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The added value of the process in climate services co-production: Lessons from Niger

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ABSTRACT

Climate services are recognized as an essential tool for sustainable development in strategic and climate-sensitive sectors. In developing countries, particularly in Africa, the literature offers successful examples of application, especially in the agricultural sector, which is dramatically sensitive to climate variability and change. While, initially, particular emphasis was placed on the outcomes of these services and the benefits they provide to users, several authors, more recently, have focused their attention on the process. A climate service is understood as a cyclical process in which the different actors interact, exchange knowledge, and establish relationships and mutual trust. This co-production process serves primarily to bridge the gap between science and society and is particularly appropriate for developing countries. Several authors claim the benefit of the co-production process improving the service usability, but rarely the intrinsic value of the process is recognized. This study aims to describe the process and document its added value using the example of Niger as a case study, where two services addressing drought and floods have recently been developed, tested, and operationalized. This experience allows for inferring lessons that can be useful for researchers and practitioners in developed and developing contexts. The value of the collaboration between different disciplines (transdisciplinarity) and roles (complementarity), and the iterative and interactive learning process emerge as key elements allowing a continuous improvement of the services and the strengthened relationship among actors. The results of this process, albeit qualitatively described in the paper, could guide researchers and practitioners in adopting such an approach and could represent a tangible example for funders and policymakers of the process's added value. Nevertheless, the article recognizes the need to develop a methodological framework for quali/quantitatively assessing the added value of the co-production process and suggests four dimensions to be considered in further research. Finally, the paper recommends the capitalization of pilot experiences through the national and global frameworks for climate services.

Practical implications

Frequently, the gap between climate science and society is the root cause of the limited usability of climate information, especially in rural environments. This gap exists in both directions, with rural populations having a limited understanding of technical-scientific information, and conversely, climate technicians and scientists being significantly disconnected from local conditions. Knowledge silos are a generalized threat plaguing innovation in different sectors, not only in climate-sensitive ones. The concept of climate services co-production aims fundamentally to bridge the bidirectional knowledge gap. Although the concept and application of climate services have been under discussion for more than a decade, it is only recently that attention has been paid not only to the benefits that physical outcomes provide to users but also to the co-production process and its intrinsic value. A climate service is defined as a process in which different actors - be they information producers, intermediaries, users, decision-makers, or other stakeholders - interact, exchange knowledge and build relationships and mutual trust. The co-production theory argues that the process has a value, ultimately greater than the outcome, which must be fully recognized to justify a method that might be seen as excessively long and costly. This study aims to document the added value of the co-production process using the example of two climate services co-developed in Niger addressing the country's

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main climate risks: droughts and floods. They have been recently developed, tested, and made operational with the support of the ANADIA projects (2013–2016 and 2017–2021) co-funded by the Italian Agency for Development Cooperation. The technical innovation of these services lies in the ability to provide appropriate hydroclimatic information for decision-making at the local scale, while the methodological innovation lies in establishing an iterative and interactive process of learning and knowledge exchange between different disciplines, sectors, and actors at the central and local levels. The implementation of such co-production process became an aggregator of strategic partnerships aimed at innovation for sustainable development. In the case of ANADIA, the value of the transdisciplinary co-production process has emerged as a central outcome of the projects.

Even if the proposal of a methodological framework for the evaluation of the process's added value is beyond the aims of this paper, the systematic analysis of the co-production process carried out in Niger highlights some lessons that may be of practical use for researchers and practitioners interested in this area.

The process of climate services co-production has an intrinsic value in addition to the benefits it brings for a better design, development, distribution, access, and uptake of outcomes. The added value of the process lies in bridging the gap between different knowledge systems allowing cross-fertilization between disciplines and complementarity between different levels of decision-making. The process allows the creation of a community of equals, the democratization of the access to climate information and knowledge, and the establishment of relationships of mutual trust.

The process must be cyclical, iterative, and interactive. Innovation is introduced by trials, which are tested, evaluated, and improved repeatedly with the participation of all stakeholders each for their role. On-going changes and adjustments indicate process effectiveness, participation, and interest in improvement. Even if a cycle does not produce the expected improvement in outcome, it is still beneficial because it has explored a new hypothesis and strengthened the synergy among the players.

Climate scientists and experts at NMHS are not used to adopting social science approaches for actors' engagement, partnership, trust-building, and knowledge sharing. The co-production of CS requires shaking the paradigm of a linear innovation process from producers to users. Innovation is a cyclical process where differences in knowledge and points of view are an asset and an added value, if the players are able to accept and adopt them. The willingness to learn from others is therefore the first requirement for actors to be involved in the process.

Collaboration in co-production brings people together across two different axes: disciplines and roles. Both these types of collaboration lead to a better understanding of the context and the needs, opening the way to decision-oriented services. The first advocates for scientific transdisciplinarity allowing the integration of climate-related knowledge with other sectoral knowledge (environment, agronomy, pastoralism, economy, etc.) in a perspective of cross-fertilization (van Breda and Swilling, 2019). The second relates to the concept of complementarity between knowledge systems and broadens the admissible knowledge in the CS production process and includes non-scientific knowledge and perspectives from communities and decision-makers. Furthermore, the second level promotes the shift of the service ownership from the project core team to the community of actors and this is critical for the sustainability beyond the project life span. In addition, and strategically even more important, the collaborations and relationships established, as well as the habit of cooperating and learning together, create a virtuous cycle enabling further developments, innovations, and applications even in other sectors not initially targeted by the service.

Monitoring-Evaluation and Learning (MEL) are a fundamental component of the iterative and interactive social learning process sustaining the co-development of CS. MEL not only allow the progressive improvement of the service but strengthen partnership among actors, creates ownership of the service, and finally fortifies sustainability. Moreover, by demonstrating the value of the service MEL can convince policymakers and funders to make additional investments. However, the value of the co-production process cannot be assessed only in terms of physical outcomes. The process value is difficult to measure since it is an intangible outcome. Therefore, a reference framework for acknowledging the substantial value inherent in the co-development process is needed.

From the experience and perception of the stakeholders involved in Niger, we suggest considering the following four dimensions in the evaluation of the added value of the process in climate services co-production:

1. Value added to the Climate Service co-production: This dimension explores the value created beyond more conventional approaches on the service production and the improvement over time due to progressive technical enhancement resulting from the co-production process. It can be assessed on every step:
   - o Identification of needs: better definition of roles, responsibilities, establishment of agreements, identification of the decision-making context, specific needs of users and relation with climatic risks.
   - o Development of solutions: participation of all stakeholders and contribution with different systems of knowledge.
   - o Delivery of information: appropriateness of content, format, language and timing, agreements with intermediaries.
2. Value added to the Climate Service functioning: This dimension explores the value created beyond more conventional approaches on the service efficiency/effectiveness, and can be evaluated on:
   - o Access to information: awareness of users about communication channels and appropriateness of the channels in respect to users needs.
   - o Uptake of the services: trust and appropriateness to the social context built over time through the iterative process.
   - o Action by Users: matching identified needs, enhancement of service impacts due to increased users' ability to act on information and advises, attributable over time to the iterative process.
   - o 14. MEL: improved feedback mechanism (enhanced capacity of technical-scientific actors to gather feedback from users and intermediaries), involvement of stakeholders and proposals/requests for improvement.
3. Value added to the expansion of the service: this dimension explores the value created beyond more conventional approaches on the service scaling-up, expansion and financial sustainability after the first funding period:
   - o Geographical expansion: new areas/communities covered after the end of the funding cycle that enabled its co-production.
   - o Extension of the scope of the service: types of decisions supported, new risks addressed, new sectors involved after the end of the funding cycle that enabled its co-production.
   - o Diversification of the funding mechanism: new financial partnerships involving public and private funders or new mechanisms of cost-sharing and business.
4. Value added toward new services: this dimension explores the value created beyond more conventional approaches in building the capacities of actors and stakeholders for imaging and producing new services:
   - o New knowledge: increased transdisciplinarity and increased technical capacities of stakeholders for further development, but also in terms of increased demand for services (new or improved) from users' communities.
   - o New relationships: relationships or agreements adopted by the involved actors with other actors in the same value chain or in another related to the co-produced service, increased trust by the public, enduring relationships and agreements

established among stakeholders after the co-production process.
- o New services: identifying, designing, developing new services by the different actors originally involved.

We are convinced that the description, albeit qualitative, of these benefits is useful in informing and persuading researchers and practitioners to adopt such an approach; nevertheless, the article recognizes the need to develop a methodological framework for quali-quantitatively assessing the added value of the co-production process. Such a framework could address the above mentioned four dimensions. Moreover, we recommend that lessons learned through case studies such as the one documented in this paper are capitalized by the Global and National Frameworks for Climate Services.

Data availability

Data will be made available on request.

1. Introduction

Climate services (CS) link “climate knowledge and action at the science-society interface” (Bremer et al., 2019) and imply “the transformation of climate-related data together with other relevant information-into customized products such as projections, forecasts, information, trends, economic analyses, assessments (including technology assessments), counseling on best practices, development, and evaluation of solutions and any other service concerning climate that may be of use for the society at large” (Street, 2016). Since the definition of the concept in 2011 by WMO (WMO, 2011), a climate service, rather than being a simple climate product, implies the concept of process and relations among actors. Nevertheless, CS are still often associated with a supply-driven delivery of climate information from providers to users (Brasseur and Gallardo, 2016). Back in 2012, Lemos had identified the “usability gap” (Lemos et al., 2012) between “what scientists understand as useful information and what users recognize as usable in their decision making” advocating for the evolution from a linear conceptual model to a more complex model involving multiple interactions between information producers and users. Lemos still used the traditional definitions of “users” and “producers” as main players, which nowadays are much more blurred with large literature acknowledging the importance that “users” participate in producing the service and the “producers”, in turn, use information produced by the “users”. Therefore, the roles are not static because all actors in some way produce and use information.

While confirming the starting point that climate information must be salient, legitimate, and credible (Cash et al., 2003), barriers to the “effective and reliable transformation of climate data into useable climate services” (Bremer et al., 2019) still exist both in developed (Buontempo et al., 2018) and developing contexts (Vaughan et al., 2018). These barriers are primarily determined by the process used to design and implement CS. The linear model, yet adopted by governmental organizations such as National Meteorological and Hydrological Services (NMHS) is based on the concept that it is sufficient to fill the need for climate information and therefore called by Vogel the “deficit model” (Vogel et al., 2019). Co-production of CS, including all forms such as co-design, co-development, etc., proposes an alternative method to bring the users at the centre of the activity and to establish collaborative processes of mutual learning and knowledge exchange among all actors (Weichselgartner and Arheimer, 2019). The implementation of a co-production approach necessitates a transformative shift, involving the integration of social science. This integration is crucial for understanding various sociological contexts, behaviors, and non-climate constraints that influence decision-making and adaptation in climate-sensitive sectors (Findlater et al., 2021). The extensive literature review of Vincent et al. (Vincent et al., 2018) outlines the origins and conceptual framework of co-production, which according to Lemos and Morehouse (Lemos and Morehouse, 2005) respond to the interactive science’s principles of interaction, interdisciplinarity, and reflection of user needs. Several experiences of co-production are documented by literature in developing (Butterfield and Osano, 2020; Daniels et al., 2020; Steynor et al., 2020, among others) and developed (Terrado et al., 2023; Krauß, 2020; Kruk et al., 2017; Prokopy et al., 2017 inter alia), countries. Moreover, some structured guidance frameworks for CS co-development have been recently proposed by different authors, based on specific experiences or literature review:

- The prism model of co-production suggests eight ‘lenses’ for looking at the production of climate science (Bremer and Meisch, 2017) in order to take into account the complexity of the process.
- Vincent’s Principles and Characteristics of the co-production cycle are distilled from a comprehensive literature review (Vincent et al., 2018).
- The WISER’s (Weather and Climate Information Services for Africa) manual for co-production in African weather and climate services, provides building blocks and principles based on several experiences across Africa (Carter et al., 2019).
- The Tandem framework adopted by the Stockholm Environment Institute proposes iterative steps to inform, guide and structure transdisciplinary interaction among actors (Daniels et al., 2020).

All these frameworks aim to provide theoretical as well as practical references to researchers and practitioners who venture into the science-society interface which Bremer defines as *terra incognita* and where he pragmatically suggests to ‘learn-by-doing’ (Bremer et al., 2019).

The success of a co-production process requires building a trusting relationship between the different actors (Lacey et al., 2018). This symbiosis between actors is built over time, through knowledge transfer activities and inclusive processes, based on the continuous interaction between research, technicians, decision-makers, and society. The process is progressive, iterative and resources consuming (Vincent et al., 2021). Therefore, the cost-benefit assessment could lead most institutions to consider co-production too expensive, if only the product it enables is considered as an outcome. By contrast, the co-production process has a value in itself, which may even be greater than the value of the knowledge product (Norström et al., 2020). Even if several frameworks for evaluating the outcomes of the co-production process have been proposed (Wall et al., 2017; Bremer et al., 2021; Salamanca and Biskupska, 2021; Visman et al., 2022), no method has yet been proposed for assessing the added-value of the co-production process of CS. According to Steynor (Steynor et al., 2020), a qualitative evaluation may include an improved mutual understanding of the common arena by knowledge holders, enhanced relationships built through the process, as well as a smoother flow of data, information, and feedback. Furthermore, Carter et al. (Carter et al., 2019) add the ownership of the service leading to a greater uptake and sustainability and the behavioural changes in the use of weather and climate information for decision-making.

The objective of this paper is to document the value of the process in the co-development of CS, identifying lessons learned and good practices that could be tested by researchers and practitioners in other contexts. We analyse the co-development process of two different CS implemented in Niger within the projects Adaptation to Climate Change and Disaster Risk Reduction in Agriculture for Food Security –phases 1 and 2 (ANADIA). The services address the country’s main climate risks, droughts, and floods. The technical innovation of these services lies in the ability to provide appropriate hydroclimatic information for decision-making at a local scale, while the methodological innovation lies in establishing an iterative and interactive process of learning and knowledge exchange between different disciplines, sectors, and actors at

Table 1
Description of climate services co-developed in Niger.

Service	Information	Decision-makers	Decision
Hydrological service	Flood vigilance warning	DGPC and other centralized institutions MunicipalitiesCommunity committees (SCAP-RUs)	Activating the National alerting system Alerting communities Informing community and downstream committees (SCAP-RUs)
	Flood Risk reduction plans	Municipalities	Local planning
Agrometeorological service	Seasonal forecasts and advice, 10-day agrometeorological forecasts and advice	Municipalities Local extensionists Pilot Farmers Farmers	Activating mitigation measures Advising farmers Own crop management and advising community Crops management

the central and local level. We refer to the WISER's manual (Carter et al., 2019) to analyse the process steps and we discuss the results with reference to the process principles and product characteristics identified by Vincent (2018).

Section 2 presents the services that are the object of the analysis and resumes the conceptual frameworks used for presenting the findings (section 3) and discussing the results (section 4). Section 5 resumes the lessons learned while in section 6 some conclusions are provided.

2. Materials and methods

2.1. Context

Niger is exceptionally vulnerable to climate variability and change compared to many other regions because most of its population lives below the poverty line, and it bases much of its livelihood on climate-sensitive activities such as rain-fed agriculture and pastoralism. Severe, cross-sectoral, and long-term impacts on economic, ecological, and social systems are being already observed and, in some cases, are irreversible (Hiernaux et al., 2009; Descroix et al., 2018; Fiorillo et al., 2018; Massazza et al., 2021). As a result, climate change poses additional challenges to achieving the Sustainable Development Goals. In addition, climate change and variability are often contextual and multiplying factors for migration and violent conflict (Rüttinger et al., 2015).

The potential benefit of investments in weather and CS and early warning systems (Genesio et al., 2011) far outweigh the costs of climate change and variability impacts (WMO, 2021) and, in Niger, they are considered a powerful tool for the development of climate-resilient agriculture (Tarchiani et al., 2017; Bacci et al., 2020). However, in Niger, as in many developing countries, a critical bidirectional divide exists between climate science and society in the sense that the knowledge produced by climate science often cannot be applied by potential users for a number of reasons that Lemos et al. have summarized in the term "usability gap" (Lemos et al., 2012). From one side, scientists and technical staff of NMHSs are often disconnected from the reality of rural areas and assume that scientific knowledge they produce is actionable, while often it is not. On the other side, rural communities do not understand scientific information, nor even have access to, and base their decision-making processes on empirical and traditional knowledge systems. During the last decade, the ANADIA projects have promoted a rigorous but participatory process of climate risk assessment in the Dosso (Tiepolo et al., 2018) and Tillaberi (Tiepolo et al., 2019) regions in Niger to subsequently identify the municipalities particularly at risk and facilitate the co-definition with local actors of the most suitable risk mitigation strategies (Tiepolo and Tarchiani, 2016; Katiellou et al., 2021). ANADIA has therefore promoted the co-production of CS dedicated to the rural populations, adopting a flexible and integrated approach of research for development and training (Tarchiani et al., 2020b), which allowed to co-design, co-develop, co-test, and co-evaluate with national partners and local actors CS that in the final phase have become operational. These services address the main climatic risks in Niger, namely floods and drought. More specifically, these are the Sirba Local Early Warning System against Floods (SLAPIS) and agrometeorological assistance for rural producers against droughts Table 1.

The increase in the frequency and intensity of both fluvial and pluvial flooding phenomena in Niger, especially in the southwestern area, brought, during the first ANADIA project, to identify the need to develop a flood warning system for the Sirba River, the main tributary of the Niger River in its mid-basin. The floods of the Sirba, that have become increasingly more intense and frequent, have caused significant damages in recent years not only to the riverine populations but also to those downstream of the confluence with the Niger River down to the capital Niamey (Massazza et al., 2021). SLAPIS is a community-based hydrological early warning system that provides flood impact forecasts and supports local planning in flood risk prevention (Tarchiani et al., 2020a). The system co-production started in 2018, in 2019 it was tested and progressively improved through the collaboration between scientific and technical partners, local authorities, and communities to then become operational in 2020. The system's co-production approach has paid off with the full involvement of riparian communities at all levels, from risk awareness and monitoring to warning communication and response.

Rain-fed agriculture in Niger ensures the livelihood of a large part of the population but is extremely vulnerable to climate variability and change. Droughts have a devastating impact on crop production, mainly due to the low resilience of production systems and the structural inability of smallholder farmers to adopt risk mitigation and adaptation strategies. Since its first phase, ANADIA has fostered the co-production of agro-meteorological assistance services to support smallholder farmers in coping with drought risk, allowing them to optimize available resources and improve crop yields (Tarchiani et al., 2021a). Adopting an iterative social learning approach, Niger Meteorological Department (DMN), municipalities, local extensionists, rural radios, and farmers have co-developed across several years of collaboration agro-meteorological analysis and forecasting procedures adapted to local use, an efficient mechanism for training and information as well as an effective communication system based on multiple channels, from rural radios to text and voice messages and social media. Between 2018 and 2021, 35 local workshops for 700 villages and 1469 households have been organized. In 2020, an independent impact evaluation had shown how farmers made extensive use of the agro-meteorological service ensuring a significant reduction of losses and an increase in yields by about 20 % (Bacci et al., 2023).

2.2. Methods

According to the "process-centric" approach described by Daniels et al. (2020) in this research, the service is not identified in the product itself but in the process, which is an iterative process of social learning, knowledge exchange, and monitoring to strengthen the shared ownership of the service. The process is analysed in the results according to the WISER's guidance on Equitable and Inclusive Co-production for

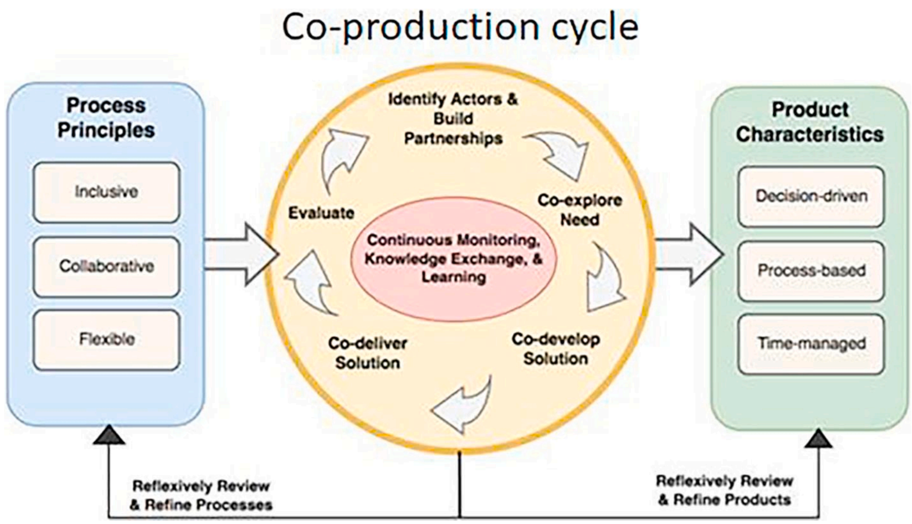

Fig. 1. Product characteristics and process principles of the climate service co-production cycle. Source: (Vincent et al., 2018).

Weather and Climate Services (Carter et al., 2019). Evidence of the added value of the process is described for each of the guidance's six building blocks:

1. Identify key actors and build partnerships aiming to ensure the inclusion of all the relevant actors including producers, users, and intermediaries.
2. Build common ground aiming to develop a common understanding, across actors and disciplines.
3. Co-explore needs focusing on the joint identification of the needs underpinning the service and definition of roles and responsibilities cementing the partnership between actors.
4. Co-develop solutions addressing the collaborative effort in which all actors share knowledge and expertise for the design of the service enabling the production of outputs as well as the uptake and use.
5. Co-deliver solutions allowing for a suitable packaging and communication strategy of the service, ensuring access, understanding, uptake, and effective use by target groups.
6. Evaluate, which is a cross-cutting block on the whole co-production process ensuring feedback and learning from the experience that strengthens the process and allows regular improvement as well as updating of the service.

The results of the research are therefore discussed using as reference the principles of the process and the characteristics of the products (Fig. 1) derived from the theory and practice of co-production (Vincent et al., 2018) which advocates for the product to be decision-driven, process-based, and time-managed, and for the process to be inclusive, collaborative, and flexible. We refer to Vincent et al. because the "process-based" lens allows us to analyse both the "more intangible results of co-production" and the production of tangible co-production outputs.

2.3. Semantics

Within this paper, the following terms are frequently used. To avoid misunderstandings, we provide a brief description here of the meaning attributed to them by the authors:

Climate service

A climate service can be defined as the systematic provision of climate information, data, and knowledge, tailored to meet the specific needs of decision-makers (individuals, local authorities, businesses, governments, among others). Climate services aim to assist users in understanding and managing climate-related risks and opportunities. These services, despite the term "climate" suggesting a long-term timescale, encompass all types of information ranging from historical climate data to observations, from nowcasting to weather forecasts, and from seasonal climate predictions to future climate projections. This seamless continuum across time is now commonly implied in the term, although some may use the term "Weather and Climate Services". In this publication, for brevity and to encompass both the agrometeorological and hydrological components, we use the more general and inclusive term "Climate Service".

Multidisciplinarity, interdisciplinarity and transdisciplinarity

Multidisciplinarity refers to an approach where different disciplines work independently on a common problem without significant interaction. Each discipline contributes insights from its own perspective, but there is limited integration of approaches.

Interdisciplinarity involves collaboration and exchange of ideas between different disciplines. The goal is to create a synthesis of knowledge by integrating insights from various disciplines.

Transdisciplinarity refers to an approach that goes beyond disciplinary boundaries to address complex problems. It involves collaboration and integration of knowledge from multiple disciplines, but it also incorporates non-academic knowledge and engages with various stakeholders, including communities, policymakers, and practitioners.

Therefore, transdisciplinarity takes a step further by not only involving multiple disciplines but also engaging with stakeholders outside academia, such as communities, policymakers, and practitioners.

Co-production of climate services

The "co-production of climate services" refers to a collaborative and interactive process involving the active engagement and partnership of all climate service's players (such as meteorologists, climate scientists, researchers, media, intermediaries, decision-makers, communities) in the development, design, and delivery of climate information and services. This approach recognizes the importance of tailoring climate information to meet the specific needs of users, taking into account their diverse contexts, vulnerabilities, and decision-making processes. In co-production, players work together throughout the entire process, from co-defining the needs, co-developing the solutions, co-delivering the information and co-evaluating the process.

While "co-production" and "co-development" share similarities in their collaborative nature, in this paper, and according with Carter et al. (2019) we use them referring to distinct processes:

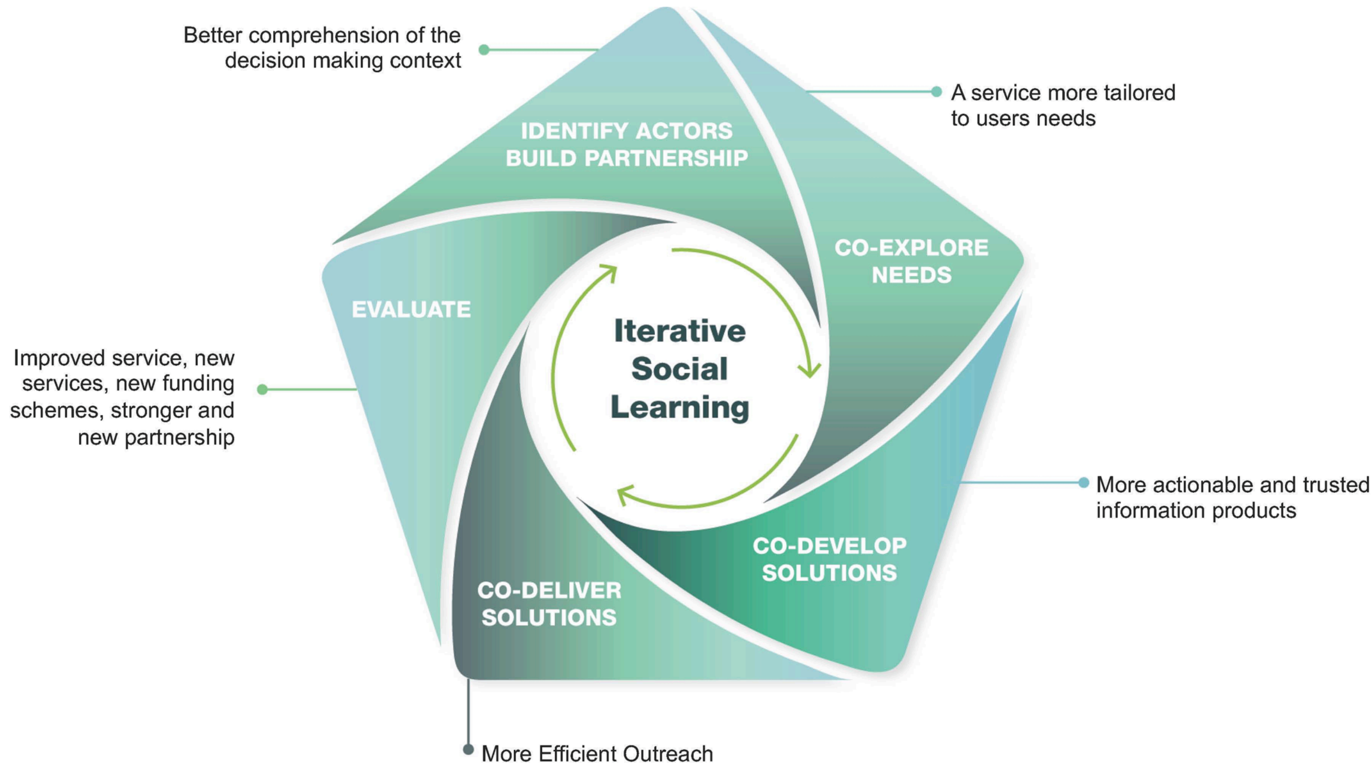

Fig. 2. The circular process for the co-production of climate services and its added value.

- Co-production refers to the whole process from identifying users to evaluating results and learning how to iteratively improve the service;
- Co-development refers to the development of technical solutions which is a block of the co-production process.

Intermediaries

NMHSs often need intermediaries (boundary organizations) to fill the gap between themselves and end-users. Intermediaries have content knowledge and play the role of a knowledge broker, or connector, in co-production (Carter et al., 2019). Their functions are to: (i) enable linkages; (ii) ensure meaningful interaction between actors; (iii) support 'language translation' so that producers and users understand each other; (iv) create or facilitate systems for knowledge access, combining different forms of knowledge (e.g. scientific and local), communication, and feedback on the use and impacts. Intermediaries can facilitate the establishment of mutual trust and the "translation" of science into the languages easily understandable by end-users. Depending on the context, these knowledge brokers can be other farmers, private companies, agricultural extensionists, NGOs or well-informed presenters and journalists working in the media (Cegnar et al., 2023).

Subsidiarity and complementarity

In decision-making, subsidiarity refers to the principle of delegating authority and responsibility to the lowest or most local level capable of addressing and resolving a particular issue. It suggests that decisions should be made at the level closest to the individuals or communities affected, unless a higher level is necessary to address problems that cannot be effectively handled at a lower level. The aim is to empower local entities, promote autonomy, and enhance efficiency by allowing decisions to be made by those with the most intimate knowledge of the situation.

Complementarity emphasizes the idea that different components or actors can work together to enhance each other's strengths and produce a more effective or comprehensive outcome. In this paper, complementarity involves combining different knowledge systems in a synergistic way, where each part complements the others, filling gaps or compensating for weaknesses.

In practical terms, these principles can be applied by assessing where decision-making authority should reside based on the specific nature of the issue (subsidiarity) and by strategically combining diverse perspectives, expertise, or resources to inform and shape decisions (complementarity).

3. Results

Since the service is identified in the process and not in the product itself, we describe the process steps for each co-produced service and the outcomes using WISER's building blocks (see in the Appendices Table A.1). For each building block we propose elements for appreciating the added value of the process Fig. 2.

3.1. Identify actors and build partnership

While in the case of the Agrometeorological service (AS) main actors were already identified through the existing transdisciplinary Community of Practice (Tarchiani et al., 2017), in the case of Hydrological service (HS) they were identified at the beginning of the process.

Preliminary explorative meetings were organized with potentially relevant stakeholders to identify different types of actors (decision-makers, intermediaries, providers of information) and the decision-making context. The process was led by the Department of Hydrology (DH). The SLAPIS core team was composed of the following competencies: Hydrologists, Hydraulic engineers, Meteorologists, EWS specialists, and Communication specialists. The identified SLAPIS's actors are specified in Table 2. The actors involved in the AS are specified in Table 3.

Table 2
SLAPIS's actors.

Project core Team	Hydrology Department (DH), Meteorology Department (DMN), National Early Warning System Coordination Unit (SAP), Polytechnic and University of Turin (DIST), Institute for BioEconomy (IBE-CNR)
International Level:	Niger River Basin Authority, AGRHYMET Regional Centre, EU-Joint Research Centre, Swedish Meteorological and Hydrological Service
National Level:	Directorate General of Civil Protection, National Food Crisis Prevention and Management System, National Early Warning System, Ministry of Humanitarian Affairs,
Local Level:	Majors (3), Decentralized technical services (9 - Agriculture, environment, pastoralism per each municipality), Vulnerability Monitoring Observatories (OSV – 3), Community Early Warning and Emergency Response Systems (SCAP-RU – 5), Rural Radio (1), Communities (5)

Table 3
Agrometeorological service's actors.

Project core Team:	Meteorology Department (DMN), Ministry of Agriculture/Department of Agricultural Statistics (DSA), National Early Warning System Coordination Unit (SAP), Institute for BioEconomy (IBE-CNR), Polytechnic and University of Turin (DIST)
National Level:	National Food Crisis Prevention and Management System,
Local Level:	Majors (8), Decentralized technical services (24 - Agriculture, Environment, Pastoralism), Vulnerability Monitoring Observatories (OSV – 8), Rural Radios (8), Communities (1 6 0)

3.2. Build common ground

While the main actors of the AS were already accustomed to collaborating, in the case of HS an initial transdisciplinary workshop was organized to gather all actors and stakeholders on December 19th' 2017. The workshop enabled a common comprehension of the problem to be addressed and a shared strategy to be followed for the co-production of a service firmly grounded but, at the same time, built on sound science and technical robustness. This first workshop was also the starting point of the iterative process of social learning, knowledge exchange, and monitoring, which continued during the following years and allowed to strengthen the shared ownership of the service. Moreover, two local meetings with the communities at risk were held at the very beginning of the process with the aim of assessing flood risk in a participatory manner (Tiepolo and Tarchiani, 2016). Those meetings, carried out in 2015, highlighted the need for a local flood early warning system.

In the case of AS, local initial workshops were organized in the target municipalities (at the beginning 3 and later 8 municipalities across Dosso and Tillaberi regions in Niger). Those workshops were organized locally to familiarize the project core team with the specific context and to allow the participation of different actors of the local community, including representatives of farmers, civil society organizations, agriculture extension system, local radios, etc.

In both cases, the main result of this block was the establishment of a common understanding of the problem and an outline of a strategy to be implemented to reduce the risk of flooding on one hand and of drought on the other hand. In the case of HS, the service was completely new to the region as the flood risk has only recently increased. Therefore, this first step was essential in creating a favorable environment and a shared starting point for subsequent developments, as well as a better understanding of a relatively recent phenomenon. In the AS case, instead, local populations were already accustomed to face drought risk, but agricultural decisions are more complex, and the local knowledge system is challenged by climate change. The interpretation of the information by the farmer is essential for the uptake and every time new information is introduced it needs to be adapted to the decision-making context. Thus, this first step enabled the integration of various knowledge levels, which is an essential prerequisite to convey information into action.

3.3. Co-explore needs

In the case of HS, an actor consultation was carried out with focus groups and interviews to co-define the different actors' needs according to their decision-making process. However, the first step was the analysis of the national alert mechanism to harmonize the decision-making needs with the National Alert Code (République du Niger, 2019), which defines the general framework of the warning process at different administrative levels: Civil Protection at a national level, Governors in the regions, Prefects in departments and Mayors in the municipalities (Article 5). Consequently, an analysis of the needs of the actors in terms of information on the flood risk was performed through semi-structured interviews with national stakeholders, technical workshops with local administrations, and focus groups with the communities. The result was the definition of the needs of each actor in terms of:

- information relevant to the decision-making process or intermediate actions;
- communication channels more suitable for each actor (email, text message, telephone, etc.)
- format of the information fitting actors' capacities of understanding and decision-making needs;
- timing of the communication according to the early warning process.

In the case of AS, the basic needs were already identified from the long-lasting collaboration between the main actors. Anyway, transdisciplinary workshops were organized before the crop season by gathering different experts such as climatologists, meteorologists, agrometeorologists, IT specialists, communicators, agricultural extensionists, pastoralists, environmentalists, and local managers of the involved municipalities. These meetings were organized regularly before the beginning of each crop season for three years. The aim was to iteratively refine the information and communication needs for the different information to be delivered at different times and in different formats. Moreover, roving seminars (RS) with farmers and local actors were also organized in each municipality before the cropping season to identify further needs arising from the field.

The technical outcome of this block for both services was the identification of the needs of different types of actors in terms of information content, channels of communication, timing, and format. The needs of intermediaries (rural radios, extensionists), who, even if they do not use the information for their decision-making, oversee its dissemination to users, have also been explored to facilitate their contribution and avoid any misunderstanding of the content to be communicated.

Moreover, this initiative has generated a notably valuable intangible result that unfolded gradually. In particular, diverse stakeholders, especially those at the local level, have perceived themselves as essential contributors to the process. This has led to the development of stronger and more trusting relationships with experts at the national central level. An illustrative example of the enhanced value of this initiative is the autonomous establishment of WhatsApp groups by the National Meteorological Department, a feature that was not originally envisaged. These groups facilitate direct communication with local stakeholders.

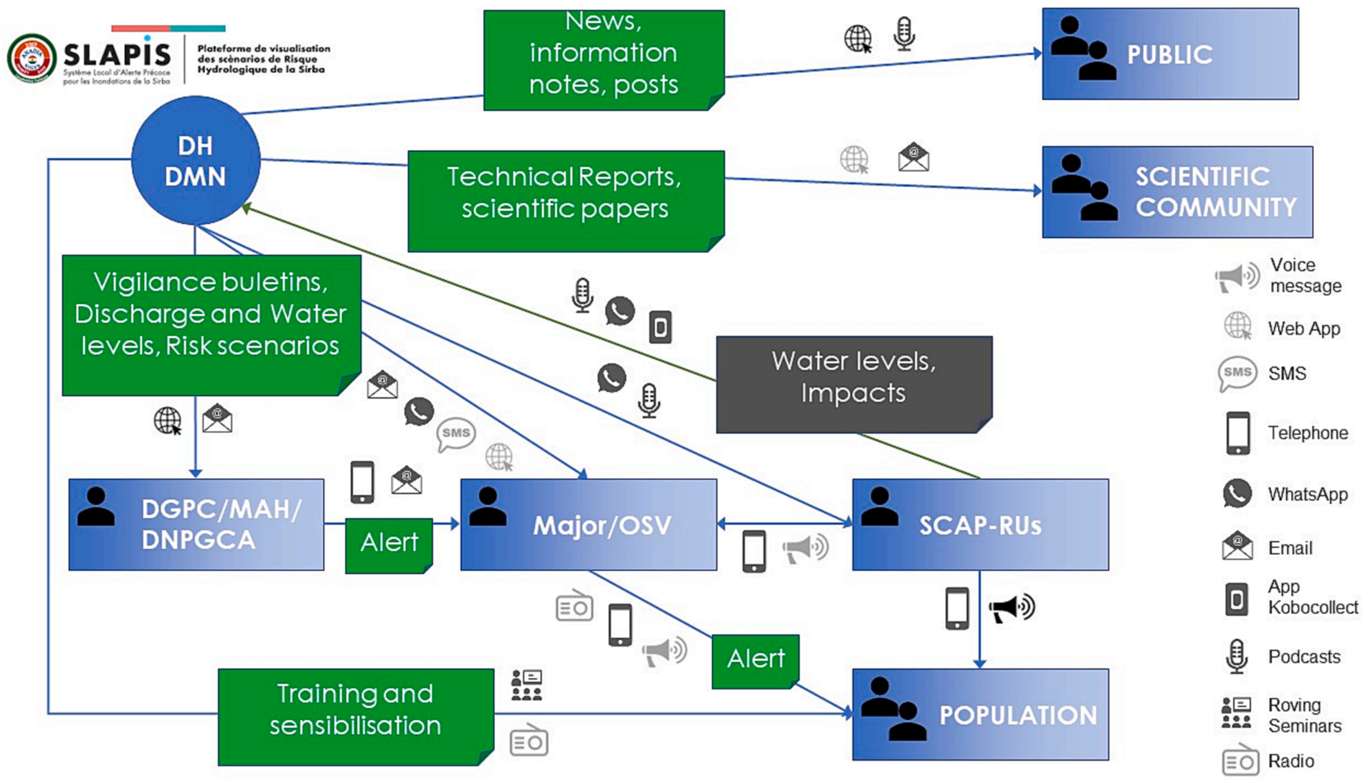

Fig. 3. Hydrological Service communication mechanism.

3.4. Co-develop solutions

The HS includes two levels of solutions co-development. The first one is the technical level supported by a transdisciplinary working group composed of hydrologists, hydraulic engineers, IT experts, communicators, local planning experts, and disaster risk reduction specialists. This technical working group regularly interfaced with institutional decision-makers (local managers, OSV, agricultural extensionists) to receive feedback and suggestions. The second level specifically addressed the need for the inclusion of users' and intermediaries' knowledge in the process of service production. OSV and SCAP-RUs, respectively at the municipality and community level, actively participated in the co-development ensuring locally observed water levels and trends, observed flood damages, and local response strategies. The two levels regularly and iteratively exchanged and shared knowledge to co-develop and improve the technical solutions.

In the case of AS, similarly, the technical level of solutions co-development was ensured by a transdisciplinary working group interfaced with the local level. The collaborative effort to develop appropriate solutions also in this case was centred on the inclusion of users and intermediaries in the process. Local knowledge integration in the service concerned crop phenology, market prices, pasture condition, water point condition, livestock condition, locally observed rainfall, and food security conditions, provided by extensionists and pilot farmers. An appropriate mechanism for feedback from local players was also implemented ensuring the continuous improvement of the service.

The outcomes of this block are the proposed solutions, co-developed through specific iterative and collaborative mechanisms involving players at all levels. The inclusion of local knowledge was greatly helping the uptake and use by communities of both services. In the case of the HS, the installation of coloured hydrometric staffs managed by the SCAP-RUs increased awareness of the flood risk among communities by showing the levels of the hazard thresholds—the height that the flood can reach. Local hydrometric staffs also empowered communities with direct observations useful for the whole system and directly for the concerned community and those downstream, following the approach described by many authors in Asia (IFRC, 2012; Mercy Corps and Practical Action, 2010). In the case of AS, the direct observation of rainfall by farmers in their field using cheap rain gauges distributed by the project empowered farmers in taking an autonomous decision but also cemented the sense of collaboration with technical actors and increased the trust in the service, enabling farmers to directly verify the forecasts.

With regard to AS, the value of the process has been clearly assessed by Bacci et al. (2023), emphasizing that the product of the service doesn't guarantee per se positive impacts. Whereas a combination of product delivery with awareness rising and training ensured by the cyclical iterative process with the farmers, implemented by the project, does provide socioeconomic benefits.

3.5. Co-deliver solutions

Last-mile communication of HS builds on a communication plan co-designed via focus groups with local governments and community representatives. Starting from the needs assessment, multiple communication channels were activated ensuring the access and understanding of different actors and the availability of information at a timing suitable to take action (Fig. 3). Information on the state of vigilance provided by DH at different administrative levels is transformed into alert messages by the competent institutions according to the magnitude and amplitude of the forecasted flood risk. Moreover, a set of measures were adopted to create awareness at a community level about the flood scenarios and the actions to be taken in the case of a warning. A simple visualization approach was adopted to aid the interpretation of flood scenarios (Budimir et al., 2020), using a four-color classification (ISO, 2015). Colours are the core of warning messages and are associated with discharge, return periods (RP), and impacts on the main riverine settlements (Massazza et al., 2019). The four-color classification of water levels was reproduced on qualitative hydrometric gauging staffs installed along the river, as well as on information panels in the villages

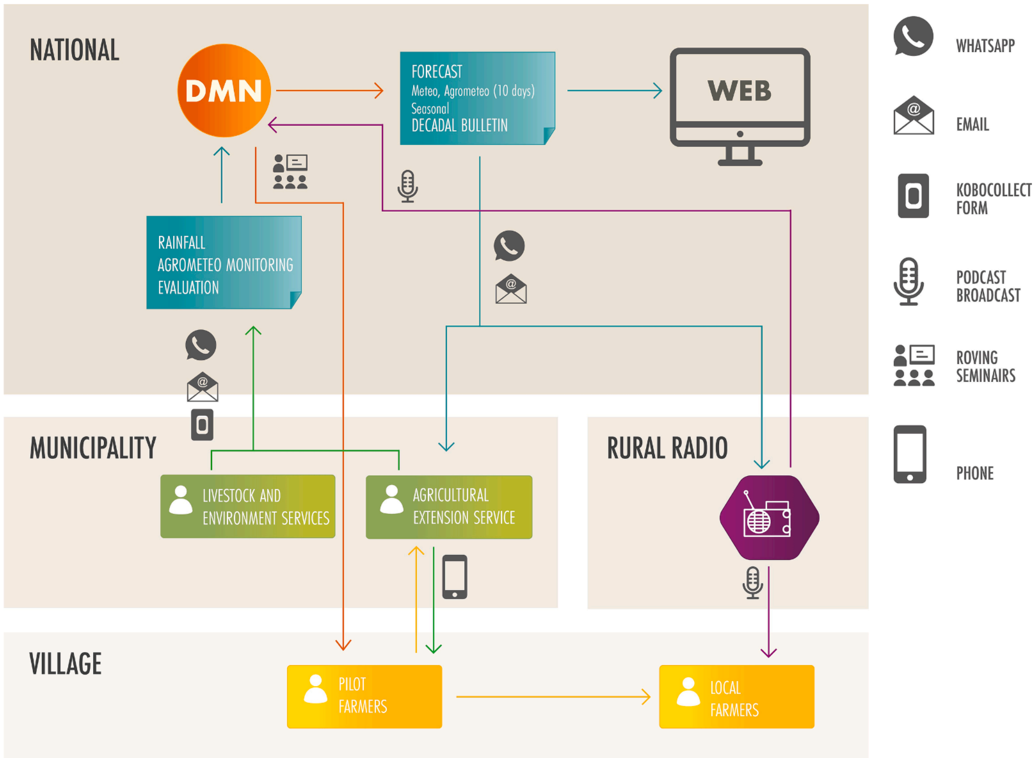

Fig. 4. Agrometeorological Service communication mechanism.

indicating priority actions to be taken. Essentially, green stands for a normal condition, meaning a no-impact scenario, yellow (RP 10 years) stands for minor impacts, orange (RP 30 years) stands for significant impacts and red (RP 100 years) stands for severe impacts. Furthermore, community preparedness and self-reliance in dealing with floods were strengthened with RS on hydrological risks. Adopting and adapting the approach used for drought risk management (Stigter, 2016), RSs become a one-day community meeting held each year before the flood season. They raise awareness and build an understanding of actions to be taken according to different flood scenarios and increase the interaction, trust, and confidence between the local actors and technical staff of the NMHS (Tarchiani et al., 2020a). We do not have metrics to support an assessment of the process added value in this block, nevertheless the fact that coloured gauging staffs are still in place and communities care them encourages the belief that the process has contributed to the sustainability of the entire service.

Rural radios are at the centre of the last mile communication of AS, nevertheless, ICT is gaining momentum even in rural remote areas. In the case of AS, ICTs (particularly smartphone applications such as WhatsApp and Kobocollect) enhance the interaction and information exchange among the system actors and contribute to changing the relations between information providers, extension officers, and farmers. Digital technology also empowers communities to contribute to the service co-production (observed data and local conditions) and provides timely feedback on information received and its performance, thereby improving their engagement in the whole AS (Fig. 4). Nevertheless, rural radios still are the most powerful tool to reach farmers directly. However, the effective use of these intermediaries requires several steps. The first one is the training of the radio operators who must be able to understand the content of the agro-meteorological advice. The next one is the translation of the advice produced in French (the official language) into the various local languages by the radio operator. The last step (not in chronological order) is the training of farmers in the appropriate use of the advice received by radio. Training and awareness-raising were ensured by RS carried out in each municipality every year before the beginning of the cropping season. This last step demonstrated to be critical in terms of uptake and impact of the service, as well as in building trust between local and technical players. The Niger experience confirms results obtained also in other West African countries such as Ghana, Mauritania, Burkina Faso, Senegal, and Ivory Coast (Tarchiani et al., 2021b; Ouedraogo et al., 2018; Tarchiani et al., 2018, Tarchiani et al., 2017).

3.6. *Evaluate*

The HS was tested during two hydrological seasons before being fully operational. A collaborative evaluation mechanism was adopted once a year after the hydrological season to identify limits and propose improvements. The evaluation was ensured by the transdisciplinary working group with feedback from local players. The improvements concerned both the technical and scientific performance of the service as well as the delivery and users' engagement mechanism. Technically, the web services used for retrieving, storing, and elaborating the observed and forecasted data were progressively improved by adopting international open standards and protocols (De Filippis et al., 2022). From a scientific perspective, progressive and iterative calibration and optimization of hydrological and hydraulic forecasts in the study area strongly improved the service accuracy (Massazza et al., 2020; Passerotti et al., 2020). The delivery component was also improved by introducing, in 2019, a semi-automated warning issuing system, allowing technical staff of DH to be alerted in real-time of scenario changes and consequently adapt and send a precompiled vigilance bulletin. Users' engagement and awareness was improved by installing the coloured staffs and introducing the RS in 2019.

The same approach of collaborative and iterative evaluation of the service was adopted also for AS, but in this case, the process was more structured. The performance of provided services was evaluated continuously during the season by local extensionists through evaluation forms compiled and sent to the service provider every 10 days. Each year, DMN deployed an evaluation mission in each municipality, visiting a sample of farmers to get feedback from the field. In 2019, a qualitative assessment of the use and impact of the service by farmers was carried out on a limited sample, showing how farmers made extensive use of agrometeorological forecasts and information, received directly (via radio or observed through rain gauges provided by the project) or indirectly through the agricultural extension service. In 2020, an impact evaluation was entrusted to a third party, the National Institute of Agronomic Research of Niger, on a much larger sample representing of the eight pilot municipalities. The results essentially confirmed those of 2019, showing that farmers, trained and currently using the services, increased yields by around 20 % compared with untrained farmers (Bacci et al., 2023). Moreover, each year after the crop season, a transdisciplinary workshop for collaborative identification of improvements was organized. Those workshops facilitated the identification of new needs for the development of new products, the enhancement of existing ones, and the improvement of communication and data collection mechanisms. This ongoing and iterative process of evaluation, learning, and knowledge exchange served to reinforce partnerships and collaborations, ultimately resulting in a more prominent, efficient, and reliable service. The external evaluation of the project also emphasized the significance of the entire process beyond the sole service outcome. This information subtly emerged from the narrative, in fact the method adopted was rather traditional and did not specifically aim to infer the added value of the process. Nevertheless, the actors' recognition of this added value motivated us to write the present paper.

4. Discussion

The theory of co-production applied by Vincent et al. (2018) to CS identifies from literature three main characteristics of the product of the co-production process, where "product" is intended as the whole service and not the single tangible outcome. To ensure that the co-produced service meets these characteristics, the authors distil three principles that must guide the process. We will then look at whether and how the services co-produced in Niger meet the product characteristics and whether and how the co-production process enables an added value.

4.1. Product characteristics

4.1.1. Decision-driven

The first characteristic is that the service is decision driven. In this definition lies the difference between climate information and climate service, as indicated by numerous authors in literature (Vincent et al., 2018a; Carter et al., 2019; Daniels et al., 2020 inter alia). Hence, the service must address a specific need of one or more categories of decision makers. In the case of the HS (see in the Appendices Table A.2), the categories of decision makers are located at different levels, whose roles and responsibilities are defined at the general level by the National Alerting Code. At the specific level they have been defined trough the participatory process creating a common understanding of the decision-making context (how, when and who issues a flood alert) and through the exploration of needs (what they need to know before giving the flood alert). To better support the decision of local authorities to issue alerts and of communities to take informed and responsive action, the hydrological warning is based on potential impacts, as suggested by the World Meteorological Organization (WMO, 2015). Impact based flood warning combines hazard, exposure, and vulnerability data to forecast the flood risk and support decision making. The ultimate objective is to encourage early action that reduces damages and loss of life from floods.

In the case of AS alike (see in the Appendices Table A.2), there are decision makers at different levels, but the farmer is the final responsible for crop management. Sahelian smallholder farmers face countless daily difficulties and therefore the AS is only a contribution toward climate smart and sustainable agriculture (Tarchiani et al., 2017). AS addresses two different types of decisions depending on the time frame. Strategic decisions are the choice of the crop variety, the choice of the parcel or the level of investment, and consequently of credit to be requested to which the service responds with warnings and advice based on seasonal climate forecasts. Tactical decisions, on the other hand, are the choice of planting date, fertilization period, phytosanitary treatment, or weed control, which are supported with warnings and advice based on the one- to ten-day weather or agro-meteorological forecasts. As also emphasized by Nkiaka et al. (Nkiaka et al., 2019), this direct link between service and decision greatly reduces the risk of producing irrelevant or unusable information. Another important aspect is that AS goes down to the scale of the municipality. A dimension that requires a deep understanding of territory characteristics including the production system and the effects of weather on it. Certainly, the high resolution of the products and their timely dissemination represent the technical innovation of AS.

4.1.2. Process-based

This characteristic leads back to the idea that the service does not coincide with the product, but includes the concept of a collaborative process seeking wider, longer term benefits than the outcome itself such as "foundational human and institutional capacity development and relationship building" (Daniels et al., 2020). Therefore, the process is central and often more important than the single outcome (Norström et al., 2020). As highlighted by the most recent literature (Vincent et al., 2018; Carter et al., 2019; Daniels et al., 2020; Visman et al., 2022), it is a continuous and circular learning process in which all the actors are involved, each one with their background, role, and responsibility. In the case of HS, since the service is completely new, the genesis was the flood risk assessment on the riverine communities (Tiepolo et al., 2019), bringing to the identification of stakeholders, their needs, and the consequent prototype of service. This initial part of the process was rich in interactions and knowledge exchange hence building new relationships between the technical-scientific actors and local ones. Subsequently, the process continued circularly and iteratively testing, evaluating, and improving, during a two-year period.

The AS process originated far in time, from a community of practices that was well-rooted in the country, as in all of West Africa, since the 1980′s drought in Mali (Hellmuth et al., 2007), then promoted by the WMO (Tarchiani et al., 2017) and transformed in Niger into an agrometeorological service. In fact, unlike Burkina Faso, where the same service is promoted by the National Meteorological Service but with a top-down and linear approach (Tarchiani et al., 2021b), in Niger, significant resources have been invested in the interaction between players through social iterative learning, knowledge exchange, and service monitoring/evaluating/improving. The service builds on the competencies of both local authorities and national technical services according to subsidiarity and complementarity principles of decision decentralization.

In both cases, the added value is that, besides the technical improvements, the process strengthened the shared ownership of the services, which, although operational, are still ongoing projects. Indeed, the transdisciplinary collaboration between technical actors and decision-makers is established and continues beyond specific funding, and the Government of Niger engaged in expanding and scaling up both services.

4.1.3. Time-managed

In agriculture and water management, seasonality and the weather drive any decision, be it respectively strategic and tactical. The HS is triggered by hydrological and hydraulic forecasts, when thresholds are passed flood scenarios activate, and semi-automatic warnings are issued to decision-makers. The lead-time for hydraulic forecasts is 10–48 h and 1 to 10 days for hydrological ones. Local authorities therefore have this timeframe to declare and disseminate the alert to communities. AS works on seasonal and 10-days periods during the crop season. Information products are prepared and disseminated according to their relevance to crop practices, crop calendar, and rainy season stages (seasonal forecasts and advice before the onset of the rainy season; intra-seasonal forecasts and advice every 10 days during the season). In both cases, the performance of the communication mechanism is, therefore, of the utmost importance. ICT helps in a country where information dissemination networks are weak, distances are large, and the technical services have suffered a chronic lack of financial resources for many years. Consistent with findings from other studies (Munthali et al., 2018), we experimented that digital technology enhances the interaction and information exchange among actors, reshaping the relations between information providers, extension officers, and communities. Moreover, digital technology ensures prompt feedback from the field and generally fosters the engagement of local participants in the service. In this perspective, the process's value lies in the shared understanding of service timing, both from central and local perspectives. For instance, when a forecaster from the DMN fell ill and the substitute failed to send weather forecasts for two days, the WhatsApp group was inundated with requests for forecasts and inquiries about the delayed arrival.

Process principles

4.2.1. Collaborative

The first principle of the process is pointing to the collaboration, which is functional first and foremost to the development of a partnership of equals, allowing to identify needs and co-develop the service. All actors benefit from stronger relationships gaining an improved understanding of the decision-making context, the complexity, and uncertainty of climate and weather information, and different perspectives in risk management. The transdisciplinary exchange makes it possible also to embed in the climate service information that is not only research-based nor climatic (Terrado et al., 2023; van Breda and Swilling, 2019). Indeed, research-based climate knowledge needs to be complemented by other environmental and socioeconomic knowledge to be "decision-relevant'' (Weichselgartner and Arheimer, 2019). Moreover, the collaboration with local and community-based institutions is particularly relevant for the co-production process because it ensures the inclusion of knowledge systems, different from the 'science', which have evolved over time in the local conditions and therefore with a real word perspective (Vogel et al., 2019).

The process of CS co-development in Niger was strongly collaborative and transdisciplinary and went across different administrative levels to identify decision-making context, needs of different users and intermediaries, information products, formats, delivery mechanism, and timing. Collaboration was central in the whole process, including the monitoring and evaluation phases which allowed an iterative improvement of the services and increased ownership by actors. Transdisciplinarity was a key element of the collaborative approach; confirming Vogel et al. (Vogel et al., 2019), it allowed to build relationships that went beyond the life of the project, allowing the various national and international technical institutions to harbour a frank and continuous exchange of knowledge, information, and data. This will ensure also greater sustainability of the process which remains "open to emergent issues that may change the course of the interaction". Moreover, such relations contribute to strengthening public institutions in charge of service management and building their adaptive capacity (Armitage et al., 2011).

In the specific case of the services developed in Niger, the aspect of collaboration among national technical institutions (transdisciplinarity) and with local authorities and communities (complementarity) was particularly useful and relevant. Previously, the collaboration between DMN and DH was purely formal. Through HS this collaboration has become operational, including the exchange of data and information. The next step, achieved through both HS and AS is the collaboration between national and local institutions. Traditionally NMHSs have little relationship with users and very little with local governments, both because they are used to providing non-specific and non-localized information products and because they traditionally adopt a linear "deficit model". AS and HS allowed for a change of mentality, an openness to the reception of users' needs, and the construction of common and non-top-down processes in the production of services. In the case of AS, the collaborative process was developed in different forms, appropriate for specific interactions between different types of actors: transdisciplinary workshops (iterative and interactive learning), RS (knowledge exchange, awareness, and training), social media (feedback from the field) and surveys (evaluation of the service). The structured collaboration at so many levels made it possible to open discussions and to create awareness, which was previously unimaginable. Even if in a different context, Steynor et al. (2020) report a similar experience in South Africa where "the transdisciplinary process has also allowed for an open flow of information and enhanced the professional relationship between the City and the University researchers, narrowing the science-society gap".

An element that can improve the collaboration, which has emerged but not yet been completed, is the formalization of the collaboration with an agreement that legally defines the roles and responsibilities of different players at different levels. However, the determining success factor is the motivation of the players; where local players were more proactive, the process worked better, and consequently the service was more efficient.

4.2.2. Inclusive

The second principle suggests the process to be inclusive, involving as many different actors as possible ensuring relations that otherwise would not be possible. The inclusion principle is therefore strictly connected to the transdisciplinary collaboration in the production of knowledge. To be inclusive, the process requires a large investment of time and resources to ensure appropriate spaces of interaction and to build a trusting relationship (Lacey et al., 2018). Developing this trusting relationship is neither an easy or a short path and requires taking responsibility for maintaining it beyond the confines of a single project. Furthermore, when speaking of inclusion, one can refer to the inclusion of people or knowledge. In the latter case, it is particularly appropriate to include non-climatic information, local knowledge (Roncoli et al., 2002), and empirical knowledge of the users (Clifford et al., 2020), as well as their feedback (Bacci et al., 2020).

Inclusion requires great effort and time, consequently, if, from a purely theoretical point of view, it would be optimal to include all potentially interested players in the process, from a practical point of view this is often not possible. Indeed, a selection of users is often necessary and Baulenas et al. (Baulenas et al., 2023) propose guidelines for user selection and engagement that integrate 5 + 1 steps: "defining why, where, whom, which attributes, and which intensity and how to iterate with stakeholders". There are several methods to interact with the stakeholders, ranging from basic desk research activities to more sophisticated and resource-intensive methods such as focus groups and semi-structured interviews. In Niger, inclusion in the process was mediated locally by actors identified at the community level. In the case of HS, communities were included in flood risk assessment, identification of response measures, flood monitoring, and in the dissemination of service products. In general, there was reliance on SCAP-RUs to include different social groups in community events. Nevertheless, it was not possible to verify if this process provided an equal representation. In the case of AS, the process of including the different components of the agricultural production system was driven by the agricultural extension and the decentralized technical services. Equally, there is no certainty that the representation was fair. In conclusion, we can argue that the process has been partially inclusive.

An important element to consider for inclusion is its economic sustainability over time. For AS, for example, other players could be included, widening the range of potential users and intermediaries. On the other hand, this further enlargement requires more resources that can hardly be taken over by a project. The further enlargement of the players requires an evolution of the service financing method, as in fact shown by the consensus of the players involved. The perspective for the expansion of the service requires an approach of complementarity and co-financing by the various actors. At the central level, the national technical institutions will have to include a specific budget line for the management of the service, while the local authorities will, in turn, have to cover local costs in their annual budget, especially the contribution of the extension and the municipal technical services. This same approach was suggested by Steynor et al. (2020) in their case study in South Africa. Other local players, such as farmers' associations in turn could contribute by absorbing the costs for the involvement of their members. The participation of private partners has also been envisaged, such as agricultural input suppliers, agricultural insurance companies, and credit institutions, with whom local agreements could allow the establishment of a public–private partnership that would help expand the service and ensure its sustainability. A further collaboration involves community players, such as rural radios, so far involved with specific agreements with the project, but in the future, the costs should be absorbed either through private contributions or through local administrations.

4.2.3. Flexible

Flexibility is an important principle in co-production because it implies that the service can be improved progressively over time. This is possible if a process-based approach is adopted, and the system structure is neither rigid nor closed. Flexibility is promoted by the adoption of an evaluation mechanism (Vincent et al., 2018; Visman et al., 2022) and an iterative learning process (Lundvall, 2016) that involves the various actors and different knowledge systems. This continuous knowledge exchange, monitoring, and learning demonstrated to be particularly useful in Niger to strengthen the whole process, to refine the services' products, and to introduce further products not identified at the beginning. Indeed, the initial co-exploration of needs was necessarily experimental, since it was also the core team working in *terra incognita* and having few points of reference. The flexibility allowed to iteratively adjust solutions and delivery mechanism according to the evaluation process.

Technical choices can have a significant influence on service flexibility. In the case of HS, a Service-Oriented Architecture (SOA) was used to build the system infrastructure adopting Open Geospatial Consortium (OGC) protocols and open-source technologies and software components. This flexible architecture allowed the integration of several interoperable web services allowing the management of multiple data sources and multiple forecast ranges (hydraulic 48 h, hydrological 10d) from global or regional providers and real-time observations. Moreover, the SOA-based development approach allowed the system to be flexibly adapted to changing standards and technologies. For example, the service had to deal with the update of new versions of the global hydrological model (GloFAS). Changes in input products have been easily managed thanks to the flexible data model adopted. The flexible infrastructure also allows the service to be easily updated and further expanded. For example, updating the water level-discharge equation automatically updates the discharge data calculated from real-time observed water levels (De Filippis et al., 2022).

5. Lessons learned

The systematic analysis of the process of co-development of CS carried out in Niger with reference to recent literature allows us to highlight some lessons that could be of practical use for setting-up co-production processes and also for defining a methodological framework for the evaluation of the process added value in climate services co-production.

The process of climate services co-production has an intrinsic value in addition to the benefits, it brings a better design, development, distribution, access, and uptake of outcomes. The added value of co-production lies in bridging the gap between different knowledge systems allowing cross-fertilization between disciplines and subsidiarity between different levels of decision making. The process allows the creation of a community of equals, hence democratizing the access to services and knowledge, and the establishment of relationships of mutual trust.

The process must be cyclical, iterative, and interactive. Innovation is introduced by trials, which are tested, evaluated, and improved repeatedly with the participation of all stakeholders each for their role. Changes and adjustments indicate process effectiveness, participation, and interest in improvement. Even if a cycle does not produce the hoped-for improvement in outcome, it is still beneficial because it has explored a new hypothesis and strengthened the synergy among the actors.

Co-production is based on an iterative and interactive social learning approach. Climate scientists and experts at NMHS are often not used to adopting social science approaches for actors' engagement, partnership and trust-building, and knowledge sharing. The co-production of CS requires shifting the paradigms to which we have been accustomed in the vision of a linear innovation. Innovation is instead driven here by a cyclical process where differences in knowledge and points of view are an asset and an added value if the actors are able and willing to accept and adopt them. The willingness to learn from others is therefore the first requirement for actors to be involved in the process.

Collaboration in co-production brings people together across two different axes: disciplines and roles. Both these types of collaboration lead to a better understanding of the context and the needs, opening the way to decision-oriented services. The first advocates for scientific transdisciplinarity allowing the integration of climate-related knowledge with other sectoral knowledge (environment, agronomy, pastoralism, economy, etc.) in a perspective of cross-fertilization. The second relates to the concept of complementarity between knowledge systems and broadens the admissible knowledge in the CS production process and includes non-scientific knowledge and perspectives from communities and decisionmakers. Furthermore, the second level promotes the shift of the service ownership from the project core team to the community of actors and this is critical for the sustainability beyond the project life span. In addition, and even more important strategically, the collaborations and relationships established, as well as the habit of cooperating and learning together, create a virtuous cycle enabling further developments, innovations and applications even in other sectors not initially targeted by the service.

Monitoring-Evaluation and Learning (MEL) are a fundamental component of the iterative and interactive social learning process sustaining the co-development of CS. MEL not only allows the progressive improvement of the service but strengthens partnership among actors, creates ownership of the service, and finally fortifies sustainability. Moreover, MEL demonstrating the value of the service can convince policymakers and funders to make additional investments. However, the value of the co-production process cannot be assessed only in terms of physical outcomes. The process value is difficult to measure as it is an intangible outcome. Therefore, a reference framework for acknowledging the substantial value inherent in the co-development process is needed. The co-production of CS is a complex process that should not be underestimated. However, it can now be approached in a more systematic way compared to just a few years ago. There are reference frameworks (Vincent et al., 2018; Daniels et al., 2019; Visman et al., 2022) and manuals (Carter et al., 2019) that can greatly support those who venture into this *terra incognita*, as Bremer referred to just in 2019 (Bremer et al., 2019). Anyway, it requires the proper implementation of a long cycle of funding in terms of time and resources that funders are not always willing to allocate. The experience in Niger lasted 9 years, from 2013 to 2021, and the funding Agency, the Italian Agency for Development Cooperation, allowed relative flexibility in budget allocation. The project in its second phase built on the results of the first phase and was able to embrace needs that emerged during the process even if not considered from the beginning in the implementation plan. The project therefore allowed a long-term perspective, and the development of several tools for capacity building of local stakeholders and actors at national and local levels.

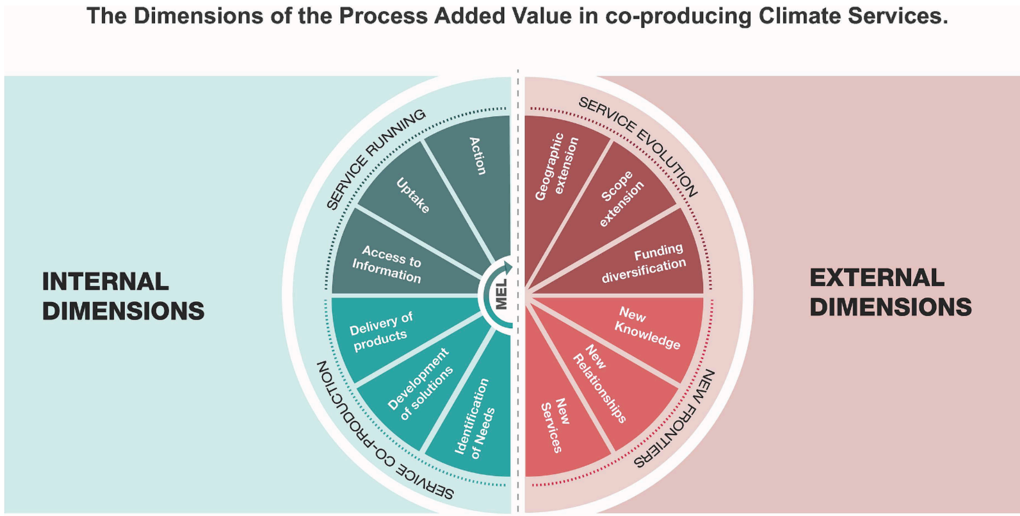

Fig. 5. The Dimensions of the Process Added Value in co-producing Climate Services.

From the experience and perception of the stakeholders involved in Niger, we suggest considering the following four dimensions (Fig. 5) in the evaluation of the added value of the process in climate services co-production:

1. Value added to the Climate Service co-production: This dimension explores the value created beyond more conventional approaches on the service production and the improvement over time due to progressive technical enhancement resulting from the co-production process. It can be assessed on every step:
   - o Identification of needs: better definition of roles, responsibilities, establishment of agreements, identification of the decision-making context, specific needs of users and relation with climatic risks.
   - o Development of solutions: participation of all stakeholders and contribution with different systems of knowledge.
   - o Delivery of information: appropriateness of content, format, language and timing, agreements with intermediaries.
2. Value added to the Climate Service functioning: This dimension explores the value created beyond more conventional approaches on the service efficiency/effectiveness, and can be evaluated on:
   - o Access to information: awareness of users about communication channels and appropriateness of the channels in respect to users needs.
   - o Uptake of the services: trust and appropriateness to the social context built over time through the iterative process.
   - o Action by Users: matching identified needs, enhancement of service impacts due to increased users' ability to act on information and advises, attributable over time to the iterative process.
   - o MEL: improved feedback mechanism (enhanced capacity of technical-scientific actors to gather feedback from users and intermediaries), involvement of stakeholders and proposals/requests for improvement.
3. Value added to the expansion of the service: this dimension explores the value created beyond more conventional approaches on the service scaling-up, expansion and financial sustainability after the first funding period:
   - o Geographical expansion: new areas/communities covered after the end of the funding cycle that enabled its co-production.
   - o Extension of the scope of the service: types of decisions supported, new risks addressed, new sectors involved after the end of the funding cycle that enabled its co-production.
   - o Diversification of the funding mechanism: new financial partnerships involving public and private funders or new mechanisms of cost-sharing and business.
4. Value added toward new services: this dimension explores the value created beyond more conventional approaches in building the capacities of actors and stakeholders for imaging and producing new services:
   - o New knowledge: increased transdisciplinarity and increased technical capacities of stakeholders for further development, but also in terms of increased demand for services (new or improved) from users' communities.
   - o New relationships: in terms relationships or agreements adopted by the involved actors with other actors in the same value chain or in another related to the co-produced service, increased trust by the public, enduring relationships and agreements established among stakeholders after the co-production process. New services: identifying, designing, developing new services by the different actors originally involved.

6. Conclusion

In Niger, the process of integrating scientific, technical, and local knowledge demonstrated to be relevant and effective in fostering innovation in agriculture and disaster risk reduction. In particularly adverse conditions, such as those in Niger, even minimal innovations in the system can prove incredibly concrete and effective if conceived, developed, and managed through a co-production process. The logic of "service co-production" acts as a bridge between science and society, at whatever decision-making level they may be. To produce an innovative service and for it to be used and give results on the field, a strong collaboration between technical skills and local knowledge is needed, thus establishing a mutual relationship of cooperation and trust between the parties. This symbiosis between the actors is built over time, through knowledge transfer activities and inclusive processes, based on continuous interaction between researchers, stakeholders, and society. The implementation of such co-development processes becomes an aggregator of strategic partnerships aimed at innovation for sustainable development.

In the case of ANADIA, the value of the transdisciplinary co-production process has emerged as a central outcome of the project, even if the project evaluation tools didn't specifically address this feature. Therefore, this experience confirms that the quality of the process cannot be assessed from the output alone (Vogel et al., 2019; Steynor et al., 2020; Visman et al., 2022) and ongoing changes and adjustments are a signal of the process's success. However, the process is not free and requires time and effort. It must be adequately supported with appropriate budget lines that allow for continuous and regular

Table A.1
Process blocks for Hydrological and Agrometeorological Services.

Process blocks	Tools		Outcomes
	Hydrological service (HS)	Agrometeorological service (AS)	
Identify actors and build partnership	Preliminary explorative meetings with potentially relevant actors to identify different types: decision makers, intermediaries, providers of the information	*Actors already identified through existing transdisciplinary Community of Practice*	Decision-making context
Build common ground	Initial transdisciplinary workshop	Initial local workshops	Common understanding of stakes and possible strategies
Co-explore needs	Actors' consultation (focus groups and interviews) to co-define the decision-making context and different actors' needs	*Basic needs already assessed*Before season: transdisciplinary workshops (climatologists, meteorologists, agrometeorologists, IT specialists, communicators, agricultural extensionists, pastoralists, environmentalists, local managers) and roving seminars (farmers and local actors) for identifying the further need for different information, to be delivered at different times, and in different formats	Service characteristics
Co-develop solutions	Transdisciplinary Working group (hydrologists, engineers, IT, communicators, local planning experts, local managers, agricultural extensionists, disaster risk reduction specialists) Inclusion of users and intermediaries in the process of service production. Local knowledge integration in the service (locally observed water levels and trends, observed damages, local response)	Iterative process of social learning; Proposed solutions Iterative improvement of solutionsInclusion of users and intermediaries in the process of service production. Local knowledge integration in the service (crop phenology, market prices, pasture condition, water point condition, livestock condition, locally observed rainfall, food security conditions)	Information products
Co-deliver solutions	Formal bulletins, Roving seminars, telephone, voice and text messages, Social networks,Traditional networks, rural radios, peer-to-peer (local observers)	Formal bulletins, Roving seminars, telephone, voice and text messages, Social networks,Traditional networks, rural radios, peer-to-peer (local observers)	Dissemination system
Evaluate	Collaborative testing and evaluating (once a year after the hydrological season) Collaborative identification of improvements transdisciplinary working group	Collaborative testing and evaluating (continuously through evaluations forms and once a year after the cropping season with a survey) After season: transdisciplinary workshop for collaborative identification of improvements	New needs, improved products, improved dissemination, strengthened partnership

interactions also considering that in African societies, in person meetings are still fundamental, and often compulsory. This process goes beyond the normal project cycle. Therefore, there is a need for longer cycles of funding and flexibility in budget allocations and activity planning. In this perspective, the ANADIA projects were an example of good practice of the Italian Development Cooperation Agency. Nevertheless, further investigation is needed to develop suitable and sustainable methods for assessing the added value of the co-production addressing the four dimensions of i) service co-production, ii) service functioning, iii) service expansion and iv) the new services. Finally, the authors recommend capitalizing the results and lessons learned through case studies within the National Frameworks for Climate Services at

Table A.2
Product characteristics and process principles for hydrological and agrometeorological services.

		Hydrological Service	Agrometeorological Service
Product Characteristics	Decision-driven	Based on the potential impacts and decisions to be taken by actors at different levels (National, Municipality, Community) to prepare and reduce damages of the flood	Based on strategical and tactical decisions for crop management to be taken by farmers both for risk reduction or opportunities valuation
	Process-based	Defined through an iterative process of social learning, knowledge exchange, and service monitoring to strengthen the shared ownership of the service; Integrated into the national alerting system; Based on the competence of local authorities according to subsidiarity and complementarity principles	Defined through an iterative process of social learning, knowledge exchange, and service monitoring to strengthen the shared ownership of the service; integrated into the agricultural extension system
	Time-managed	Warnings generated when risk thresholds exceeding are forecasted; Alerts triggered on receipt of warnings or when risk thresholds are exceeded locally	Information products are prepared and disseminated according to their relevance in relation to cropping practices, cropping calendar and rainy season stages (seasonal forecasts and advice before the onset of the rainy season; intra-seasonal forecasts and advices every 10 days during the season)
Process Principles	Collaborative	Collaborative process transdisciplinary and across different administrative levels to identify decision making context, needs of different users and intermediaries, information products, formats, delivery mechanism, timingIterative and collaborative monitoring and evaluation (transdisciplinary working group) to improve service and ownership	Community of Practices to define basic needs and products characteristics.Iterative social learning (transdisciplinary workshops), knowledge exchange (roving seminars) and evaluation (feedbacks forms and surveys) to improve the service
	Inclusive	Inclusion of communities in risk assessment and identification of response measures. Inclusion of communities in flood monitoring and in the dissemination of service products.	Inclusion of main local stakeholders in the process of co-development
	Flexible	Service-oriented IT architecture, flexible data model ensuring easy update and integration of new data, interoperability of services integrating multiple data sources and multiple forecast ranges (hydraulic 48 h, hydrological 10d)Open communication mechanism for warnings (Alerts under local authorities' control)	Service flexible to integrate new indices and products once they have been suggested by users and tested

country level and within the Global Framework for Climate services internationally.

CRediT authorship contribution statement

Vieri Tarchiani: . **Maurizio Bacci:** Investigation, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendices

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