

CASE REPORT



Fostering sustainability skills in communities: a co-creation-oriented capacity-building workshop on climate services in Posadas, Misiones, Argentina

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Abstract

This article describes a capacity-building initiative in Posadas, Misiones, Argentina, focused on training non-meteorological agents for co-creating climate services. Through a comprehensive training course in 2024 for multisectoral actors, participants gained knowledge about sustainability and learned to develop indicators tailored to local realities. Leveraging the expertise of researchers, the project applied WMO's Competency Frameworks for providing Climate Services to various territorial actors, ensuring tailored solutions. The initiative fostered a dynamic space for stakeholder exchange, facilitating collaboration and innovative approaches to addressing climate challenges. Insights from this dual-purpose initiative, a capacity-building workshop and an early co-creation stage shed light on the importance of grassroots engagement, community involvement, and interdisciplinary collaboration in promoting sustainability and resilience in the face of climate variability and change. The research results highlight how meteorological and climatic conditions impact various sectors, providing insights into sector-specific vulnerabilities and challenges. Additionally, the study identifies adaptation measures across different time scales, addressing both short-term responses and long-term strategies to enhance resilience.

Keywords Sustainability skills · Capacity building · Climate services · Co-creation · Interdisciplinary collaboration · Argentina · international cooperation

Introduction: climate services from scientists to society

In the 21st century, the world is grappling with complex challenges driven by climate variability and change, necessitating informed, judicious decision-making at every level

from individual households to international forums. Understanding recent climatic changes and the trends in extreme weather events is crucial, as is recognising their impacts across various sectors such as risk reduction (Speight et al. 2021), agriculture (Malhi et al. 2021), health (Davis et al. 2021), energy (Gil et al. 2021), and water management (Liu et al. 2021), or tourism (Scott et al. 2011; Font-Barnet et al. 2021). This context has spurred the development of actionable climate science and specialized climate services (CS), which provide stakeholders—including academics, NGOs, business and administrative decision-makers, policymakers at various levels, schools (and citizens—with usable and actionable information on climate variability, impacts, risks, opportunities, and uncertainties (Van den Hurk et al. 2018; European Commission 2015; WCC3 2009; Vaughan and Dessai 2014; Hewitt et al. 2012; Bamzai-Dodson and McPherson 2022; Cebrián et al. 2025).

Stakeholder participation forms the foundation of practical CS applications, with user engagement (Sprengel and

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Busch 2011) and the co-creation and co-production of climate services being essential (Suhari et al. 2022; van der Horst et al. 2022; Tarchiani and Bacci 2024). This approach is endorsed by the Global Framework of Climate Services (GFCS) and has applications beyond GFCS's priority areas, including in the tourism sector (Turton et al. 2010; Moreno and Becken 2009; Pandey and Rogerson 2018; Hopkins 2014; Morrison and Pickering 2013; Boqué-Ciurana et al. 2022; Matthews et al. 2021). The collaboration between decision-makers, climate scientists, and specialised academics is vital for leveraging expertise to address challenges effectively (Briley et al. 2015; Golding et al. 2017; Dow and Carbone 2007). The use of climate and meteorological information can significantly benefit societies by increasing adaptability to climate variability and change (Vincent et al. 2018; Williams et al. 2015; Soares et al. 2018; Pernelis et al. 2013; Nepal et al. 2024) and providing social and economic advantages by reducing the impacts of hazardous natural events and enhancing national economies (WMO 2015; Fazeli et al. 2024; Nikolakis et al. 2024). The economic value of forecasts and CS, as outlined by Lee and Lee (2007), hinges on the additional profits that decision-makers can achieve by utilising these services, with demand-based methods showing that users have varying willingness to pay for valuable and practical information services (Rollins and Shaykewich 2003; Clements et al. 2013; Yousofpour et al. 2024). Moreover, some climate services and indices have been transformed into financial products, such as weather derivatives, further underscoring the economic value generated around them (Alexandridis et al. 2020; Boyd et al. 2020; Nam et al. 2024), indicating market readiness to invest in beneficial climate information.

The northeast region of Argentina faces particularly significant impacts from climate change. One of the most concerning trends is the increased frequency and intensity of heat waves (Cimolai and Aguilar 2024). Additionally, changes in precipitation patterns have been observed, with some areas experiencing increased rainfall while others face more frequent dry spells (Barros et al. 2015). These changes in temperature and precipitation patterns increase the risk of wildfires in the region (Argañaraz et al. 2015). The combination of more frequent and intense heat waves with altered rainfall distribution creates conditions conducive to fire ignition and spread, posing significant threats to ecosystems and communities. Climate projections suggest these trends will continue and potentially worsen in the coming decades. This level of change would likely exacerbate existing climate-related challenges and create new ones, potentially causing severe damage to Argentina's people and economy (Barros et al. 2015).

Building on this context, we present a capacity-building workshop in Posadas (Misiones, Argentina), co-organised

with REDAPPE under the URV Solidària framework, as an applied setting for co-created climate services. This article has three aims: (1) to identify how meteo-climatic conditions impact different sectors and to define adaptation measures to address those impacts across different time scales; (2) to document the co-creation process, training design, and co-developed outputs from the workshop; and (3) to explain how capacity building can be realised beyond climate specialists through the co-development and implementation of climate services. Throughout the paper, we treat capacity building and co-creation as mutually reinforcing: the workshop is framed as a capacity-development intervention that simultaneously delivers the first stages of the co-creation pathway, enabling non-specialists to participate meaningfully in indicator design and adaptation planning. This study reports on the early co-creation stages—needs identification (user-led variable/threshold elicitation) and indicator specification—alongside capacity building and initial uptake. Prototyping/piloting and full operational deployment of climate services lie beyond the present scope and will be reported elsewhere.

Methods

Training design

Step 1. Building capacity for sustainability: establishing a framework for empowerment: the case of Posadas, Misiones, Argentina, Misiones, Argentina

This research describes the design of a capacity-building framework for sustainability empowerment. It presents the experience of a week-long workshop involving diverse stakeholders in Misiones Province, Argentina. Located in the country's northeastern region, Misiones is renowned for its rich biodiversity, encompassing diverse ecosystems such as rainforests, rivers, and unique flora and fauna. This ecological diversity contributes to the province's natural beauty, serves as a crucial reservoir of genetic resources, and provides invaluable ecosystem services. Misiones preserves 52% of Argentina's biodiversity and hosts one of the world's biodiversity hotspots, the Atlantic Forest (IPEC Misiones 2018). The province also boasts a strong cultural heritage, including Indigenous communities whose traditional knowledge and practices are deeply intertwined with sustainable resource management. These communities' practices illustrate long-term, nature-based stewardship relevant for adaptation. While Misiones is known for its ecological importance, it also faces land-use challenges. Expanding agricultural and forestry activities raises trade-offs between

economic development, environmental conservation, and social equity (Ferrero 2013).

These dynamics motivate sustainable strategies that address multiple stakeholder interests. Furthermore, Misiones is actively working to combat climate change and biodiversity loss. The province has developed strategic plans to reduce and capture greenhouse gas emissions (UNDP Argentina 2024). It is implementing actions to adapt to the inevitable impacts of the climate crisis, thereby reducing vulnerability and supporting sustainable development over time (Cambio Climático Misiones, n.d.). In this context, Misiones serves as a suitable testbed for applied capacity-building in climate services.

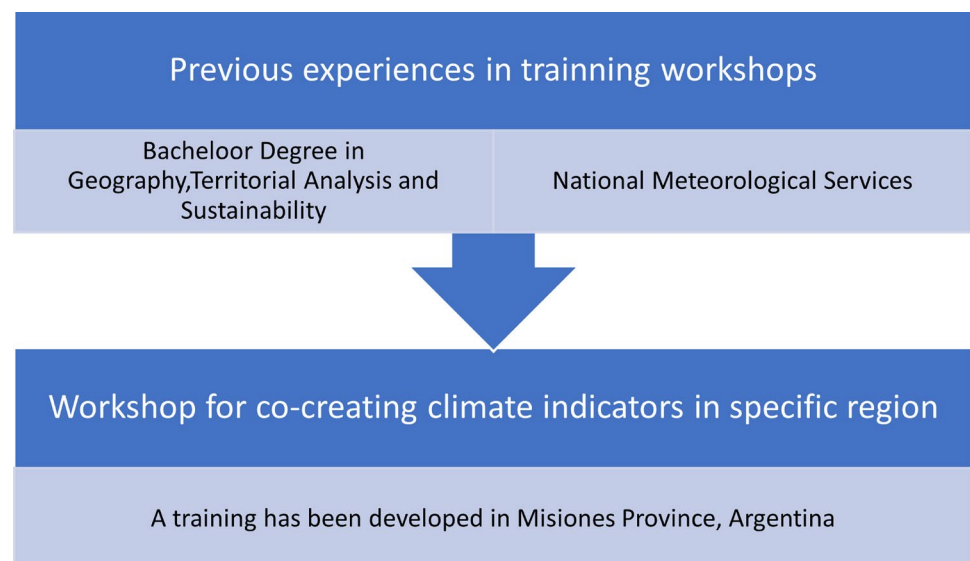
To construct the training framework, we blended two fundamental components: the competencies for climate service provision as defined by the World Meteorological Organization (WMO 2019), which set global standards for the creation and dissemination of climate-related information, together with the authors' pedagogical and training experience; and the co-creation methodology for climate services designed by Font-Barnet et al. (2021), which employs focus groups and mind maps to define the objectives and scope of climate services based on local users and stakeholders. This participatory approach centres user-led problem framing and variable selection, providing the theoretical basis for co-created indicators and measures. The training sessions were designed to move from theory to practice, enabling participants to compute and outline operationalisation pathways for these services with the abilities and skills acquired. The process emphasises collaborative learning and practical engagement to produce user-relevant, context-specific outputs.

In response to the critical need for climate services, the World Meteorological Organisation (WMO) convened expert teams in the previous decade to draft the Competencies

for the Provision of Climate Services (WMO, 2019). The framework articulates distinct competency domains; in this study we operationalised three that are directly actionable in short-format training for mixed audiences: C1—Climate data management and quality control (data access, curation, metadata, basic QA/QC and homogeneity checks); C2—Climate product development (deriving and documenting sector-relevant indices and products, including basic validation and reproducibility); and C5—Climate communication and user interface (audience analysis, uncertainty-aware messaging, formats and channels for decision support). We translated each competency into plain-language learning outcomes and concrete tasks for participants: under C1, guided access to datasets and worksheet-based QC; under C2, co-definition of sector indicators and hands-on computation with Climpack; under C5, preparation of short sector briefs and peer presentations.

The approach scales up to experienced users the scheme of two subjects in the Universitat Rovira i Virgili (Fig. 1), where WMO competencies are embedded in the Geography, Territorial Analysis, and Sustainability degree (Olano Pozo et al. 2024), to design the Misiones workshop for a mixed audience. Drawing on Project 3 (C1: data management/quality control; C2: product development, including homogenization) and Project 5 (C5: communication and co-creation in key sectors), we translated these competencies into a three-layer scaffold for non-specialists: Foundation (concept primers and guided demos), Practice (small-group computation with mentoring), and Application (sector cases and briefs). The agenda was explicitly mapped: Days 1–2 delivered C1 (data access, QC, and initial indicator computation), Days 2–3 connected co-creation to C2/C5 (co-defining indicators and messages with users), and Day 4 assessed C5 (oral/visual communication of results). This alignment clarifies what was co-created—user-led variables/

Fig. 1 Flow from previous tailored workshop experience to Posadas workshop



thresholds, sector indicators, and adaptation options—and why the WMO framework was appropriate for the target audience (see Fig. 2).

Step 2. Collaborative methods: stakeholders' engagement through REDAPPE think tank

In the co-construction of climate services, the critical steps include clearly identifying stakeholders and understanding the value proposition for users. Bremer et al. (2021), Larosa and Mysiak (2020), and Stegmaier et al. (2020) emphasise the importance of engaging users as equal partners throughout development to deliver user-centred services. Such engagement ensures quick, cost-effective access to relevant data and projections, thereby strengthening decision-making. From a co-creation perspective, the capacity-building workshop was explicitly mapped onto the co-creation pathway: it covered Phases 1–3 (scoping → co-design → validation of indicators/adaptation options) and stopped before Phase 4 (piloting/operationalisation).

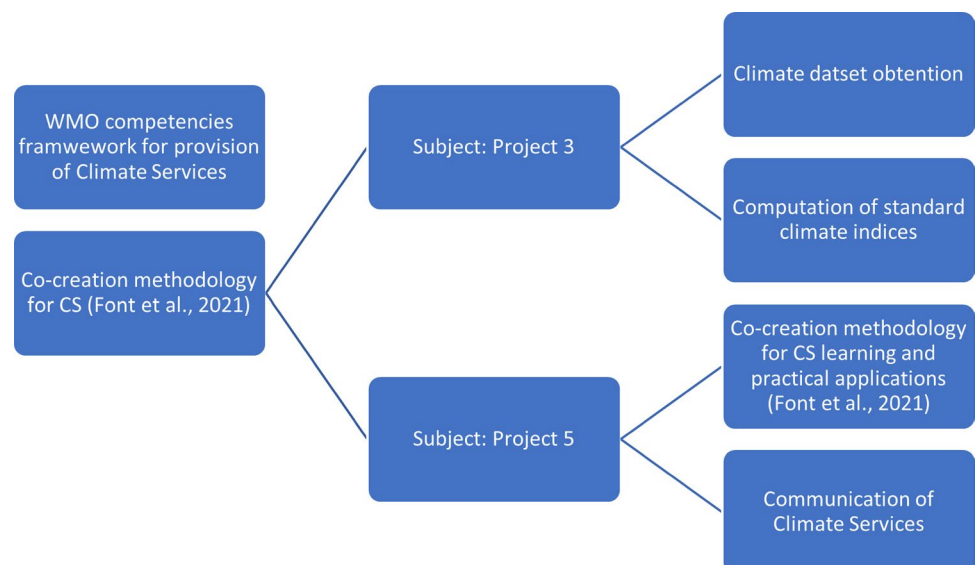
The methodology adopted for engaging trainees involved forming focus groups comprising local stakeholders (academics, students, technical staff, businesses, managers, administration officials, and potential users) organised as a workshop (see participant profiles). Following the co-creation model of Font-Barnet et al. (2021), we used a phased, iterative process—(a) scoping the decision context with users, (b) eliciting information needs and feasible data sources, (c) co-designing indicators and use cases, and (d) validating and refining outputs through feedback loops—so that each phase produced concrete artefacts to carry into the next. Extending beyond tourism, the engagement was structured around three user-led steps: (i) identify study objects/decision contexts and the stakeholders involved; (ii) identify climate variables of concern and optimal/threshold

conditions for those contexts; and (iii) identify adaptive actions at different timescales. In practice, Step 1 maps to Font-Barnet's "scoping," Step 2 to "co-design of information/indicators," and Step 3 to "validation and application" (action pathways). This explicitly places users in the lead in selecting variables and defining the information the service needs to address. Actions at each stage included: a problem/decision canvas (Step 1), a user-justified shortlist of variables with thresholds and data availability notes (Step 2), and an adaptation options matrix by timescale, actor, and feasibility (Step 3). Accordingly, the primary co-created artefacts are the user-led variable registers, sector-specific indicator specifications, and adaptation matrices; delivery channels, update cadence, and interface choices.

Focus group discussions serve as a qualitative technique for studying opinions and attitudes, reducing researcher bias and enabling emergent insights (Vaughan and Dessai 2014; Xu et al. 2018). Mind maps were used to capture and organise collective input, visualising relationships between ideas and supporting consensus around critical issues. Consistent with Font-Barnet et al. (2021), mind maps functioned as the core co-creation artefact and were iteratively updated across phases to register dependencies (e.g., weather windows, operational thresholds), uncertainty notes, and candidate data sources; each cycle closed with a convergence check before advancing to computation or piloting. This approach, validated by Reckien et al. (2013) for socially sensitive adaptation options, fosters dialogue between scientists and users to analyse vulnerabilities holistically and define scenarios, thereby producing co-created, sector-specific climate services (Muñoz et al. 2014; Vedeld et al. 2019).

The cooperation for workshop design and execution began in 2023 and concluded in March 2024, with follow-up. REDAPPE mapped actors across the region and integrated stakeholders from public and private sectors, civil

Fig. 2 Connections of the WMO competencies and subjects for learning those competencies



society, and academia. A transparent, criteria-based selection prioritised proactive profiles with territorial impact capacity, reinforcing the project's federal and inclusive vocation and democratising access to international training in northeastern provinces (Juste and Cherini 2024; Cherini & Sacco in REDAPPE, 2024). REDAPPE's sustained engagement before, during, and after the workshop underpinned continuity and the potential for long-term impact (<https://redappe.org.ar/urv/>).

Training development

Step 3. Workshop development

An agenda was crafted to facilitate understanding of climate services and their practical application. Framed as a participatory methodology, the process was designed to stimulate informed demand for climate information by starting from user problems and iteratively translating them into data needs, indicators, and action pathways. The agenda's goal was to enable participants to co-create indicators and adaptation measures for priority sectors/activities and to outline next steps for operational use.

Final agenda of the workshop

Day 1: Introduction. The first day was for presenting workshop objectives, introducing fundamental concepts of climate change and climate services, and establishing shared context and roles. Capacity building focused on a common vocabulary and a problem/decision canvas completed in mixed-profile groups.

Day 2: Experiences and Calculation of Indicators. During the process, we explore methods for calculating climate indicators; present relevant experiences to motivate participants; and train participants in Climapact to build competencies for indicator creation. Hands-on labs were scaffolded (foundation → practice → application), with mentor rotation, checklists for data access/QC (WMO C1), and short “show-and-tell” segments to consolidate skills.

Day 3: Co-creation Methodology. We operationalised a participatory co-creation protocol to align scientific evidence with user requirements, completing three user-led stages (decision/problem scoping → variable/threshold elicitation → action design across time scales). In facilitated clinics, problem canvases were translated into user-led variable shortlists (justification, candidate data sources, QC considerations) and then into sector-specific indicator specifications (definition/formula, computation and temporal aggregation, interpretation, uncertainty notes). These indicators are the primary co-created outputs; the climate-service layer (dashboards, briefs, alerts, delivery channels,

update cadence) is co-developed during piloting/implementation. Role rotation ensured non-specialists chaired variable selection, consistent with Font-Barnet et al. (2021), anchoring measurement to locally salient decision contexts and ensuring traceability from user need to indicator design.

Day 4: Talks and Group Presentations. Talks on provincial climate policies, environmental legislation, and climate communication; groups present sector, variables of concern, and co-created indicators and adaptation measures, with peer feedback. Communication drills (brief → storyboard → pitch) were assessed with a rubric aligned to WMO C5.

Day 5: Fieldwork. In the last days, participants visited site visits (e.g., Biofábrica and a tea plantation) to observe how meteorological conditions affect production. Participants completed field-journaling templates (decision context, operational windows, weather constraints) to ground-truth indicators and adaptation options.

Step 4. Training area and trainee profiles

The training on climate services, set against the backdrop of Posadas, Misiones, Argentina, leverages the region's unique geographical and socio-economic landscape as a living laboratory for applied learning. With its diverse industrial base and rich natural resources, Misiones presents fertile ground for exploring the application of climate services across various sectors. Posadas, the province's bustling capital, bridges the urban and natural environments, offering insights into integrating climate data into urban planning, agriculture, energy production, and natural conservation. This region, characterised by its industrial activities including wood derivatives, agro-industry, and textile production, along with its vast tourism potential highlighted by the Iguazú Falls and the Jesuit Missions, provides a comprehensive context for participants to understand and address the challenges posed by climate variability and change. The training aims to equip stakeholders from diverse sectors with the skills and knowledge to use climate services for sustainable decision-making, emphasising the practical application of climate information to enhance resilience and promote sustainable development within Misiones' dynamic economic and natural landscape.

The participant selection strategy, serving as a stakeholder-mapping step for the climate services workshop, was based on a multifaceted approach that encompassed diverse disciplines and perspectives relevant to the predetermined sectors. This approach ensures the inclusion of a broad spectrum of participants, each bringing unique insights and expertise critical to the interdisciplinary nature of climate services in Misiones and Posadas. The rationale behind the inclusion of specific profiles is as follows:

- **Technicians at Municipal, Regional, and National Levels across Various Sectors:** These individuals are endowed with intricate knowledge of policies, regulations, and sector-specific challenges across different tiers of governance. Their engagement is indispensable for a nuanced understanding of the prevailing regulatory landscapes and articulating technical development requisites.
- **Managers of Protected Areas:** Their firsthand experience in managing and conserving natural and protected landscapes is pivotal for weaving sustainable practices into the fabric of climate services and addressing conservation challenges with precision.
- **Energy Sector Technicians and Managers:** Central to the dialogue on sustainable and efficient energy transition, their contributions are essential for uncovering innovative solutions and establishing best practices within the energy domain.
- **Sector-specific Entrepreneurs:** Their insights into the economic viability and potential for innovation within their sectors are instrumental in bridging sustainability with economic growth and development.
- **Academic Faculty and Researchers:** They contribute theoretical underpinnings, contemporary research findings, and innovation, which are crucial in merging theoretical knowledge with practical applications.
- **Legal Experts:** Their understanding of the legal framework surrounding the identified sectors, alongside their ability to pinpoint areas necessitating legal reform or the introduction of new regulations, is crucial.
- **Policy and Decision Makers:** Their inclusion guarantees that the training aligns with and informs current and forthcoming policy initiatives, thus facilitating the strategic incorporation of sustainable practices.
- **Undergraduate and Postgraduate Students:** As the emerging cadre of professionals, their education in sector-relevant subjects is anticipated to yield long-term contributions towards innovation and sustainability.
- **Additional Technical Experts:** Including technicians from various related fields enriches the discourse, fostering a multifaceted exploration of challenges and solutions.

This strategy underscores a commitment to fostering a comprehensive and collaborative framework for capacity building in climate services. It highlights the workshop's aim to address the complex interplay between sustainability, climate change adaptation, and mitigation through an interdisciplinary lens.

Results

Step 5. Outcomes

As described in the Methods, the workshop was organised into four multidisciplinary working groups (5–8 participants each). Each group selected a topic in which to co-create indicators aligned with local priorities. The themes were:

1. (1) Urban planning (Posadas, Misiones).
2. (2) Hydroelectric energy production (Yaciretá, Misiones).
3. (3) Tourism (Saltos del Moconá, Misiones).
4. (4) Solar energy production in Misiones.

Step-1 (context scoping) focused on identifying enabling and constraining factors in each sector/territory, thereby situating the analyses that follow (O1/O2). Each group produced three artefacts: a variable register (variables of concern and preliminary thresholds with data sources), a sector-specific indicator specification, and an adaptation matrix across operational/seasonal/strategic horizons—constituting the primary co-created outputs (O2) and the empirical basis for Objective.1.

Across groups, four cross-cutting foci consistently emerged:

- **Infrastructure:** Participants focused on urban, energy, and water infrastructure, recognising their critical role in shaping the territory's development and sustainability.
- **Climate and environmental factors:** Groups consistently considered the impact of climate change and local environmental conditions on their chosen subjects.
- **Legislation and agreements:** The importance of regulatory frameworks and inter-institutional agreements was highlighted as a key factor influencing territorial development.
- **Community perception and demand:** Participants emphasised considering local community needs, perceptions, and demands in planning processes.

These shared elements across tables demonstrate a holistic approach to territorial analysis:

- **Energy production and infrastructure** were central to discussions, reflecting their fundamental role in urban and regional development.
- **Environmental factors**, including climate, vegetation, and water resources, were consistently evaluated for their impact on planning and sustainability.

- Community needs and perceptions were prioritised, indicating a shift towards more participatory and inclusive planning processes.
- The significance of legislation and agreements was recognised, underscoring the need for robust policy frameworks to support sustainable development initiatives.

In summary, Step 1 delivers Objective 0.2 (co-creation artefacts) and sets up the sector-specific impact and measure analyses reported under Objective 1; it also consolidates skills and networks that underpin Objective 3, detailed later in the capacity-building results.

Sectoral impacts: relationship between meteorological conditions and target sectors

In the second step, the groups analysed the impact of meteorological variables on the selected sectors (Fig. 3): urban planning in Posadas, hydroelectric energy production, solar energy generation, and tourism in Saltos del Moconá. The results highlight the complex interplay between climate factors and these sectors, revealing both opportunities and challenges for sustainable development in the region.

For urban planning in Posadas, moderate precipitation and lower temperatures were found to have positive impacts. In contrast, extreme weather events such as high temperatures ($>40\text{ }^{\circ}\text{C}$), strong winds ($>100\text{ km/h}$), and heavy rainfall ($>100\text{ mm/day}$) pose significant challenges. These patterns indicate exposure to heat, wind-gust damage, and pluvial flooding, motivating climate-resilient urban design and operations.

Precipitation in the La Plata Basin and vegetation cover benefited hydroelectric energy production, while drought, strong winds, and excessive water flow ($>60,000\text{ m}^3$) were identified as major negative factors. Operational sensitivity to inflow variability underscores the relevance of watershed management and adaptive reservoir rules under changing hydro-climate regimes.

Increased sunny days and higher radiation intensity positively influenced solar energy generation. However, extreme weather events, including severe storms, hail, and strong winds ($>150\text{ km/h}$), challenged it. Findings point to the need for storm-contingency protocols, preventive maintenance, and infrastructure hardening to protect yield.

These results highlight the need for robust solar infrastructure and diversified energy strategies. Tourism in Saltos del Moconá thrived on days without rain and moderate temperatures ($12\text{--}30\text{ }^{\circ}\text{C}$). Conversely, intense precipitation, storms, and extreme temperatures ($>35\text{ }^{\circ}\text{C}$) negatively impacted tourism activities. This supports seasonal planning and climate-informed visitor management to align operations with comfort and safety thresholds.

Taken together, these impact profiles complete Objective 1's first component (sectoral impacts) and provide the evidence base for the adaptation portfolios presented in Section [Adaptation portfolios by sector and timescale](#).

Adaptation portfolios by sector and timescale

Figure 4 synthesises stakeholders' adaptation portfolios across operational (daily/weekly), seasonal (intra-annual), and strategic (multi-annual/decadal) horizons. These portfolios constitute the second component of objective 1 (measures). They are derived from the co-created matrices and variable/threshold registers developed in the workshops (O2). They are deliberately structured to stimulate practice-oriented uptake and sustained demand for climate information (O3).

Solar energy (Misiones). The portfolio prioritises, at the operational horizon, battery-charging management, storm-contingency and wind-shutdown protocols, together with preventive maintenance and panel inspection. Seasonally, emphasis shifts to optimising equipment usage and scheduling cleaning/derating. Strategically ($\sim 10\text{--}30$ years), the pathway envisages system re-engineering and grid integration, progressing towards alternative energy business models (e.g., energy sharing/selling). These measures are anchored in user-specified variables (solar radiation, wind gusts) and preliminary thresholds elicited during co-creation (O2), translating indicator signals into operating rules and medium-term planning for objective 1, while embedding standard operating procedures and checklists that train non-specialist staff in data-informed routines (O3).

Tourism (Saltos del Moconá). Operational/weekly actions include projecting park openings from climate variables and spatial overlays, vector-borne disease control, and fire-management readiness. Seasonal actions emphasise resource optimisation and inclusive climate communication; strategically (~ 10 years), the portfolio includes upgrades to sewage, telecommunications, and the electrical grid, alongside diversification of activities and gastronomy, with a 30-year vision of an integrated, sustainable tourism system. Co-designed comfort and safety thresholds for temperature and precipitation (O2) serve as decision rules for opening and closing and staffing, in line with objective 1. In contrast, institutionalised routines across visitor services and safety teams broaden capacity beyond climate specialists (O3).

Urban planning (Posadas). Operational measures include early warning systems and alerts, daily waste collection, and weekly creek cleaning. Seasonal priorities cover emergency protocols, water access and rainwater harvesting, and the rollout of green infrastructure and energy-efficiency actions. Strategically (~ 10 years), plans include citizen-managed

Fig. 3 Impact of meteo-climate variables on selected topics

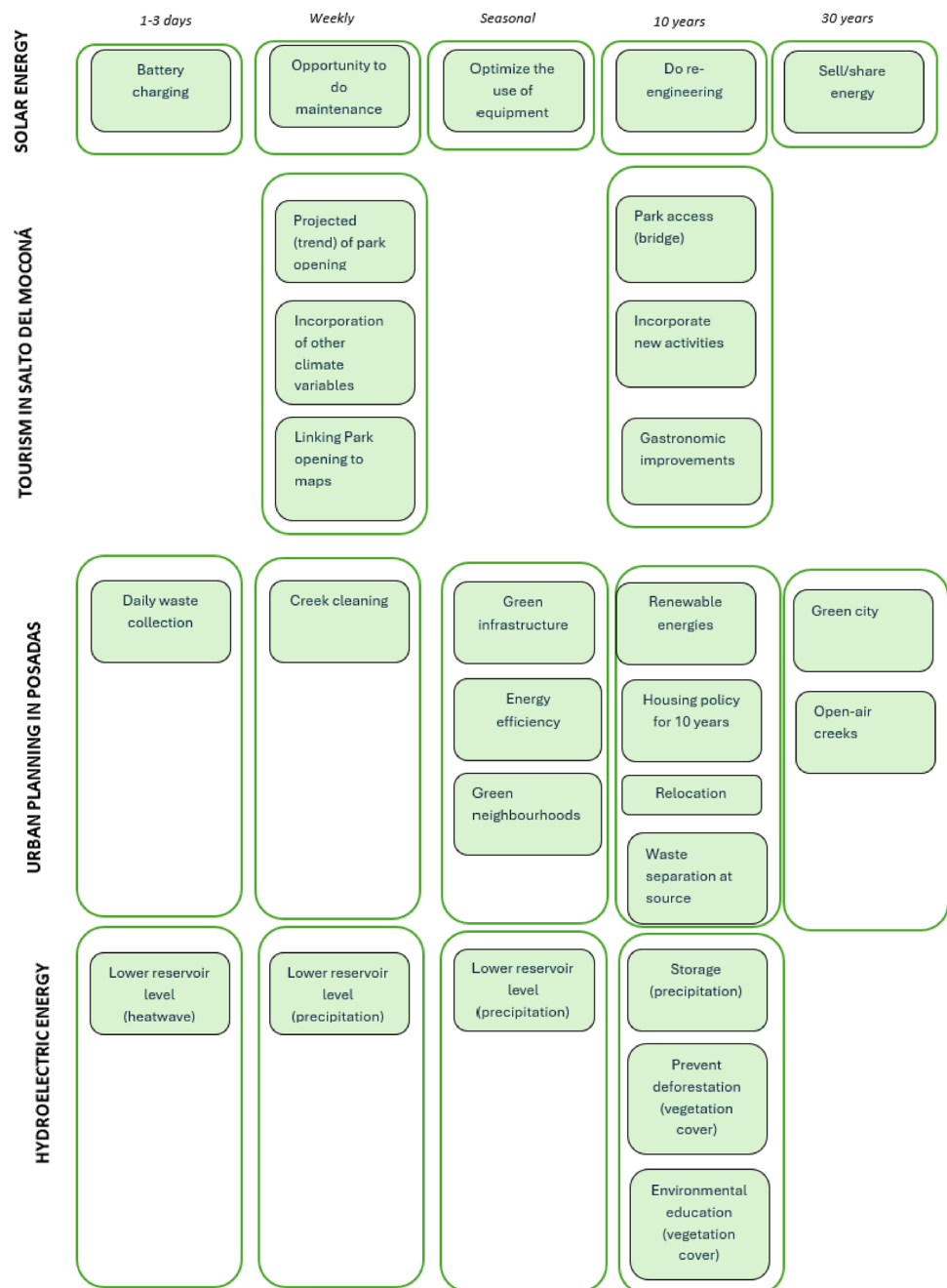
	Impact of meteoroclimatic variables					
	(+++)	(++)	(+)	(-)	(-)	(--)
Urban planning in Posadas		Pp Low T°	Frost	Pp < 40 mm / monthly Hail Wind > 60km/h	Humidity 30% / 90% T° > 35°C	T° > 40°C Wind > 100 km/h Pp > 100mm/daily
Hydroelectric energy	No wind Pp in La Plata Basin Vegetation cover	Heat wave in Brazil	Overcast sky	Heat Clear skies	Excess pp Land use change	Drought Strong winds Fires Flow > 60,000 m3
Solar Energy	> days with sun > radiation intensity (R > 20 mj/m2)	Altitude Latitude	Wind	Excess wind (speed > 50 km/h) Dust in the air Cleaning or maintenance	Very humid periods (RH > 80%; > 5 consecutive days) T > 25°C Cloudiness	Climate extremes: severe storms Hail Wind (> 150 km/h) Rain > 25 mm Rainy days Smoke/smog
Tourism in Saltos del Mocona	Days without rain (Low?) probability of pp	Mean T° 30° > x > 12°	La Niña	Low Pp Wind High UV index	Electric storms T° > 35° Mean T° > 90p	Intense Pp El Niño Hail Storm River height Accumulated pp

alert systems, climate shelters, cool roofs, and drainage upgrades, alongside housing and waste reforms; the 30-year vision converges on a “green city” with open-air creeks and enhanced risk communication. User-specified variables (heat, extreme rainfall, wind gusts) and preliminary thresholds (O2) underpin alerting criteria and design standards,

which are then converted into maintenance regimes and capital plans for objective 1. Cross-department workflows and citizen protocols established through the training extend operational literacy in climate information (O3).

Hydroelectric energy (Yacretá). Operational/weekly focus lies on managing reservoir levels during heatwaves

Fig. 4 Adaptation measures by topic in different time scales to face beneficial meteo-climatic conditions

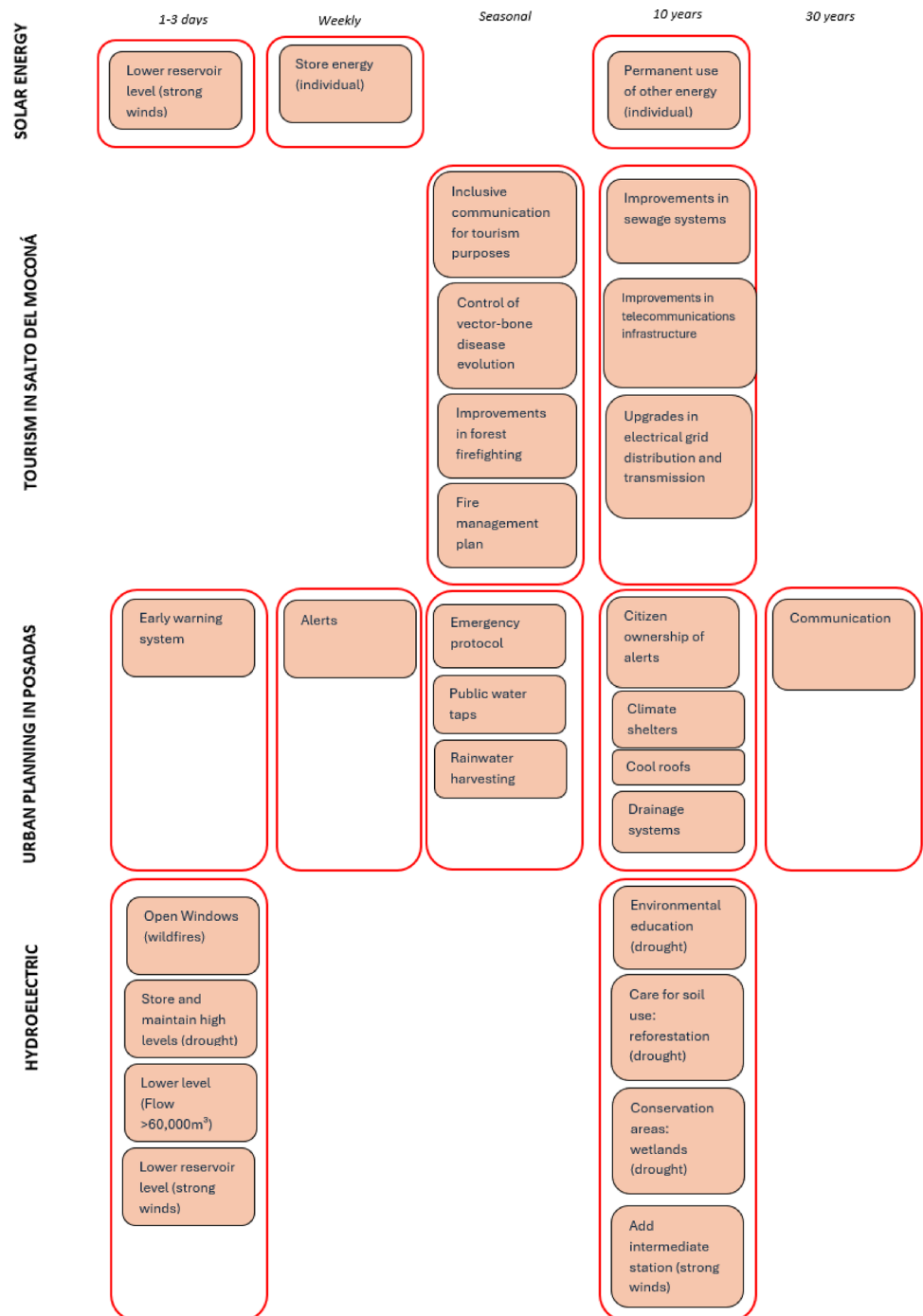


or low precipitation and addressing high-wind impacts, with drought and wildfire contingencies; seasonal measures add coordinated inflow monitoring and watershed actions. Strategically, the portfolio includes precipitation storage, (re)afforestation and deforestation prevention, wetland conservation, environmental education to enhance vegetation cover, and the addition of intermediate energy stations. These actions are keyed to the co-created sensitivity profile (inflow variability, wind, drought) and indicative thresholds (O2), which are translated into operating rules and investment pathways for objective 1. Shared indicator use across plant operators and watershed partners consolidates

multi-actor capability and demand for climate information (O3).

Taken together, the sectoral portfolios operationalise objective 1 using artefacts generated through objective 2, while the embedded routines, roles, and feedback loops cultivate sustained, user-driven demand and capability for climate information (O3). The resulting artefacts represent outputs of the needs-to-design stages; pilot prototypes and operational services are planned as subsequent phases (see Fig. 5).

Fig. 5 Stakeholders' perceptions of sustainability challenges and actions across four domains and timeframes



Post-workshop impact and future perspectives

This section addresses Objective 3, detailing how competencies were built beyond climate specialists, how the co-created artefacts from the workshop (Obj.2) were consolidated, and how these processes generated sustained demand for climate information while enabling the operationalisation of the adaptation portfolios reported in Section [Adaptation portfolios by sector and timescale](#) (Obj.1). The

follow-up activities functioned as bridging actions towards piloting (e.g., refining variables/thresholds, drafting adoption steps), rather than full-scale deployment.

Capacity-building mechanisms and 4-month follow-up Capacity was developed through four complementary levers: (i) scaffolded learning (concept primers → guided demonstrations → mentored group work); (ii) peer learning (mixed profiles, role-rotation, structured peer feedback); (iii) job aids (QC and computation checklists, mind-map

templates, problem canvases); and (iv) assessment-for-learning (micro-tasks with rapid feedback explicitly tied to C1/C2/C5). After the workshop, a 4-month follow-up maintained momentum via (a) monthly online clinics on indicator computation, interpretation, and communication; (b) an asynchronous help-desk for data access/QC and Climpact workflows; (c) a shared repository with templates, example scripts, and sector briefs; and (d) mini-pilots in which groups refined variable sets, updated thresholds with local data, and drafted adoption steps with host institutions. Together, these activities consolidated competencies, embedded routines, and stimulated practice-oriented demand for climate information.

Survey evidence and early uptake All respondents strongly agreed or agreed that the workshop helped them build professional networks and that the presentations were relevant to their work. Knowledge gains were rated 17/20 strongly agree and 3/20 agree; topic selection and depth were 13 strongly agree/7 agree. The only item with mixed views was duration (7 strongly agree/12 agree/1 disagree), suggesting modest scope for adjustment. Within four months, at least five participants integrated indicators into practice, including: an adaptation plan for the city of Posadas incorporating climate information; a historical climate-data recovery initiative and inclusion of climate layers in the Provincial Institute of Statistics and Census yearbook map; and new climate-related lines of work in regional universities. These adoptions expand capacity beyond climate specialists and simultaneously advance Objective 1 by embedding indicators and thresholds into real decision-making processes.

Synergies, barriers, and next steps New inter-institutional synergies emerged from the peer networks formed during and after the workshop, supporting shared use of indicators and coordination across sectors. Persistent barriers include limited staff time and the absence of formal mandates requiring climate information in routine workflows, both of which constrain prioritisation. The following steps should therefore focus on consolidating lightweight job aids, clarifying roles and hand-offs across departments, and pursuing organisational agreements that normalise indicator use.

Overall, these post-workshop processes consolidate Obj. 3, reinforce the co-created outputs of Obj. 2, and enable the sustained, demand-driven use of climate information required to operationalise the adaptation measures of Obj. 1.

Discussion

This study explored the development of sustainability skills within communities (Franklin et al. 2011) by focusing on the co-creation of climate services (Font-Barnet et al. 2021)

and capacity-building (Ziervogel et al. 2022) for non-meteorological experts in Posadas, Misiones, Argentina. We conceptualise the workshop as a capacity-development intervention embedded within a broader co-creation pathway: training activities (scaffolded learning, peer work, job aids) are the mechanism through which non-specialists gain the skills required to lead co-creation steps such as variable/threshold elicitation and indicator design. Through a participatory approach (Font-Barnet et al. 2021), we identified critical areas for knowledge exchange and skill development that align with the region's socio-environmental challenges. The findings demonstrate the importance of tailored capacity-building initiatives in promoting local climate resilience and fostering community engagement, as Sussking and Kim (2022) stated. Methodologically, our contribution is bounded: we report an early/mid co-creation stage (needs identification → user-led variable/threshold elicitation → indicator specification → initial adaptation portfolios) that is deliberately delivered through a concrete capacity-building design (scaffolded learning, peer learning, job aids, assessment-for-learning), *not* complete piloting or operational deployment.

The co-creation process proved transformative, aligning climate services with the needs and realities of non-meteorological experts. Engaging diverse stakeholders—including local government officials, industry representatives, and community members—ensured that the knowledge shared was relevant and actionable, as demonstrated by Golding et al. (2017), Bojovic et al. (2021), and Baulenas et al. (2023). This participatory approach fostered trust, ownership, and long-term commitment to sustainability goals. Significantly, the inclusion of stakeholders without a meteorological or climatological background expanded the reach of climate knowledge, bridging gaps that often exist between science and policy or practice (Bhagavatula et al. 2013; Howarth et al. 2022; Frantzeskaki et al. 2019). At the same time, we note method-sensitive risks: potential facilitator effects and power asymmetries during variable selection, groupthink in focus settings, and uneven technical baselines across participants. We mitigated these via role rotation, structured canvases/mind maps, and rubric-guided feedback, but residual bias cannot be excluded.

The co-creation workshops revealed key barriers and opportunities, as stated by Font-Barnet et al. (2021) and Boqué-Ciurana et al. (2024). Stakeholders emphasised the need for accessible communication of climate data, as developed by Herring et al. (2017), contextualised training materials (as highlighted by Nordgren et al. 2016), and ongoing mentorship. Addressing these barriers required technical expertise and adaptive teaching strategies prioritising inclusivity and collaboration. As a result, participants were better equipped to understand climate risks and apply

this knowledge to decision-making within their respective domains, as identified by Shakya et al. (2018).

This initiative highlighted the critical role of capacity building in nurturing sustainable competencies, such as collaborative problem-solving and scenario-based planning. By participating in the co-creation process, stakeholders developed skills beyond technical knowledge of climate data and information. For example, participants learned to assess interconnections between climatic and socio-economic factors, enabling them to identify solutions that are both effective and equitable. However, indicator specifications and thresholds were preliminary, contingent on available data and expert judgment, and not yet validated against operational performance; piloting should include sensitivity testing, uncertainty communication, and user-centred evaluation of fitness-for-purpose.

Moreover, the focus on interdisciplinary learning encouraged collaboration among sectors, fostering innovative solutions tailored to the local context. These cross-sectoral exchanges emphasised the importance of shared knowledge in addressing complex sustainability challenges, as highlighted by Bryson et al. (2015).

The case study in Posadas underlines the importance of grounding sustainability initiatives in local contexts, as Darier and Schüle (1999) mentioned. Misiones' unique ecological and socio-economic characteristics informed the design of training activities, ensuring that the solutions proposed were feasible and culturally appropriate. At the same time, the insights gained have broader implications for sustainability science and practice.

Globally, the findings contribute to a growing body of evidence supporting participatory approaches to capacity-building. As climate challenges intensify, empowering communities to co-create and utilise climate services is becoming increasingly essential. More cautiously, we suggest that our approach offers a portable scaffolding for non-specialists to lead variable/threshold elicitation (a transparent chain from user need → indicator specification → adaptation options, and a follow-up model that converts training into early uptake; its general value rests on future tests of effectiveness during piloting and operational roll-out. This study offers a replicable framework for engaging diverse stakeholders, integrating local knowledge with scientific expertise, and an approach that could be adapted to similar contexts worldwide.

Conclusion

This study demonstrates that a short, structured intervention can stimulate user interest in climate information and surface sector-specific information needs among non-specialists.

Rather than claiming complete co-creation and deployment of climate indicators, our primary contribution lies in enabling participants to articulate decision contexts, prioritise variables and preliminary thresholds, and outline adaptation options meaningful to their work settings. In doing so, the workshop catalysed early, practice-oriented demand for climate information and established routines and networks that support continued learning and collaboration. By designing the workshop as both a capacity-building intervention and the initial phase of a co-creation pathway, we show how skills development and user-led indicator design can be advanced in a single, integrated process.

By grounding activities in local realities and using a scaffolded, participatory design, the programme helped participants translate abstract climate concerns into concrete questions and actionable next steps. The resulting artefacts—problem/decision canvases, user-led variable registers, initial indicator specifications, and adaptation matrices—should be read as pre-piloting outputs that bridge needs identification and subsequent service development. The immediate outcomes include strengthened peer connections, early examples of indicator uptake in institutions, and clearer pathways for integrating climate information into operational and strategic decisions.

Two limitations temper these findings. First, the time frame was insufficient to assess long-term competence retention or organisational change; future work should include longitudinal evaluation and objective skill measures. Second, some stakeholder groups—particularly rural and Indigenous communities—were under-represented; targeted outreach and inclusive facilitation are needed to ensure equity and relevance.

Overall, the work offers a replicable approach for moving from articulating interests and needs to testable, pre-pilot artefacts that can inform the co-development and implementation of climate services. The value of the approach rests on its capacity to convert user questions into data requirements, preliminary indicators, and adaptation portfolios—and to build the motivation and capability required to carry those elements forward into piloting and operational use.

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