQR (goal <2.5)	2.0	1.0	2.0	2.0	3.0	2.0

Figure 10: Best Practices ranked by their perceived benefit to the CS market

Table 5: Statistical Evaluation of eDelphi on most detrimental malpractices

	Datasets too big to process, too complex to understand	Misleading data presentation negatively influencing their interpretation	Lack of common understanding of CS and their usefulness	Investment in CS not seen as justified	Little to no communication with CS providers, no feedback exchanged	Bad science communication within or from the science community	User-centric CS approach not prioritised	Reluctancy to pay for standards
Standard Deviation (goal <1.5)	2.18	0.91	1.74	1.86	1.53	1.39	1.68	1.99
Mean (goal >8)	8	9	8	8	8	8	8	7
Median	8	9	8	8	9	8	8	8
Agreement around mean (goal >75%)	76%	93%	83%	86%	86%	90%	90%	76%
Q3	10	10	9	10	9	9	10	9
Q1	7	8	7	7	7	8	7	6
IQR (goal <2.5)	3.0	2.0	2.0	2.8	2.0	1.0	3.0	3.0

Malpractices ranked by their perceived detriment on the CS market:

1. *Misleading data presentation negatively influencing their interpretation (very good consensus)*

2. *Bad science communication within or from the science community (very good consensus)*

3. *Little to no communication with CS providers, no feedback exchanged (very good consensus)*

4. *User-centric CS approach not prioritized (weaker consensus)*

5. *Lack of common understanding of CS and their usefulness (weaker consensus)*

6. *Investment in CS not seen as justified (weaker consensus)*

7. *Reluctancy to pay for standards (very weak consensus)*

8. *Datasets too big to process, too complex to understand (very weak consensus)*

Figure 11: Malpractices ranked by their perceived detriment on the CS market

The survey therefore indicates a **ranking** of most beneficial best practices (Figure 10) and most detrimental malpractices (Figure 11). This ranking is based on both the numerical value given to the practices as well as the level of consensus reached among the stakeholders (see the above tables 4 and 5).

5.2 Discussion of eDelphi Results

The above results and subsequent ranking of best practices and malpractices reveal several aspects about the stakeholder perception of the CS market. Generally, there was more and higher consensus around the best practices than the malpractices. Additionally, some discussion points emerged:

1. The promotion of **upskilling in CS user communities** is accepted as a best practice with very good consensus. This highlights the need for capacity building and awareness raising in CS user communities. Similarly, making budgets available within end user communities to hire technically skilled and/or experienced staff is crucial to bring this best practice into the operational management of end user organisations. This is often also tied to political will and largely driven by individuals with the passion to put this work on their organisation's agenda. This relates to the **investment in CS not being seen as justified** as a detrimental malpractice, albeit this was ranked with weaker consensus.

2. Notably, the **inclusion of CS user feedback at every step of the development** of the CS is a best practice that is accepted with only weaker consensus. This is contrasted by the **lack of communication or feedback exchange** between CS user and provider being accepted with very good consensus as a highly detrimental malpractice. This indicates a need to re-think the entire CS design and development process to be more inclusive and more representative of end user needs.

3. The **communication gap** between science (i.e. providers) and users is accepted with very good consensus as a highly detrimental malpractice and mirroring this ranking, **knowledge sharing and cross-sector collaboration** was ranked as a highly beneficial best practice with very good consensus. These results highlight the need for increased collaboration across sectors, which can help with fostering better communication skills within the scientific community. Cross-sectoral, collaborative and cooperative new ways of working would benefit the CS market on both the provider and user side.

4. Notably, the malpractice that refers to the impact of **standardisation** was ranked with the lowest average score and received lower rankings with generally weaker consensus among stakeholders. The best practice related to standardisation, however, was ranked higher with good consensus. This result can be interpreted in different ways and may be explained by a multitude of reasons. For one, the low ranking may reflect limited stakeholder awareness or engagement with the concept of standardisation and/or existing CS standards, suggesting a gap between standard development and user/provider uptake. On the provider side, the absence of regulatory or financial incentives to adopt these standards may have contributed to their low perceived impact on the CS market. The technical complexity or resource burden associated with implementing these standards may have discouraged uptake among stakeholders. Similarly, organisational inertia or resistance to standardisation may have also influenced how this best practice and malpractice was ranked. This mirrors what stakeholders mentioned about standardisation during the D4.3 interviews: there is generally an interest in standardisation (supported by it being recognised as a best practice), but financial or operational factors often hinder the adoption of standards. These findings suggest a need for targeted communication, capacity building, and clearer value propositions around underutilised standards to enhance their role in shaping a robust CS market.

Due to time constraints, and comparably high consensus having been reached in round 1 (i.e. at least 75% consensus around mean for all best practices and malpractices), the decision was made not to conduct a second round of eDelphi.

5.3 Recommendations based on eDelphi Results

The eDelphi results, while not wholly representative of the CS market, as noted in Section 3.3, give a general insight into the best practices and malpractices that are seen as influential by CS market participants and experts on the CS market.

Based on these results and the above discussion, a set of recommendations that are **backed by high stakeholder consensus** for the success of the CS market can be issued here (see Figure 12).

These recommendations are largely supported by the findings of Chapter 4 on the assessment and increase of Climate Service Impact. It follows therefore that aligning with those recommendations that promote best practices and avoid malpractices would also lead to an increase of CS impact. All recommendations issued in this report are summarised in Figure 15.

Recommended best practices for the Climate Services Market

- *The upskilling of internal staff on the user-side, as well as the support of this upskilling on the provider side.*

- *A collaborative and open knowledge-sharing approach between providers and users of CS.*

- *Centering the user in the CS development process and setting up recurring feedback mechanisms between user and provider.*

- *To avoid misunderstandings and misinterpretation, ensure clear documentation, metadata, and/or data labelling to support correct interpretation of CS data on the user side.*

- *Facilitate better science communication both within the scientific community and from the scientific community towards end users.*

- *Better communication around the usefulness of standards for the CS market.*

Figure 12: Stakeholder consensus-backed recommended best practices for the CS market

6. Foresight of demand evolutions and market developments

This section explores demand trends for CS and outlines key market developments based on the analysis of relevant literature on the CS market.

Key sectors driving demand

CS uptake is most advanced in economic sectors that are more directly affected by the impacts of climate hazards. Sectors prioritised by the Global Framework for Climate Services (GFCS) namely agriculture and food security, disaster risk reduction, energy, health, and water tend to have more readily-available information on how CS can be applied within the sectors, and what the drawbacks to using them are (State of Climate services 2024, WMO). The strongest users of CS are typically the sectors that are exposed to climate variability and extremes and required to make medium- to long-term planning decisions involving significant investment. Agriculture is typically highly dependent on rainfall patterns and temperature extremes and is a high priority area for research and development within CS as shown in Figure 13.
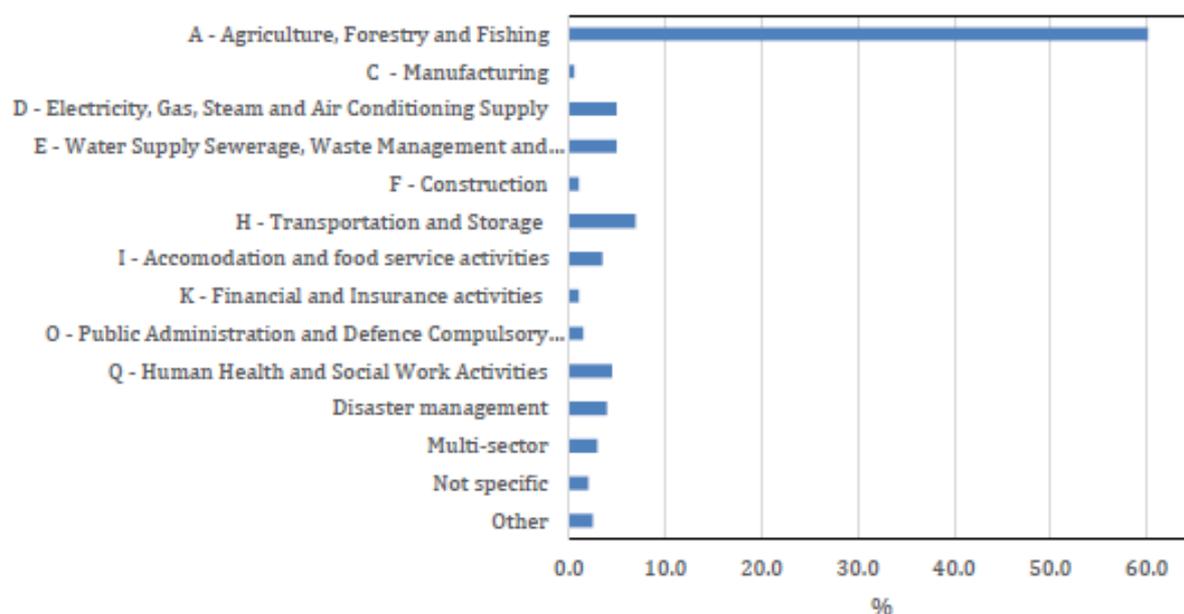
Figure 13: Sectors covered by studies on evaluation of Climate service/information Source: Climateurope2 D3.1 (2024)

Additionally, the demand for CS in urban planning is steadily increasing. Cities are actively seeking tailored CS to support the development of resilient infrastructure and robust adaptation plans. Integrating climate adaptation comprehensively into municipal planning not only enhances resilience but also unlocks multiple co-benefits combining adaptation, mitigation, and sustainable urban development (REACHOUT Project, 2023) (Raffaele Giordano, 2020) (Rob Swart, 2021).

Types of CS in demand

Surveys conducted under the MARCO project (Tart *et al.* 2020) reveal that users most commonly rely on annual climate data, followed closely by seasonal, sub-seasonal, and historical observational data. In contrast, the use of longer-term climate projections is significantly lower. They highlight that stakeholders across sectors tend to show a stronger interest in short-term climate and weather services, as they perceive historical observational data as more reliable and actionable than long-term future projections

User expectations and usage patterns

CS are in demand across a broad spectrum of users, including universities, NGOs, international organisations, governmental bodies, and private-sector companies. This diversity reflects the growing relevance of climate information in both policy and operational decision-making environments.

According to findings from the MARCO project, CS are most often used to support strategic decision-making, and also for applications in social and non-financial benefits, and risk management. This indicates that users perceive more value in CS to shape long-term resilience strategy rather than just responding to short-term risks. Improving data quality was highlighted as the top priority to enhance CS, followed closely by improvements in the design and functionality of services and products (Tart, 2016). These preferences highlight the critical importance of reliable and user-centred CS delivery.

Many studies have explored how the quality of climate data can influence user perceptions on the CS value. Hill and Mjelde (2002) identified several critical elements that affect forecast use and value,

including accuracy, lead time, specificity, spatial resolution, and the way weather parameters are reported. Tart *et al*. (2020), Msemo *et al*. (2021), and Frei *et al*. (2014) emphasise that the value of CS depends heavily on the accuracy, reliability, and consistency of the data provided. Frei *et al*. (2014) and Tart *et al*. (2020) highlight the importance of ensuring that spatial, location- and temporal resolutions are appropriate for making robust decisions. As a result, high-resolution and location-specific information is essential.

6.1 Key drivers of demand growth

The demand for CS is driven by growing external pressures, mainly policies, regulations and higher awareness on climate change impacts.

- The increased frequency of extreme weather events including floods, droughts, heatwaves, and wildfires is pushing public and private stakeholders to leverage CS for risk reduction. The World Meteorological Organisation (WMO) has highlighted that the demand for CS has never been higher, particularly in regions affected by extreme weather events (WMO, 2024).

- Regulatory frameworks such as the Corporate Sustainability Reporting Directive (CSRD) or the Task Force on Climate-related Financial Disclosures (TCFD) do not directly require the use of CS but create strong incentives for organisations to rely on climate data, projections, and analytical tools. Meeting these disclosure requirements often necessitates the use of CS to assess physical and transition risks, model future scenarios, and inform strategy. For example, TCFD provides a globally recognised framework for integrating climate risk into financial and governance decisions, adopted by national regulators and private institutions (TCFD, 2017).

6.2 Market developments - Digital tools to innovate CS delivery

Climate service providers are increasingly offering interactive platforms, dashboards, and educational interfaces that serve diverse user needs. For example, climate dashboards are increasingly developed (e.g., NOAA's Climate.gov and COCLICO) showing temperature trends, CO_2 concentrations, El Niño indices, etc. Another example is the City Hub framework, developed in the project REACHOUT for urban self-assessment. It helps cities evaluate their adaptation capacities, identify gaps, and track progress. It also supports the institutionalisation of CS by integrating them into local governance cycles, highlighting a growing niche for place-based services tailored to specific governance and social contexts (REACHOUT D4.2, 2024). This shift toward multi-functional platforms highlights a broader trend: CS are evolving from simply providing raw data to offering practical, decision-ready tools that support adaptation planning, risk management, and investment decisions.

These findings align with the three main market trends identified by Matthies and Ramirez (2024) for Climateurope2 Deliverable 4.3 (Figure 14). The Figure also includes the influence of Artificial Intelligence and other new and emerging technologies, which are identified as key market developments in this report.
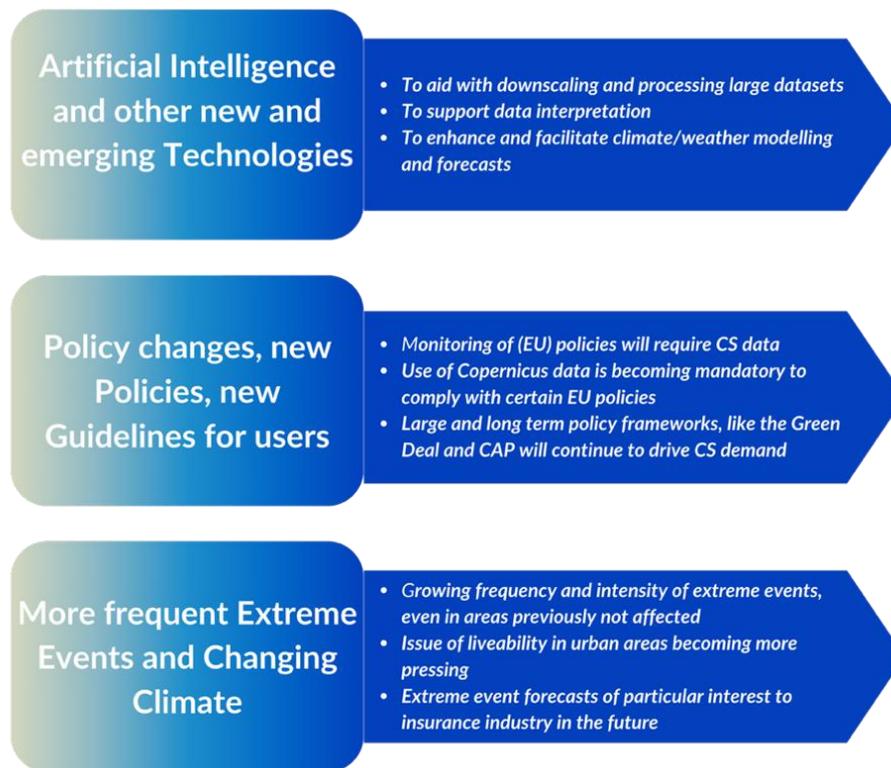
Figure 14: Market Trends identified in Deliverable 4.3 (Matthies and Ramirez, 2024)

Market facilitating and stimulating services for CS (linked with Climateurope2 D4.7)

The CS market traditionally refers to the ecosystem of providers, users, and intermediaries involved in the development, delivery, and use of CS. In WP4 the definition is expanded to include the market stimulating and market facilitating services that help increase the interest, visibility, and expertise of CS. These actors don't typically deliver end-user services directly but play a crucial role in sustaining the CS ecosystem by facilitating the development and visibility of CS, providing funding, standards, capacity-building and knowledge sharing opportunities. While the CS market is expanding, several challenges remain including:

- The accessibility and awareness of CS: Many potential users (businesses, policymakers, municipalities) are unaware of available CS or do not understand how to integrate them into decision-making.
- The mismatch between users' needs and the service: Climate information is often too technical and complex for non-experts to use effectively, or the information provided often does not match users' needs. Bridging this gap will require a more thorough understanding of the demands of users (Maurice, 2017).
- Lack of common standards and terms making it difficult for users to compare and trust CS.
- Limited economic viability of CS: Many CS rely on public funding and grants, making long-term financial sustainability a challenge. More funds need to be allocated for chartering the "last mile" of CS (Hermansen, 2021)

7. Conclusion and Summary

This report provides a cohesive assessment of the current state of the CS market, consisting of insights gained from an eDelphi study with key CS market actors as well as an in-depth analysis of the relevant scientific publications on the topic of CS impact assessment and increase.

An updated, ranked, catalogue of best practices and malpractices was provided and summarised (Fig. 2), along with recommendations for increasing and assessing the impact of CS (Chapter 4). Additionally, the key trends and drivers that will steer the demand for CS in the future and therefore have significant influence on the market as a whole, were identified and presented.

The full set of recommendations issued in this report is summarised in Figure 15.

Summary of Recommendations issued in D4.6

Recommendations for assessing the impact of Climate Services

- *Promote flexible, user-oriented evaluation frameworks*
- *Encourage adoption of standard yet adaptable indicators*
- *Embed evaluation mechanisms from the early design stages*
- *Use participatory methods to capture user experience and value*
- *Share results and lessons learned openly across the sector*

Recommendations for increasing the impact of Climate Services

- *Prioritise co-production and long-term stakeholder engagement*
- *Ensure services align with operational and policy needs*
- *Invest in communication, visualisation, and capacity building*
- *Foster institutional coordination and system integration*
- *Leverage innovation and technology to reach under-served users*

Recommended best practices for the Climate Services Market

- *The upskilling of internal staff on the user-side, as well as the support of this upskilling on the provider side.*
- *A collaborative and open knowledge-sharing approach between providers and users of CS.*
- *Centering the user in the CS development process and setting up recurring feedback mechanisms between user and provider.*
- *To avoid misunderstandings and misinterpretation, ensure clear documentation, metadata, and/or data labelling to support correct interpretation of CS data on the user side.*
- *Facilitate better science communication both within the scientific community and from the scientific community towards end users.*
- *Better communication around the usefulness of standards for the CS market.*

Figure 15: Summary of Recommendations issued in D4.6

7.1 Next steps

As this report marks the second iteration in a recurring series of deliverables, the recommendations and the catalogue presented here will be updated once more to include the final set of recommendations (June 2026). The aim is to build on the knowledge base that was built up for this and the previous report, as well as the network of contacts within the CS market that were established and grown during the interview and eDelphi process. The final iteration will also build up on the extensive literature analysis conducted for this report.

8. Bibliography

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9. Annex

9.1 eDelphi Survey

Climateurope2 eDelphi questionnaire

Dear Participant,

Thank you for taking part in this eDelphi questionnaire.

The questionnaire should not take more than 15 minutes and is ideally done without consulting additional materials or resources. Your response is submitted **anonymously**, without the collection of any personal data, and we are grateful to you for being as honest as possible in your ranking.

In the context of the Climateurope2 project, Climate Services (CS) are defined as involving the *generation, provision, and contextualisation of information and knowledge derived from climate research for decision making at all levels of society*. The project is interested in identifying the key best practices and most detrimental malpractices prevalent in the CS market to then issue recommendations available to all participants in the market. This way, the project aims to support the development of a more equitable CS market.

Please rank the impact of the Best Practices and Malpractices listed below — identified through expert interviews conducted previously — on the delivery and implementation of climate services, using a scale from 1 to 10.

For any questions, please do not hesitate to contact us:

antonia.matthies@climate-kic.org or kevin.ramirez@climate-kic.org

We thank you for your participation.

Best wishes,

The Climate KIC Climateurope2 team

* Indicates required question

Which category do you best fit in? *

○ User of Climate Services

○ Provider of Climate Services

○ Expert with knowledge of the Climate Services market (not an active participant in the market)

○ Other: _____

Best Practices
How important is the listed Best Practice for the success of a Climate Service?

Promoting internal upskilling of staff and/or having technically skilled staff in the organisation *

1 2 3 4 5 6 7 8 9 10

not important ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ very important

Linking local/in situ data with large climate models *

1 2 3 4 5 6 7 8 9 10

not important ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ very important

Knowledge sharing and cross-sector collaboration *

1 2 3 4 5 6 7 8 9 10

not important ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ very important

Integrating user feedback at every step of CS development *

1 2 3 4 5 6 7 8 9 10

not important ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ very important

Making CS so user-friendly that users do not require technical skills to use them *

1 2 3 4 5 6 7 8 9 10

not important ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ very important

Following/using standards to generate trust *

1 2 3 4 5 6 7 8 9 10

not important ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ very important