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Co-production of climate services: challenges and enablers

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Climate change is often connected to an increase in weather extreme frequencies and severity, demanding an increased necessity in mitigating greenhouse gas emissions, adapting to and building resilience to these changes and impacts. This happens in a background of climate variability that already impacts several climate-sensitive sectors. There is an urgent need for fit-for-purpose climate services and service professionals to support these mitigation and adaptation efforts. Co-development of climate services can enhance their usefulness (context-specific and fit for purpose), usability (easy access and handling), and usage (transfer and upscale) by ensuring appropriate and iterative engagement between climate service providers and users, development of timely, reliable and usable products, and the provision of services to users in a truly accessible manner. Achieving co-development asks for reframing and scaled-up transdisciplinary, sustained, and multidirectional approaches between a diversity of information users and providers. For these processes, it is key to also address and further minimize or overcome barriers of co-production, while supporting enabling and accelerating mechanisms, better preparation of climate services providers including National Meteorological and Hydrological Services, private actors, civil society, and academia for interdisciplinary and transdisciplinary work, enhanced individual and institutional capacity development and governance mechanisms.

KEYWORDS
climate services, co-production, transdisciplinarity, barriers, enablers

Introduction

Climate is changing in most regions of the World. Since global record-keeping began in 1850, the 10 hottest years all occurred in the last decade with 2023 the hottest on record (National Oceanic and Atmospheric Administration, 2023). This becomes obvious through changes in ‘our’ weather, which are detectable in observations of a large variety of weather variables. Extreme weather events that significantly impact societies, like storms, heat waves, droughts, cyclones and flash floods are getting more severe, last longer, occur in new seasons or are becoming more frequent in different regions of the globe (IPCC, 2021). Current assessments suggest that humanity has already breached the safe operating space for six out of nine key planetary boundaries (Richardson et al., 2023). Regional thresholds and Earth system boundaries are about to be crossed (Rockström et al., 2009a, 2009b, 2023), and a sustainable climate resilient environment for society is at risk.

Societies wishing to avoid irreversible changes and to minimize losses and damages would need to undertake urgent mitigation of global warming. Socio-economic systems must be transformed both to limit GHG emissions and to adopt carbon-neutral lifestyles. Societies must also adapt to ongoing climate extremes and climatic changes, and those communities who are at risk require access to timely and reliable climate services and products and processes to enhance prospective, early action and response to the impact of climate changes (UNDP, 2024). Climate services are key to support societies mitigating global warming and anticipating and adapting to the impacts of climatic changes. They guide processes toward climate resilient human development.

The term ‘climate services’ refers to a complex combination of data, processes, products, actors, sources of knowledge, delivery modes, and organizations, that ensure climate knowledge is not only scientifically robust, but also ‘fit for purpose’ in a particular decision-making context (Doblas-Reyes et al., 2021; Hewitt et al., 2020). As identified since the onset of improvements in El Niño-Southern Oscillation predictions in the late 1980s; many ‘climate services providers’ are public organizations such as national meteorological or hydrological services, and applied research institutions while others are private sector providers all acting as boundary organizations between researchers and users of climate knowledge (NRC, 1999; Agrawala et al., 2001). To develop and deliver such multisectoral knowledge, services require systematic, coordinated approaches that enable and sustain the partnerships, quality-assurance, accessibility, stakeholder engagement, and knowledge-tailoring needed to support decision-making ranging from disaster risk reduction to resilient infrastructure development (Pulwarty and Sivakumar, 2014; Hewitt et al., 2020; Jasanoff, 2004). In line with the Paris Agreement of the United Nations (2015), climate services and products must be based on the “best available science,” while also considering local, context-specific or domain relevant knowledge.

Research into challenges and enablers of co-production of climate services is critical to identify the best practices for promoting interactive science, equity and inclusivity by empowering societal actors, disproportionately affected by climate change, to effectively participate in decision-making regarding climate adaptation and or resilience. While there is abundant literature in cultivating the concept of knowledge ‘co-production’ for advancing climate mitigation, adaptation and resilience, significant gaps in our understanding of challenges and enablers of co-production of climate services are slowing down successful action. This mismatch still exists despite clear acknowledgment of the value of two-way social learning and synergic science for sound decision-making in climate action (IPCC, 2022). This paper addresses this disparity by (i) exploring the challenges and barriers in co-production of climate services; (ii) assessing enablers and accelerators; and (iii) providing recommendations to address some of the challenges in the co-production process.

In this perspective paper, the term ‘climate services’ refers to the processes of development, packaging, translation and communication of climate-related data and other relevant sources of knowledge into customized and routinely delivered knowledge and information products. We note that for the purposes for this paper, we are not engaging in reframing overarching frameworks of “climate services” (e.g., Bremer et al., 2019) but directing our focus towards practice. To that end, climate services practitioners in addition to researchers are included in the author list. In practice, and as longstanding experience shows the success of climate services can be judged by their usefulness, usability, and usage for supporting or improving decision making (NRC, 1999; Boon et al., 2024).

The concept of co-production …in the context of co-development and co-creation

The value to decision-making implies the critical need to understand user needs, values, and decision contexts through appropriate competence in specific sectors or contexts, and processes of co-design and co-production with all relevant stakeholders. Co-production processes go beyond consultation and are iterative, sustained processes of relationship building, empowerment, capacity building, development of shared understanding and joint outputs (Ostrom, 1996; NRC, 1999; Carter et al., 2019; Bojovic et al., 2021; Jasanoff, 2021). This calls for appropriate and iterative engagement and co-design between climate service providers and users, timely and reliable products, and the provision to users in an accessible manner (Christel et al., 2018). A co-development framework creates a space where joint visioning, querying of benefits and uncertainties, and revised problem definitions based on new knowledge etc. are taking place. Co-development includes co-production and is broader in terms of collaborative processes and the sustained enabling capabilities therein, that shape a (hopefully) more sustainable and equitable today and for the future, i.e., beyond traditional risk management approaches. Examples of these spaces include the WMO Regional Climate and National Climate Fora (Hewitt et al., 2020; WMO, 2024), which are evolving beyond the crafting of joint outlooks of impending conditions into active spaces for information exchange and co-development of integrated knowledge.

Climate service ‘users’ are in fact a heterogeneous mix of stakeholders, who often have different goals and desired outcomes (e.g., water for economic vs. environmental and cultural purposes). Most often co-production processes take place across researchers, practitioners, and stakeholder groups operating under different criteria and decision-making arrangements (Pulwarty et al., 2009; McClure et al., 2024) requiring transdisciplinary competence, reaching both public and private sectors as well as civil society. They each have very different backgrounds, decision and value frames, and come from all geographical and institutional scales: international, regional, national, sub-national, community and local levels. They also act within their institutional, cultural and financial services settings that can enable or constrain decision-making choices and flexibility. Users' priorities, competencies, and knowledge are key in the development of climate services that are fit for purpose, and they are essential to the co-development of climate services. There is thus an urgent need to rapidly advance the understanding with respect to communication amongst and between differing knowledge types and categories of "use." It is particularly relevant to generate place-based climate services in climate-data-sparse regions across the globe, putting those local people who are affected by changing climate at the forefront of climate action.

As with many fields engaged in the use of science for decision making, insights that facilitate understanding of the decision context are central (Pulwarty et al., 2009; Daniels et al., 2020; Reveco-Umana, 2023). The approach requires gaining a better understanding and mapping of the user decision-making processes and resource dependencies, and where/how and when weather and climate information might best be incorporated into these processes.

A significant aspect is the co-development of climate information products that target important thresholds of system response, for example specific precipitation rates that overwhelm sewers, heat levels that stunt crop growth, or snowpack that is insufficient for skiing. This information requires iterative interaction between climate and domain experts in agriculture, water resources, ecosystems, cities, infrastructure, human health, energy, transportation, and other sectors that each have their own characteristic profile of climate hazards and risk tolerance. Efforts to identify the climate conditions that are important for a given stakeholder benefit from a recognition that climate conditions that are hazardous for one system may be benign or even beneficial for another, so it is important to assess a wide variety of climate-related impact drivers (Ruane et al., 2022). Collaborative identification of thresholds, as well as the types of changes that matter most (magnitude, frequency, duration, seasonal timing, spatial extent), helps researchers determine datasets, bias-adjustment, downscaling, and analysis priorities to produce appropriate climate service products. This level of specificity is critical given that adaptation is not implemented generically but tailored towards increasing resilience of a particular system to a particular set of hazards.

Barriers, enablers, and accelerators of co-production processes

Users are often unfamiliar with the services available and which ones to trust. Fundamentally important for successful co-production processes of climate services are the knowledge about enabling, accelerating, and restricting conditions. Barriers to effective co-production are manifold and hamper the entire value chain, from the idea to the implementation. They include lack of financial and human resources, lack of documentation and guidance, lack of existing infrastructure/data/fit for purpose models, lack of communication/collaboration and lack of knowledge exchange as well as missing governance mechanisms (Mahon et al., 2019). Furthermore, independent evaluation schemes that favor scaling-up of equitable services are lacking in most cases (Doblas-Reyes et al., 2024; Visman et al., 2022). Co-production, if done poorly, can exacerbate power asymmetries favoring the already technologically sophisticated (Vincent et al., 2020) and can result in negative impacts. It can produce externalities for people not included in the co-development process, and on places, resources, and ecosystems external to the immediate region of analysis. Documented empirical lessons on the use and value of information or the impact of lack of use or appropriate use in significant recent events are needed.

Within the academic communities limited collaboration between the social sciences and climate science leads to extractive engagement and lack of trust (Jasanoff, 2021). In addition, both physical and social sciences can privilege the role of researchers and academic products over practitioner's experience, limiting meaningful transdisciplinary co-development. At the same time, this might lead to a dominance of scientific and data driven perspectives. Furthermore, co-production is a resource intensive process, even if funding is available, which often suffers from rapid turnovers of stakeholders/policy makers and researchers (partners change, capacity is lost, project/grant lifetimes; limited or asynchronous fieldwork windows).

Limited communication between users and providers due to lack of opportunities and their diverse backgrounds cannot cure the insufficient awareness among users regarding suitable climate service providers to fulfill their specific needs. The multitude of choices, such as emission scenarios, models, and data sources, or the level of uncertainty, can leave users feeling bewildered and apprehensive when it comes to utilizing climate information. Benchmarks for establishing the minimum quality necessary for climate information (e.g., use of data from a multi-model ensemble) are needed.

In addition, lack of climate-related observations, and the lack of sectoral and societal data in each context poses large challenges in climate service production (Carr et al., 2020; Cullmann et al., 2020; Mahon et al., 2019). Users perceive the existing climate information as inadequate or insufficient, often due to limitations such as low reliability at high spatial resolution or a lack of transparency about uncertainties. The wealth of climate data is increasing and readily accessible and sufficient to inform a wide array of decisions. The pivotal inquiry centers on identifying which decisions can be optimally informed by the available information and the appropriate characterization of uncertainties.

To overcome barriers and to make co-production more efficient and effective, the clarity and joint understanding of the envisaged products as well as the level of engagement are prerequisites and the process should be agreed upon at the start of the co-development process (Mahon and Trotman, 2023; Steuri et al., 2022; Carter et al., 2019). This includes a dialogue about the specific context (fit-for-purpose vs. one-size-fits-all) and determines the level of engagement for users, providers, and purveyors, also considering that different users may wish to engage in different levels of co-production and might not be able to engage in the entire process due to time and resources restrictions.

Defining, in the co-exploration and co-design phase, the specific assets affected by particular weather and climate conditions and thresholds, would reveal the actors' values frames, and the resources needed. Examples could be the assessment of climatic impact-drivers, the development of impact and stress-testing models for proposed investments or adaptations, and the delivery of guidance or collaborative frameworks for action. This latter function involves both researchers and practitioners working to remove impediments to the flow of information and addressing the nodes that prevent the entire process working as a coherent, inclusive knowledge system.

A good practice example is the ‘Future Resilience for African Cities and Lands’ (FRACTAL) project (2015–2021, https://www.fractal.org.za/lusaka/). FRACTAL worked in eight Southern African cities (Blantyre, Cape Town, Durban, Gaborone, Harare, Lusaka, Maputo and Windhoek) to understand and advance relevant scientific knowledge about regional climate responses to human activities (such as burning fossil fuels or changing land surface cover), and to work with decision makers by enhancing the integration of this knowledge into medium to long-term climate-sensitive decision-making at a city-regional scale (particularly decisions relating to water, energy and food with a lifetime of 5 to 40 years). Within this project 12 guiding principles were identified that align with the growing body of knowledge on principles for co-producing climate services for effective climate resilience research through collaborative transdisciplinary learning. The application of such principles highlights a shift from a focus on climate service products to a collaborative transdisciplinary knowledge co-production process in which co-design and collaborative learning is the defining characteristic and that enhances stakeholders’ understanding and capacity in urban planning, despite challenges posed by resource limitations in developing countries. Additionally, in this process, both stakeholders and modelers alike build their capacity to understand the decision context and the potential of climate information in urban planning processes (McClure et al., 2024).

In addition, acceleration of co-development and uptake and scaling of climate services can be achieved by a better preparation of climate service providers, particularly national meteorological and hydrological services, private sector, and academia, enhanced capacity development across providers and users as well as strengthening of governance mechanisms (Guentchev et al., 2023). Some options are listed in the following:

- Establish transdisciplinary academic-practitioner communities with adequate financial resources.
- Establish and/or implement academic promotion guidelines that credit efforts to engage with stakeholders and guide outcomes.
- Establish context-specific standards, guidelines and good practices for the creation of user-tailored climate information.
- Develop curated and well-documented hands-on tools that allow users to explore scientific spaces and uncertainties.
- Enhance capacity development for both users and providers including but beyond climate training to include vulnerability assessments and network building.
- Enhance governance mechanisms, including fostering a culture of partnerships between executive governmental bodies and climate service providers from national to local levels and back.
- Develop an understanding of the socio-economic co-benefits of user-centered, context-specific climate services.

Funding mechanisms that allow for international collaboration, multi-year support, and locally led and owned activities are central to capacity and sustaining attendant enabling conditions (Pulwarty et al., 2009; Vincent et al., 2020; Vogel et al., 2019). Critical among these enabling capabilities is the implementation of legal instruments, such as laws and governance mechanisms like standards, certifications and labels, that mandate users to base their adaptation and mitigation plans on climate services provided by trusted sources (Doblas-Reyes et al., 2024). These options can be addressed by multiple strategies, for which we offer some insights below.

Early and continuous engagement of all stakeholders and building trust

Early and continuous engagement of all stakeholders stands out as one of the most successful methods for encouraging co-production of climate services. This entails recognizing all the key stakeholders, including the local communities, government ministries, department, agencies and the private sector, who have important roles in the process (Lemos et al., 2012; Norström et al., 2020). By taking on board these various stakeholders, the climate products can be developed in such a way that these services are customized to fit their unique requirements and environments (Ezeh et al., 2024). The stakeholders are engaged through planned workshops, meetings, consultation, which offer a multidirectional approach to exchange and share ideas, best practices and lessons learned (Ezeh et al., 2024; Häberlein and Hövel, 2023). Trust is the foundation of any successful co-creation process. Trust can be built transparency arrangements in funding and budgeting, data acquisition, methodologies, data-processing, interpretation, application, and reporting as well as authorship arrangements, in the case of reporting and publication (Broadhurst, 2024). Trust is also built by mutual respect and helping understand each other’s context, the entry points for action, and benefits derived from the co-developed climate products (Laufer et al., 2018).

Customize the services to the user circumstances

Giving due consideration to the situational requirements and information needs of intended users might entail co-producing vulnerability, impact and adaptation assessments to identify the climate trends and extremes in the area as well as the impacts of the climate on communities and various sectors of the economy (IPCC, 2012; Shand, 2018). In addition, it might be necessary to also assess *the contexts of non-climatic risk drivers and* socioeconomic conditions on the ground that worsen the exposure of sectors and communities to the climate extremes through gender-inclusive and fully participatory approaches. This informs the development of relevant and credible products and services that enhance the capabilities and the rate at which communities can make robust climate-informed decisions, thus addressing local challenges.

Capacity development and awareness creation

Effective adaptation and mitigation, requires human capital development for co-production of climate services. This involves increasing awareness of the needs, the benefits, and new approaches within both scientists and local communities on the importance of co-production of climate services for building resilient systems and communities (IPCC, 2012; WISER-FCFA, 2016). Approaches include developing courses or programs beyond internships and seminars to focus on stakeholders working in climate-related fields, including those providing climate forecasts on co-production processes and best practices (WISER-FCFA, 2016). This way, all stakeholders will be able to engage effectively in the collaboration process and hence, co-production of climate services and products.

Learning from best practices and establishing institutional arrangements

To promote successful co-production, it is critical to highlight and learn from best practices from those that have successfully conducted co-production efforts in the past (IPCC, 2012; Zurba et al., 2022). The goal is to inspire, offer insights, provide learning opportunities, and help avoid potential pitfalls in the communities that would like to engage in co-production (Shand, 2018; Hewitt et al., 2020). At the same time, it is important to have clear roles and responsibilities in the collaboration process. This entails agreeing on the reporting structures and procedures as well as decision making process and redress mechanisms.

Use simple language but not simpler

The field of climate science has complex terms and concepts and its own world of concepts and terms that are difficult to be understood by the non-scientific community (Costa et al., 2022). That being said the use of "simple" language should not be construed to mean backgrounding issues of uncertainty and complexity. Indeed, the appearance of misplaced concreteness can lead to maladaptive responses. For co-production to be effective, it is vital parties involved to use common language understood by both parties (Tarchiani and Bacci, 2024). This also applies to presentation of climate products, which should be done in the language understood by all parties and especially the local people (UKAID, 2019). The use of local language crates an enabling environment of locals to fully participate and put forward their ideas (Mouboua et al., 2024). The use of local languages is also consistent with the right to opinion and expression as expressed in Article 19 of the Universal Declaration of Human Rights and legal provisions of many nations across the globe (UNESCO, 2020).

Discussion

Globally, the demand for climate services on all spatial and time scales is and will continue to grow. The scientific climate-related communities rapidly need to be prepared to foster the creation of climate service infrastructures that will increase utility, usefulness, and use, to improve decision-making outcomes. This is a huge opportunity for research and innovation to overcome the lack of understanding of the decision-making landscapes in the private, civil society and the public spheres. Different user communities will ask for public products for broad use or targeted products for specific clients. Both needs must be satisfied, building on state-of-the-art knowledge, data and experience to overcome the mismatch between what is available, what is needed, and what can or should be co-produced. Civil protection, as an example, has a long tradition working with hazard information and a good understanding of vulnerability. Information by itself is not enough. Challenges persist in connecting the knowledge from disaster risk reduction and climate adaptation to the decision-making context. Climate risk information can better be connected to decisions when reticence to share proprietary data on vulnerability can be solved, tolerance levels and operational ranges of many of our systems can be identified, and information on secondary hazards, climate induced disasters and compound or sequential extremes is freely available globally.

Co-production of climate services is now standard recommended practice, but not as widely practiced as needed. Considering the specific contexts and requirements of the public, private and academic sectors, major challenges to enable and accelerate co-production and deployment of climate services should urgently be addressed.

The climate-change signal has emerged in observations outside the noise from natural variability in many regions, and models have shown some fidelity in some regions, seasons, and for some climatic impact-drivers. Although the robustness of data and models is increasing, there are still regions and seasons in which the signals found in observations are outside of the model distribution. This is partly because of the lack of quality observations for model evaluation and climate-change detection and of missing fidelity of models in some regions. Deep uncertainty also comes from wildcard events, like the regional expression of tipping points and unprecedented extremes or the unexpected evolution of non-climatic drivers (pandemics, technology developments, etc.; European Environment Agency, 2024). The intent to address these uncertainties, surprises, and perceived errors need to be reflected and addressed ahead of co-production.

Barriers to co-production and supporting processes are multifold and exist among both researchers (both physical and social) and practitioners and need to be resolved. Barriers often lie in combinations of lack of observations, financial, technical and human resources, guidance, understanding of the decision landscape, the time taken to develop trust, lack of integration across diverse knowledge systems and types of data (both quantitative and qualitative), suitable infrastructures and governance, capabilities to ensure robust transdisciplinarity, and communications and capacity that vary greatly locally.

The time is ripe to engage the socio-political contexts that can pose barriers to sustainable operationalization of climate services and to build transdisciplinary infrastructures around both social and earth system science elements for more effective climate services. Climate services need to be equally approached both from an information-driven and from a decision-context perspective. Forging stronger links between climate science and the social science and the humanities communities and methodologies would add value to the

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less explored approaches (mainly decision-context perspectives) to climate services experiences.

To enable different sectors and communities to cope with a changing climate, co-production processes and dialogues embedded within an iterative and equitable co-development framework will be different and dependent on public, scientific and private sector characteristics. This asks for learning-based transdisciplinary and bidirectional approaches between users and providers to ensure information flow, uptake, and implementation of scientifically and socially robust climate action as soon as possible. It is very much the accounting of the social, economic, historical and cultural context that makes all the difference between a successful and unsuccessful service. A better coordination of climate services across time horizons (past record lessons (forensics), present, short- and long-term forecasts, and climate projections) and across traditional agencies or disciplinary boundaries would be of benefit for climate services developers, providers and users.

Sometimes it is not possible to provide the desired climate service product amid unrealistic expectations for resolution or precision that are not possible, or information that requires far more resources than available. These shortfalls must be addressed honestly to minimize the risk that irresponsible groups may overpromise and under-deliver, which would foster maladaptation and breed distrust in climate action implementation.

There is an urgent need to promote the capacity and capabilities development of users and providers of climate services. There is also a strong need to address the processes of monitoring, evaluation and learning, often called for but little addressed in the literature. The precise nature of this capacity is an area of active research, learning and testing. Developing the capacity of both users and providers, which varies from place to place and from sector to sector, is a crucial initial step in creating effective climate services. This foundational aspect is still often overlooked and can lead to ineffective provision and uptake of climate services. Users may lack awareness and comprehension of the available climate services, and providers are not attuned to the significance of a collaborative co-production process, the specificities of the decision-context or are unprepared to actively engage with users. Each should be trained and enabled, respectively, ideally through experiential and participatory processes that need to continue beyond internships and grant timelines.

Participatory approaches that incorporate knowledge from multiple actors can help promptly inform decisions, especially in data-scarce regions. Further research is advised to create a robust framework and sustained support for applying this approach in the future. Here is also an urgent need to scale climate services beyond single use and users to large-scale delivery and use. Not doing so is a major impediment, especially to broader-scale adaptation. Reconciling scaling of climate services with co-development and thus co-production processes as new knowledge arises needs to be addressed.

While it's important to advance climate data, the overemphasis (and sometime misleading goal) on obtaining unambiguous, precise, and reliable climate information can lead to decision paralysis. Supporting researchers and users to better understand how to characterize, embrace and interpret uncertainties in forecasts and projections can help to build greater transparency and most importantly ownership and trust in the information provided and in the providers.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

DJ: Writing – original draft, Writing – review & editing. AL: Writing – original draft, Writing – review & editing. RMa: Writing – original draft, Writing – review & editing. SM: Writing – original draft, Writing – review & editing. MN: Writing – review & editing. CB: Writing – original draft, Writing – review & editing. MS: Writing – original draft, Writing – review & editing. AG: Writing – original draft, Writing – review & editing. AS: Writing – original draft, Writing – review & editing. RMu: Writing – original draft, Writing – review & editing. LA: Writing – original draft, Writing – review & editing. AR: Writing – original draft, Writing – review & editing. FD-R: Writing – original draft, Writing – review & editing. RP: Writing – original draft, Writing – review & editing. GL: Writing – original draft, Writing – review & editing. MW: Writing – original draft, Writing – review & editing. SN: Writing – review & editing.

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