



Original paper

User Perspectives on the management of climate products and services in South-East Europe: An exploratory analysis

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ABSTRACT

This exploratory study examines key challenges in managing climate data in South-East Europe (SEE)—a region of high climate vulnerability and institutional fragmentation. Based on survey responses from 81 organizations, it reveals major disparities in access, understanding, and use of climate information services (CIS). Over half of respondents use CIS products, yet many cite barriers such as limited accessibility, unclear communication, lack of user-centered design, and weak institutional support. Most data come from public meteorological agencies, but users report mismatches between data resolution and operational needs, emphasizing daily to seasonal data at local and regional scales. Significant gaps persist between existing CIS products and the needs of NGOs and local authorities. Users value CIS for research, monitoring, and education, while seeking better interpretability, integration of local knowledge, and actionable insights. The study calls for participatory, user-centered CIS design, stronger stakeholder coordination, and AI-supported approaches to enhance usability and support equitable climate adaptation across SEE.

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INTRODUCTION

Effective management of climate data is critical for informing policy decisions, guiding adaptation strategies, and supporting sustainable development. End users, ranging from government agencies and NGOs to private-sector actors and community groups, rely on a variety of climate products and services to plan operations, assess risks, and communicate findings. Access to climate products and services is usually provided with climate information services (CIS).

In South-East Europe (SEE), rapid socioeconomic change, diverse geographic conditions,

and the legacy of centralized data infrastructures present unique challenges for end users seeking timely, relevant, and actionable climate information (Milovanović et al., 2021). Despite a growing array of global, regional, national and sectoral providers delivering climate indices (e.g., average temperature, number of hot days) and specialized services (e.g., thermal comfort indices, seasonal forecasts), gaps remain in usability, accessibility, and integration across temporal and spatial scales (Radonić et al., 2020). Although SEE possesses meteorological monitoring and modeling capacities, the translation of raw climate data into end-user-oriented products often falls short of user needs. Paparrizos et al. (2025) note that although 37 WCIS providers have been identified

across Southeast Europe, these services remain at a low level of development, with limited coverage and immature operational frameworks. They highlight key issues, including fragmented funding streams, lack of standardized data integration, insufficient user-centred design, minimal private-sector engagement, and low accessibility for vulnerable end-users. In addition, key issues usually include overlapping of multiple providers offers, thus complicating user's efforts to compare and integrate information. Temporal resolutions (hourly, daily, decadal) and spatial coverages (local, regional, national) may not align with organizational requirements of the user (Milovanović et al., 2021).

In addition, costs, licensing restrictions, and technical prerequisites deter smaller organisations and NGOs from fully utilizing available services (Bijelić & Rajaković, 2021). Technical terminology, lack of tailored guidance, and limited human-centered interface reduce the interpretability of climate outputs (Radonić et al., 2020). Many end users lack dedicated personnel or departments responsible for climate change, undermining systematic data adoption. Managers often struggle to integrate climate data into broader institutional planning, resulting in ad hoc or siloed decision-making processes (Bijelić & Rajaković, 2021).

This study addresses the following research question: What are the key institutional, technical, and communication challenges affecting the management and use of climate data among end users in South-East Europe? Through an exploratory survey and review of relevant literature, we offer insights into end-user experiences, identify barriers to data adoption, and discuss implications for more inclusive and responsive climate information systems in the region.

THEORETICAL BACKGROUND

Climate Information services and end-user engagement

CIS has undergone significant transformation, evolving from rudimentary weather forecasts to complex, multi-faceted systems that support climate adaptation and resilience, particularly in vulnerable regions, such as Sub-Saharan Africa. Initial CIS models focused on information dissemination, whereas contemporary approaches emphasize participatory frameworks, diversified communication

channels (e.g., SMS, radio, mobile apps), and institutional integration with local governance to strengthen decision-making in agriculture, water management, and disaster risk reduction (Ouédraogo et al., 2018; Kayusi et al., 2024; Madhuri, 2025). This evolution has been accelerated since 2010 by increasing climate finance and the growing recognition of CIS as instrumental in achieving sustainable development objectives (Kayusi et al., 2024; Madhuri, 2025).

Nowdays, user-centered design is widely acknowledged as a cornerstone for effective CIS. Systems that identify and respond to the specific needs, socio-cultural contexts, and technological capacities of varied user groups, including farmers, local authorities, and policy actors, are more likely to yield impactful outcomes (Guido et al., 2020; Wilby & Lu, 2022). Participatory methodologies such as stakeholder consultations, field demonstrations, and co-design workshops have proven crucial in adapting CIS products and delivery mechanisms to ensure their salience and usability (Ouédraogo et al., 2018; Guido et al., 2020; Wilby & Lu, 2022). Moreover, the inherently dynamic nature of environmental and user conditions necessitates adaptable and flexible design (Guido et al., 2020). Co-production is often promoted as a guiding principle for involving non-scientists as active collaborators in shaping, funding, and using knowledge (Lövbrand, 2011).

Despite growing availability, the adoption of CIS remains uneven across various stakeholder groups. In the public administration domain, barriers include limited institutional capacity, inadequate policy integration, and infrastructural deficits that hinder data dissemination (Kayusi et al., 2024; Ouédraogo et al., 2018). NGOs often face resource constraints and technical limitations, particularly in extending services to marginalized communities (Carr et al., 2020). The private sector encounters challenges such as ambiguous value propositions, lack of financial incentives, and minimal involvement in CIS co-creation (Ouédraogo et al., 2018; Kayusi et al., 2024). Additionally, common systemic barriers span untimely or unreliable data, trust deficits, gender disparities, limited awareness, and entrenched reliance on traditional practices (Savari et al., 2023; Warner et al., 2022; Gouroubera et al., 2023; Diallo & Dossou-Yovo, 2024).

Several interrelated factors influence CIS engagement. Trust in the credibility and intentions of CIS providers significantly determines user uptake.

Building this trust requires the delivery of accurate, timely, and context-sensitive information, reinforced by transparent and responsive communication channels (Muema et al., 2018; Warner et al., 2022; Savari et al., 2024; Ngigi & Muange, 2022). Accessibility through multi-modal dissemination, radio, SMS, mobile apps, and extension services is critical in reaching heterogeneous user populations (e.g., specific marginalized groups, aged people, etc.), who may face additional structural barriers (Gouroubera et al., 2023; Muema et al., 2018). Communicating clearly climate data in locally relevant, easily understandable formats, often in local languages, enhances user comprehension and practical application (Madhuri, 2023; Chavula & Kayusi, 2025). Finally, cultural adaptation is also an important factor. Effective CIS respect and integrate indigenous knowledge systems and cultural practices, making the services more resonant and actionable for diverse user communities (Guido et al., 2020; Wilby & Lu, 2022; Pappazizos et al., 2025). Therefore, the evolution of CIS reflects a broader paradigm shift towards user-centred, participatory, and locally contextualized approaches. Addressing uptake barriers and enhancing user engagement necessitates not only robust system design and communication strategies, but also sustained trust-building, inclusive accessibility, and cultural sensitivity.

Regional disparities and institutional capacities in climate information system use

Regional disparities and institutional capacities significantly shape the use and effectiveness of CIS in South-East Europe. The region faces unique challenges due to its high sensitivity to climate change, yet climate action and data utilization remain uneven and fragmented.

There is a pronounced West-East divide in climate mitigation planning across Mediterranean Europe, including SEE. Regions and cities in the east often lag behind their western counterparts in both the availability and ambition of climate mitigation plans. This fragmentation is not fully explained by shared environmental or socio-economic characteristics, suggesting that other factors, such as institutional capacity and access to resources play a critical role (Salvia et al., 2021; Garcia-Leon et al., 2024).

The lack of strong institutional support hinders the ability of local actors to effectively use climate data for planning and adaptation (Salvia et al., 2021).

Furthermore, disparities in research participation and collaboration are evident, with Southern and Central & Eastern European researchers facing challenges in accessing funding, building interdisciplinary networks, and integrating social sciences with STEM disciplines. These institutional barriers limit the region's capacity to generate and apply local-specific climate knowledge (Foulds et al., 2023).

Regional disparities in CIS use and institutional capacity exacerbate vulnerabilities. For example, southern regions of Europe, including South-East Europe, are projected to experience a marked increase in heat-related mortality due to climate change. The lack of robust institutional mechanisms to interpret and act on climate data further widens these disparities, making adaptation and resilience-building more difficult in the most affected areas (Garcia-Leon et al., 2024; Iglesias et al., 2012).

Transnational climate networks have emerged as important drivers for enhancing commitment and ambition, especially at the regional level. Strengthening these networks, fostering interdisciplinary collaboration, and building institutional capacities are critical steps toward reducing disparities and improving the use of climate data in South-East Europe. A coordinated regional approach, such as a Mediterranean Green Deal, could help capitalize on shared resources, generate local knowledge, and support more ambitious and effective climate action (Salvia et al., 2021; Foulds et al., 2023).

METHODOLOGY

As a key component of this study, a survey targeting relevant institutions was conducted between November and December 2024. The survey design was informed by established international and European frameworks and initiatives aimed at advancing climate services and user-oriented climate data interfaces across sectors (following Falcescu et al., 2024). The sample was derived from the ClearClimate project's stakeholder mapping database (clearclimate.com), which provided a comprehensive overview of both service providers and prospective users. Respondents were categorized according to their field of activity, and representatives from diverse sectors were purposefully selected to ensure broad stakeholder representation. Invitations were distributed to more than 150 contacts, yielding 81 responses from Serbia, Romania, North Macedonia, Bosnia and Herzegovina, Slovenia, Greece, Croatia,

Montenegro, Albania, Hungary, and Italy. The survey was administered in English and Serbian. Responses submitted in Serbian were translated into English, and both datasets were subsequently integrated for statistical analysis.

RESULTS

Geographic coverage

Figure 1 illustrates the geographical distribution of surveyed organisations, revealing notable variation in national representation. Serbia accounted for the highest number of responses ($n = 37$), reflecting strong engagement. Bosnia and Herzegovina followed with 11 participants, and a moderate level of involvement. Moderate representation was also observed in Romania ($n = 8$), Greece ($n = 6$), North Macedonia ($n = 5$), and Slovenia ($n = 5$). In contrast, Albania ($n = 3$) and Croatia ($n = 4$), showed lower levels of participation, while Montenegro, Hungary and Italy were the least represented, each with a single respondent.

Diverse regional representation reflects a broad geographical engagement, while underscoring a concentration of responses from Serbia and its neighboring countries. Observed distribution is capturing region-specific perspectives and contributes

to a balanced and contextually grounded understanding of the issues explored in the study.

As shown in Figure 2, most respondents were affiliated with public administration, research and education, socio-economic development, forestry and environmental protection, and agriculture and biodiversity. Public administration and research and education were the most represented sectors (each with over 35 participants), reflecting their central role in knowledge production and climate-related decision-making, followed by socio-economic development (around 30 respondents), highlighting its relevance to sustainable growth. Fewer responses were recorded from forestry, environmental protection, agriculture, and biodiversity, indicating a need for broader engagement with these sectors.

Type of organization

The respondents were grouped into five organizational types, with non-governmental organizations (NGOs) forming the largest cluster (over 25), indicating strong engagement, particularly in advocacy or environmental work (Figure 3). Public administration was the second most represented group, followed by private-public entities, while

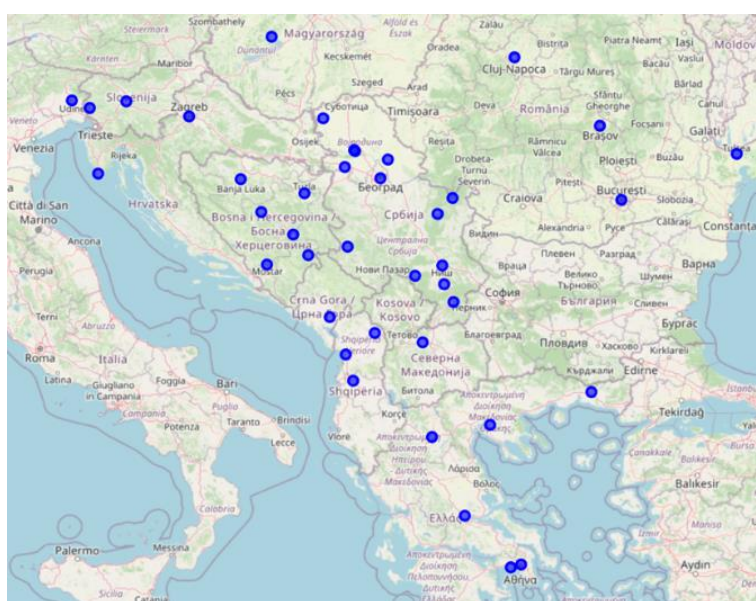


Figure 1. Geographical coverage of surveyed organizations (Source: Authors' own contribution, 2025)

universities and research institutions had the lowest representation, suggesting limited academic participation in the surveyed domain.

The smallest cluster, comprising scientific research organizations, indicates limited

market development and reveals notable disparities in user uptake across sectors, indicating uneven

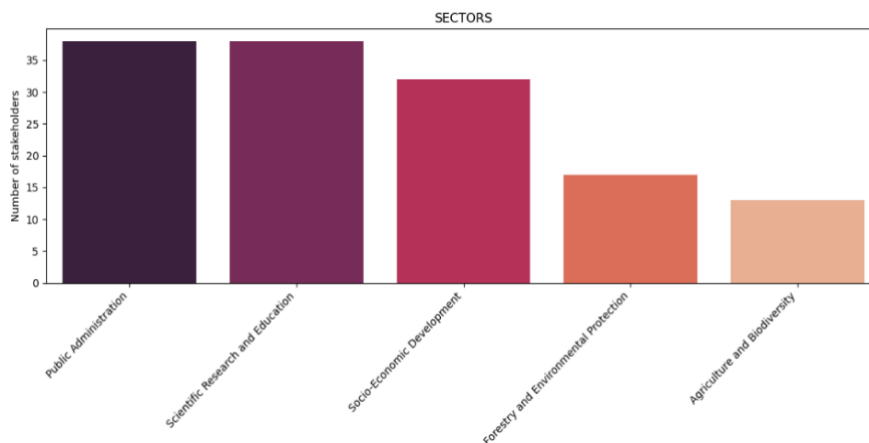


Figure 2. Number of surveyed organizations by sector (Source: Authors’ own contribution, 2025)

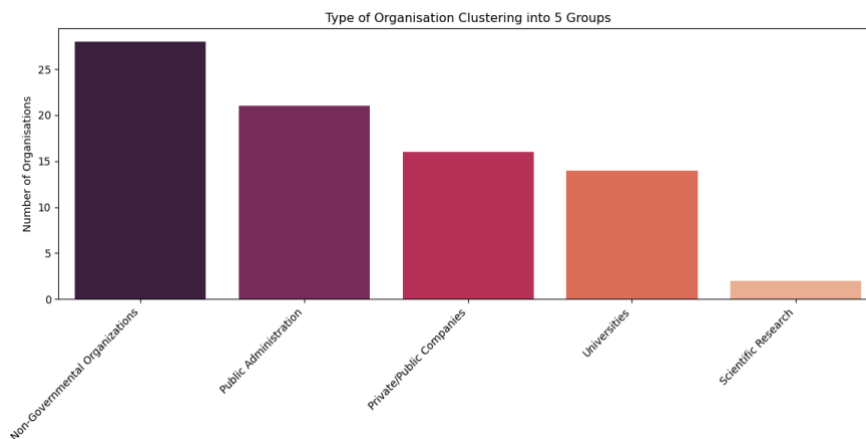


Figure 3. Organizations by type (Source: Authors’ own contribution, 2025)

representation of dedicated research entities in the dataset. This distribution underscores the prominent role of NGOs and the substantial involvement of administrative and corporate sectors, while the lower presence of academic and research institutions suggests potential lack of targeted survey selection. Share of organizations by the status of climate information service usage

As shown in Figure 4, 56.8% of surveyed organizations reported using climate products and services, while 43.2% did not. Among users, prominent sectors include environmental protection, climate research, public administration, and tourism. This sectoral distribution reflects the current stage of

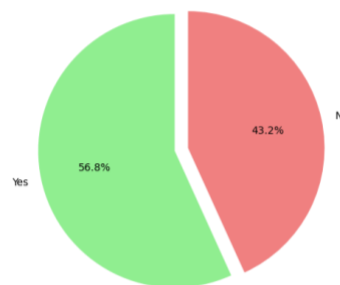


Figure 4. Use of Climate services and products in the surveyed organizations (Source: Authors’ own contribution, 2025)

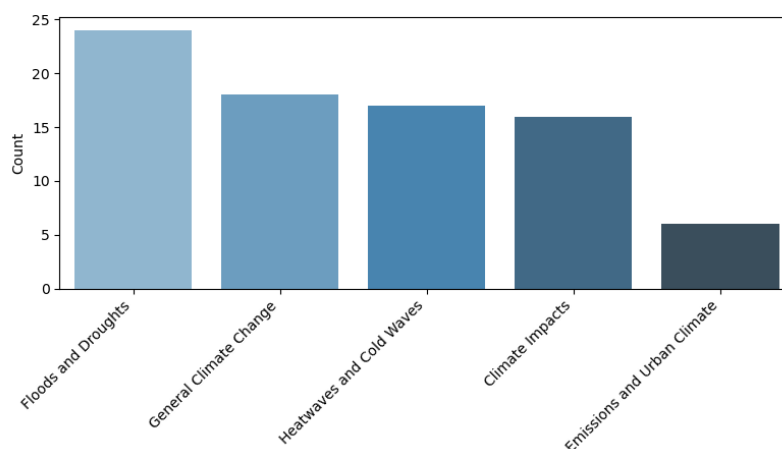


Figure 5. Frequency of various climate-related topics in everyday communication with audiences (Source: Authors' own contribution, 2025)

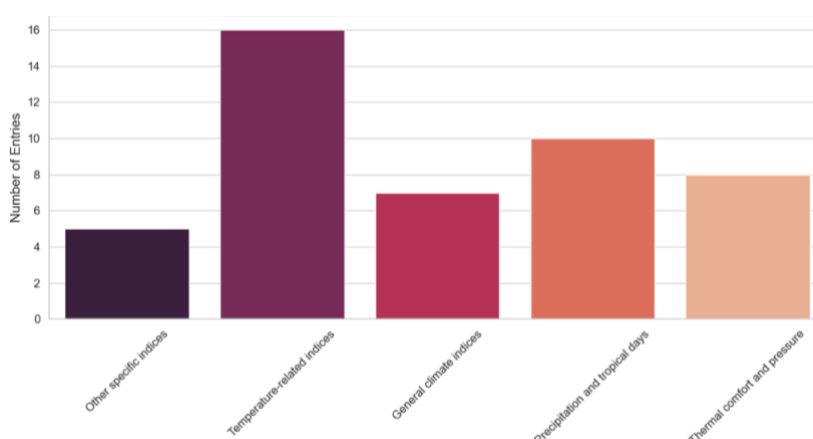


Figure 6. Climate indices and indicators currently in use (Source: Authors' own contribution, 2025)

integration of climate services into institutional practices.

Figure 5 illustrates the frequency of climate-related topics in stakeholder communication among users of climate products. "Floods and Droughts" dominate discussions, emphasizing the focus on immediate, high-impact events.

"General Climate Change" and "Heat and Cold Waves" also feature prominently, highlighting efforts to raise awareness and address temperature extremes. In contrast, topics such as "Emissions and Urban Climate" appear less frequently, suggesting limited emphasis on mitigation and urban-specific issues. This pattern indicates a communication strategy centered on extreme events and general awareness to enhance public engagement.

Analysis of survey responses from CIS users

This part of the paper is dedicated to stakeholders who use climate services and products in their work. A comprehensive approach to evaluate the effectiveness and timeliness of current climate information, products, and services, identify key future demands, and assess the need for further market development was required for this section. To achieve this, we focused on the responses of current users. We examined the types of climate data and products that are easily accessible, the categories of climate products currently in use, respondents' perceptions of their usefulness services, the providers of these products

and the source of these products. The findings discussed in these sections are derived exclusively from organizations that indicated they are active users of climate services.

Climate information

Figure 6 shows that the most organizations included in the survey used temperature-related indices, followed by precipitation and tropical days, and thermal comfort and pressure, with lesser number using general and specific climate indices.

Most institutions that belong to research use temperature and precipitation related indices, while agriculture and forestry institutions focus more on precipitation, soil moisture and discharges. Most respondents used long-term scenarios, monitoring and diagnosis, followed by general climate services, weather forecasts, and with few organizations using spatio-temporal analysis (Figure 7). The organizations that belong to agriculture and rural development mostly use climate monitoring and climate diagnosis

monitoring activities. These were followed in importance by non-financial and educational advantages, support for decision-making processes, and assistance in developing strategies. Additionally, respondents highlighted the role of CIS in facilitating adaptation to national and EU strategies for risk management. Other notable benefits included enhanced market competitiveness and financial gains, underscoring the broad applicability and value of CIS across various sectors (Figure 8).

The identified benefits of CIS reflect their multifaceted role in addressing both immediate and long-term challenges across various domains. Contributions to research, education, and monitoring are vital for advancing scientific knowledge, raising awareness, and tracking environmental and climate-related changes, which form the foundation for informed decision-making. Non-financial and educational advantages, such as capacity building and knowledge dissemination, are essential for empowering stakeholders to understand and respond to climate risks effectively. The support provided by

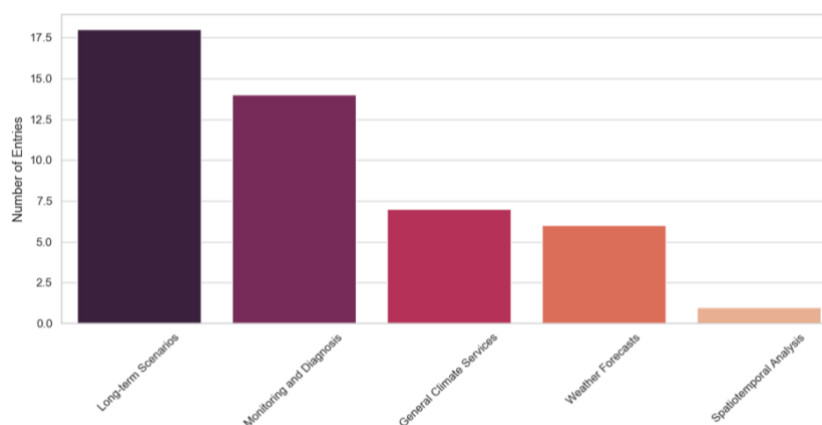


Figure 7. Climate products and services currently in use by respondent organisations (Source: Authors' own contribution, 2025)

products which is understandable due to their primary activity. Similarly, the public administration also focuses on monthly and/or seasonal weather forecasts, long-term climate scenarios and models.

Additionally, most organisations stated that they used daily climate services, followed by these who use monthly, weekly annual or occasional products, in that order.

Benefits of using climate services

Respondents identified the primary benefits of CIS as their contributions to research, education, and

CIS in decision-making and strategy development is crucial for organizations and policymakers to craft resilient and adaptive approaches to climate challenges. Moreover, aligning with national and EU strategies for risk management enables organizations to meet regulatory requirements, access funding opportunities, and ensure coherence with broader

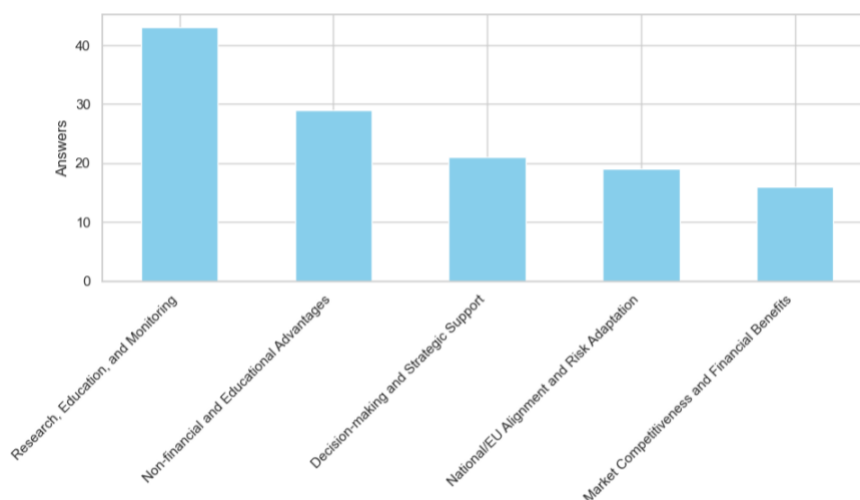


Figure 8. Benefits of climate products and services to respondents (Source: Authors' own contribution, 2025)

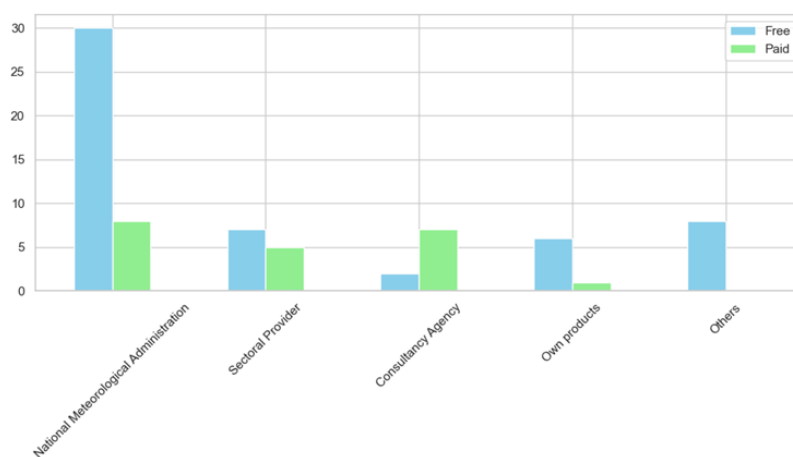


Figure 9. Sources of climate products and services utilised by the respondents (Source: Authors' own contribution, 2025)

climate goals. Enhanced market competitiveness and financial benefits further highlight the economic value of CIS, as they help organizations optimize operations, reduce risks, and tap into emerging green markets. Together, these benefits underscore the critical importance of CIS in fostering resilience, innovation, and sustainability across sectors.

Characteristics of climate services

Most of the climate products used by respondents were free (Figure 9), coming from National Meteorological Administrations. Paid products from these sources are also notable but considerably fewer.

Sectoral providers show a more balanced distribution of free and paid products, with moderate representation of both categories.

Consultancy agencies make a significant contribution to the paid category, suggesting their specialized services are often monetized, while their free offerings are minimal. Organizations developing their own products show a moderate use of free resources, with a smaller proportion attributed to paid resources. Lastly, the "Others" category reflects contributions predominantly in the form of free products, with negligible paid options.

This distribution highlights the reliance on publicly available resources, especially from the

National Meteorological Administration, while emphasizing the importance of paid services from consultancy agencies for specialized needs. It also suggests the potential role of self-reliance and innovation in generating climate products within organizations.

10 km (over 20 respondents), followed by those using resolutions of ≤ 1 km (approximately 20), and fewer using resolutions below 1 km (around 15 respondents). In terms of spatial coverage (Figure 11), more than 35 respondents indicated using locally focused products. Regional and national products

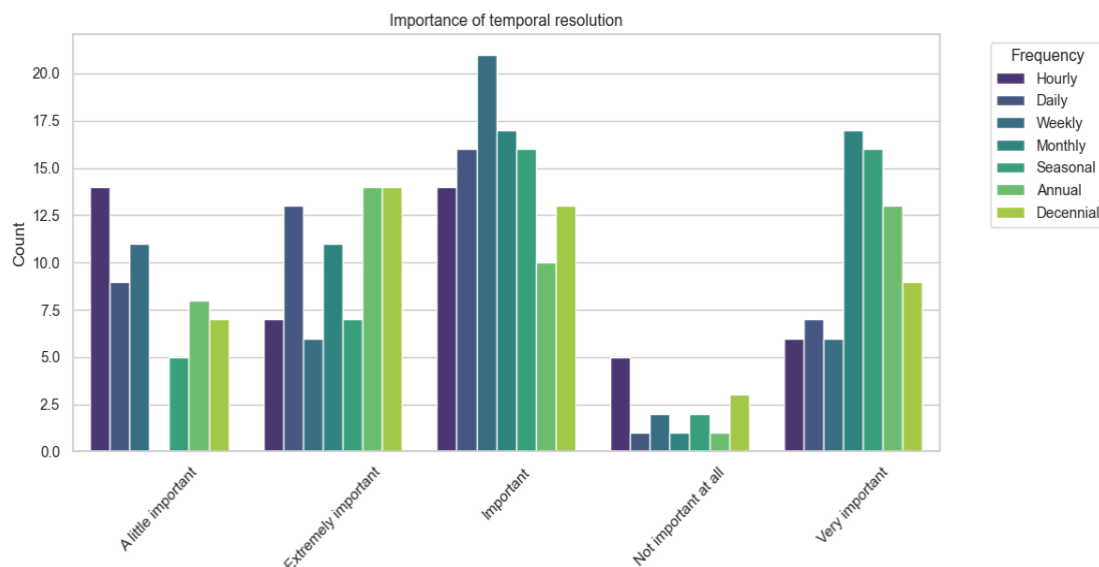


Figure 10. Temporal resolution of the products and services used by the respondents (Source: Authors’ own contribution, 2025)

Figure 10 presents the perceived importance of different temporal resolutions in climate services, ranging from hourly to decadal frequencies. Hourly and daily data are rated most frequently as “Very Important” and “Important,” underscoring their value for high-frequency applications such as weather monitoring, agricultural planning, and disaster response. Weekly and monthly resolutions also receive strong support in these categories, indicating their usefulness for medium-term planning in sectors like water management and energy. Seasonal and annual resolutions are predominantly viewed as “Important” or “Very Important,” reflecting their critical role in long-term climate modeling, policy-making, and adaptation strategies. Although decadal resolution is lower overall, its relevance for long-range research and strategic foresight is evident from its moderate importance rating. These results suggest that temporal resolution requirements differ across applications, reinforcing the need for climate services to be customized to users’ temporal needs.

The majority of respondents reported using climate products with a spatial resolution greater than

were the next most commonly used, with just over 30 users each. Fewer respondents reported using services with continental, sub-continental, or global coverage.

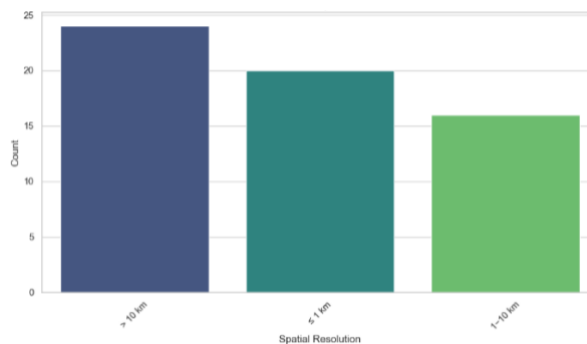


Figure 11. Preferred spatial coverage of climate services used by the respondents (Source: Authors’ own contribution, 2025)

Figure 12 presents the perspectives of current users of climate information services (CIS) regarding potential improvements. The chart displays the distribution of responses across five statements, each addressing a different aspect of CIS development. The x-axis denotes the statements, while the y-axis indicates

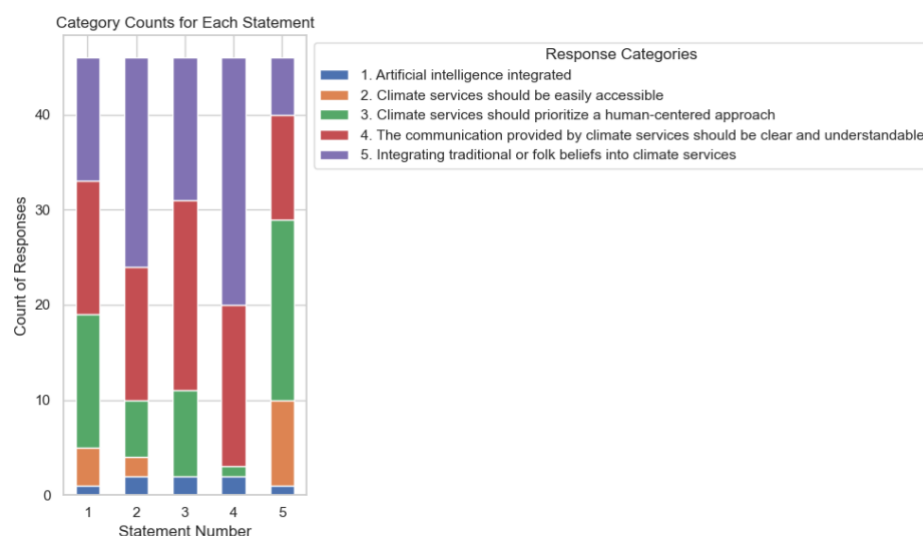


Figure 12. Need for CIS improvements stated by current users (Source: Authors' own contribution, 2025)

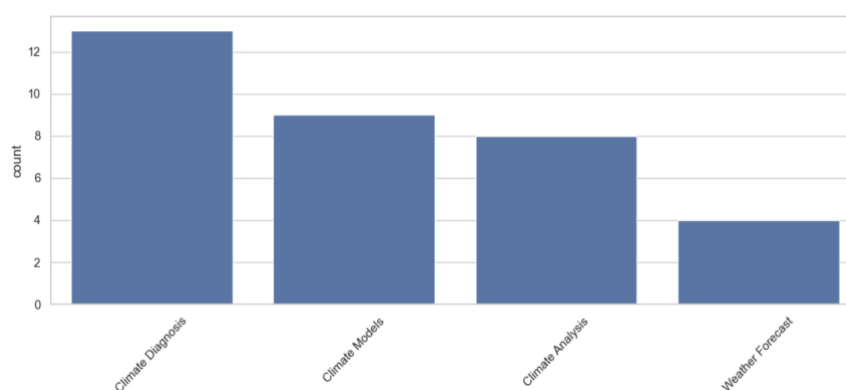


Figure 13. Perception of climate services products needed by prospective users (Source: Authors' own contribution, 2025)

the number of responses per category. The categories—distinguished by color—include artificial intelligence integration, service accessibility, human-centered design, clarity in communication, and the incorporation of traditional or folk beliefs. Statement 5, which advocates for integrating traditional knowledge, received the highest number of responses.

Statement 1, concerning AI integration, garnered low but consistent support. Statements 3 and 4, which address human-centred approaches and communication clarity, show more varied distributions, reflecting differing user priorities. Statement 2, related to accessibility, received moderate attention, indicating steady interest in enhancing access to climate services.

Climate information requirements among prospective users

This section focuses on prospective of climate services. All questions were specifically tailored to this group to explore their potential needs and expectations. The survey employed multiple-choice questions, enabling respondents to select more than one option. This format was essential due to the larger number of prospective users, as understanding their requirements is critical for designing services that support their daily operational needs.

Categories of CIS products and services that would be useful for the organization

"Climate Diagnosis" emerged as the most frequently selected category, with 12 responses, indicating a strong perceived need for tools that assess and interpret climate-related challenges. "Climate Analysis" and "Climate Models" followed closely, with 9 and 8 responses, respectively, reflecting stakeholder interest in predictive tools and analytical data to support decision-making processes. In contrast, "Weather Forecast" received only 4 responses, suggesting it may be viewed as less relevant to their needs or already sufficiently addressed by existing services (Figure 13).

The responses underscore a strong demand among prospective users for advanced diagnostic and analytical tools, suggesting that organizations are seeking to better understand and anticipate climate-related impacts on their operations. These findings highlight the need for climate services that deliver actionable insights, particularly in the areas of climate diagnosis, modeling, and analysis, in order to effectively address this group's specific requirements.

Figure 14 presents the preferred temporal resolutions of climate products and services among stakeholders who currently do not use climate services. These preferences indicate the time scales considered most relevant to their organizational activities.

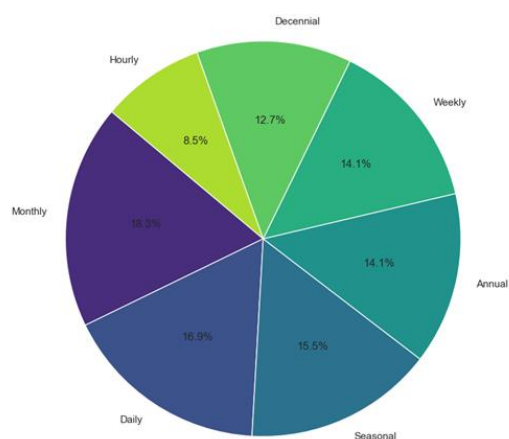


Figure 14. The preferred temporal resolution of climate products and services by respondents who currently do not use climate services (Source: Authors' own contribution, 2025)

The largest proportion of prospective users (18.3%) expressed a preference for monthly temporal resolutions, suggesting that many organizations value data summaries that capture trends over manageable timeframes aligned with reporting or planning cycles. Daily data followed closely at 16.9%, reflecting a demand for high-frequency information suitable for short-term monitoring and operational decision-making. Seasonal (15.5%) and annual (14.1%) resolution requirements were also notable, indicating the relevance of longer-term insights for strategic planning and policy development.

Weekly and decadal resolutions were selected by 14.1% and 12.7% of respondents, respectively, pointing to more targeted needs for medium- and long-term temporal data. Hourly resolution was the least selected (8.5%), suggesting that real-time, granular data is required only in specific operational or emergency contexts.

These findings demonstrate that prospective users have diverse temporal needs, spanning from immediate to long-term scales, with a particular emphasis on monthly, daily, and seasonal data. This highlights the importance of designing climate services with flexible temporal resolution options to accommodate varying operational and strategic demands.

Figure 15 illustrates spatial coverage preferences among prospective users. Local coverage was the most frequently selected (20 responses), underscoring the importance of localized climate information tailored to specific geographic contexts. Regional and national coverage followed, with 18 and 16 responses, respectively, indicating continued relevance for broader-scale applications. Sub-continental, continental, and global coverage were less frequently selected, suggesting that larger-scale data is of lower priority for many organizations.

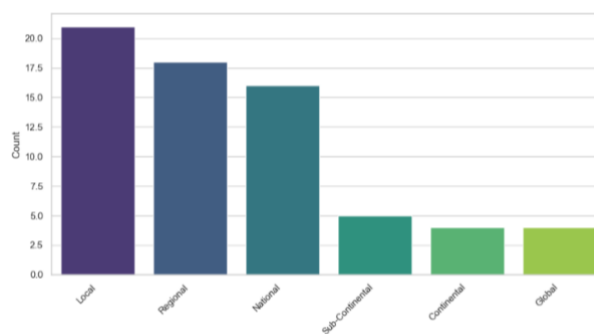


Figure 15. Spatial coverage of needed climate products and services (Source: Authors' own contribution, 2025)

Overall, these results point to a strong demand for localized and region-specific climate services, reinforcing the need to prioritize finer spatial resolutions when developing products aimed at meeting the practical needs of potential users.

Stakeholder preferences for climate service features

Figure 16 reveals a strong preference among prospective users for the integration of traditional or

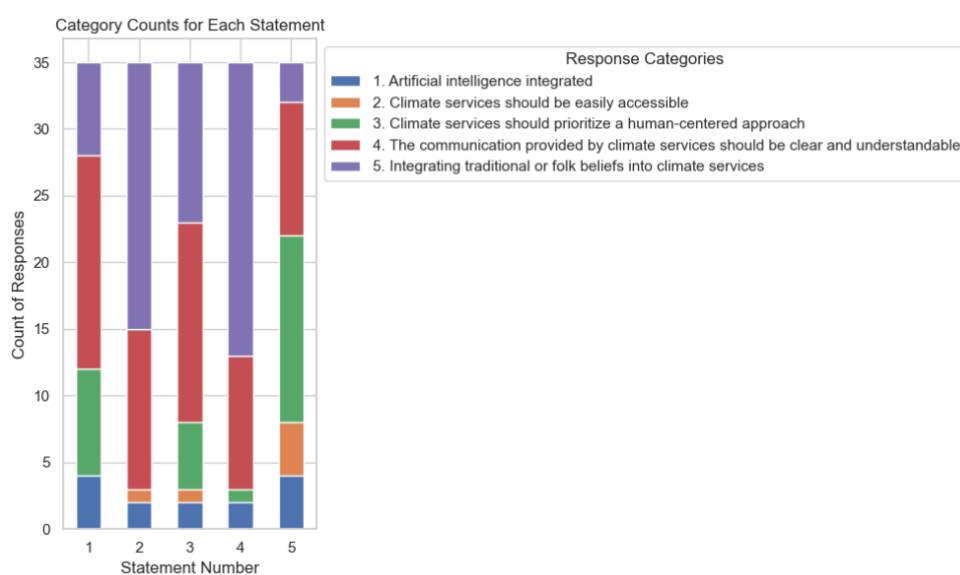


Figure 16. Need for different qualities of CIS (Source: Authors' own contribution, 2025)

folk beliefs into climate services (purple), indicating a significant interest in incorporating indigenous knowledge and cultural practices into climate-related tools. Clear communication (red) and a human-centred approach (green) also received considerable support, highlighting the value placed on understandable information and services designed around user needs and experiences.

While artificial intelligence integration (blue) and accessibility (orange) garnered fewer responses, their inclusion suggests emerging interest in technological innovation and broader access. The relatively lower emphasis on these aspects may reflect limited familiarity or a perception of secondary relevance. Overall, the findings underscore the importance of designing culturally inclusive, clearly communicated, and user-focused climate services to enhance adoption and practical utility.

CONCLUSIONS

Considering the exploratory analysis presented, several key conclusions emerge regarding the management of climate products and services in SEE.

The analysis demonstrates that public administration and the research and education sectors play a central role in the current climate services landscape, reflecting their influence on both policy and knowledge generation. Socio-economic development also feature prominently, underscoring the relevance of climate information for sustainable

growth initiatives. In contrast, forestry, environmental protection, agriculture, and biodiversity sectors exhibit more modest engagement, suggesting opportunities to deepen collaboration with stakeholders whose operations are directly affected by climate variability and ecosystem changes. Non-governmental organizations emerge as influential advocates and intermediaries, while dedicated academic research institutions are comparatively under-represented, indicating a potential disconnect between frontier research and practical service delivery.

Over half of the surveyed organizations make regular use of climate products and services, relying primarily on temperature and precipitation indices, thermal comfort metrics, long-term scenario projections, and monitoring and diagnostic tools. Monthly and daily forecasts are commonly integrated

into decision-making processes, whereas advanced analyses such as spatio-temporal modelling remain the purview of a smaller cohort of specialized users. The widespread reliance on no-cost resources—chiefly those provided by national meteorological agencies—highlights the accessibility of basic climate data, while niche demand for paid consultancy services points to emerging needs for tailored, high-value insights.

Current users express a strong interest in enhancing service accessibility, clarity of communication, and human-centred design, with a particularly pronounced call for the integration of traditional and indigenous knowledge into climate products. Prospective users emphasize the importance of diagnostic and predictive tools (e.g., climate diagnosis, modelling, and analysis) and seek flexible temporal resolutions that align with operational and planning cycles. Fine-scale spatial coverage is also prioritized, reflecting the demand for locally relevant information to support context-specific adaptation measures.

Further research directions

The findings underscore both progress and remaining gaps in the provision of climate services across SEE. To advance the field, practitioners and policymakers should foster stronger partnerships with under-represented sectors, especially forestry and agriculture, and bridge the divide between academic research and end-user needs.

Co-design methodologies that engage stakeholders throughout the development cycle will be critical to ensure that new products are both technically robust and culturally resonant. Expanding the repertoire of high-value services—leveraging artificial intelligence, traditional knowledge systems, and advanced modelling techniques—can drive innovation and enhance the resilience of communities and organizations. By aligning service development with user feedback and sectoral priorities, the climate information ecosystem can evolve to meet the complex challenges of a changing environment.

To move beyond broad policy frameworks toward impactful climate adaptation, it is essential to invest in systematic data collection that captures the nuances of local adaptation efforts, leadership structures, and the integration of citizen knowledge with scientific CIS. Recent studies highlight the transformative potential of machine learning (ML) in enabling such efforts by automating the classification,

synthesis, and analysis of vast text-based datasets, including policies, legal records, and even social media content (Sietsma et al., 2023). ML not only increases efficiency in climate research but also allows for more dynamic and scalable insights into adaptation trends (Biesbroek et al., 2020).

Funding agencies, ranging from national institutions to global bodies, can play a pivotal role in supporting this new era of adaptation research. Incorporating community-based knowledge remains equally vital, as local insights provide precision and relevance often lacking in high-level projections (Bouwer, 2023).

Socioeconomic disparities, particularly in lower-income areas of SEE such as the Balkans, continue to exacerbate climate vulnerability. Communities with limited education, older populations, or fragile infrastructure bear the brunt of climate impacts, yet receive the fewest resources and the least targeted investment. Without a clear focus on inclusivity and equity, climate resilience strategies risk deepening existing inequalities (Verma et al., 2024). To be truly transformative, adaptation planning must incorporate explicit mechanisms to prioritize marginalized communities, ensuring that adaptation does not lead to further exclusion or displacement.

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