Climate Services 26 (2022) 100297

Contents lists available at ScienceDirect

Climate Services

journal homepage: www.elsevier.com/locate/cliser

Defining metrics for monitoring and evaluating the impact of co-production in climate services

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A R T I C L E I N F O

Keywords:
Africa
Climate-resilient development
Adaptation
Monitoring and evaluation
Resilience
Ethics

A B S T R A C T

Despite increased commitment to co-production as a route to developing decision-relevant climate services, there has been less focus on the metrics or criteria for determining their success and impact. Drawing from literature and recent experiences from both operational- and research-focused climate resilience-building initiatives in Africa, we propose a framework and consider various approaches for monitoring and evaluating both the process and outcomes of investments in climate services co-production, so that scientific excellence can be monitored alongside development impact. This framework combines principles- and process-based approaches to track changes amongst the various parties involved in co-producing climate services. The development and application of this framework raises fundamental questions regarding the metrics for measuring the impact of co-production in climate services and the principles – including inclusivity, diversity and ensuring value for all partners in the process – on which these are based. The framework and its metrics contribute to the emerging field of monitoring and evaluation of climate services co-production, and will be of use in improving the robustness of the field going forwards.

Practical implications

1. **The importance of Monitoring, Evaluation and Learning in co-production of climate services**
   - While the importance of co-production in supporting the development of decision-relevant climate services is increasingly recognised, it is resource intensive.
   - Yet there remains a lack of agreed monitoring, evaluation and learning (MEL) frameworks for assessing which co-production approaches are proving most effective and the extent to which collaborative climate-resilience building initiatives achieve both socio-economic impact and scientific excellence. Given growing awareness that the way research priorities are established and measured is fundamental to promoting greater equity, there is an urgent need to address this gap.
   - MEL is a vital part of the co-production process. It has value in recognising the importance of ongoing dialogue and feedback not only in meeting donor reporting requirements and supporting project management, but also in maximising the impact of the co-production process while informing social and physical science research. Moreover, monitoring the steps in the process of co-production enables tracking of incremental change, in advance of more fundamental or transformational change to which climate resilience-building initiatives can contribute. How MEL is undertaken can, in itself, impact the outcomes of co-production efforts. For instance, participatory MEL (MEL that actively involves the project stakeholders and particularly those people most directly impacted by climate-related risks) can strengthen ownership and sustainability. Moreover, enabling

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https://doi.org/10.1016/j.cliser.2022.100297
Received 23 June 2021; Received in revised form 10 January 2022; Accepted 8 April 2022
Available online 17 April 2022
2405-8807/

sustainable systems for participatory monitoring and evaluation can bolster institutional capacities to demonstrate the value of climate services. Through identifying continuous systems for user feedback (as proposed within the World Meteorological Organisation's Global Framework for Climate Services (GFCS) 'User Interface Platform') and strengthening capacities for MEL within partnering meteorological agencies and research institutions, such systems can provide a basis from which to make a business case for increased national, local and international funding to support their activities.

2. **The current gaps in Monitoring, Evaluation and Learning of co-production in climate services**
   - Co-production efforts can be strengthened through building on existing sector-specific MEL expertise. The humanitarian and development sectors have well-established frameworks for tracking impacts and ensuring their accountability amongst the people they are seeking to support (e.g. CHS Alliance et al., 2014; OECD/DAC, 2019) Natural science has well-established systems of peer-review and scrutiny, through journal submissions and scientific conferences, to ensure excellence in scientific knowledge. While the linkages between systems for monitoring socio-economic impacts and advancements in science remain insufficient, strengthening their alignment offers important opportunities for co-benefits. A number of climate-resilience building initiatives have, for example, afforded insufficient consideration of forecast skill, a key issue in meteorological research and where participatory evaluation of forecast skill (where users provide feedback on local observations and impacts) offers the potential for important mutual benefits: improved models, more accurate and relevant forecasts and identification of new research questions related to evolving societal concerns (Youds et al., 2021).
   - Most fundamentally, whether undertaken within humanitarian, development or research programmes, MEL is often perceived as a reporting requirement, lying in a 'grey' area outside existing development or scientific research governance frameworks, rather than as an integral element of co-production in climate services. Whilst funders increasingly require ethical standards to be upheld, there is growing literature pointing to the importance of considering ethics in both climate services and co-production (e.g. Adams et al., 2015; Goldman et al., 2018). Existing ethics standards and principles provide an important foundation for MEL of multi-partner climate resilience-building initiatives.
   - Learning from across climate resilience-building initiatives has also highlighted the need to strengthen the MEL capacities of partnering meteorological agencies and research institutions, establish programme-level MEL frameworks and capacities, and ensure sufficient resourcing of project- and programme-level MEL activities. Maximising the value of investments in co-producing climate resilience requires reviewing the process, methods, capacities, resources and timeframes required to identify and measure agreed metrics, and how these can be sustained within mandated institutions. National frameworks for climate services and linkage within existing national monitoring and evaluation frameworks offer important opportunities to ensure sustainable and integrated monitoring of climate services.
3. **A proposed framework for monitoring the impact of co-production in climate services initiatives**
   - Many countries, including in the global South, are developing national mechanisms to operationalise the GFCS . The 2019 Manual: 'Coproduction of African Weather and Climate Services' (Carter et al., 2019) pools emerging learning from across a wide range of contexts, countries and regions to distil a series of six building blocks and ten principles that should underpin climate services co-production efforts. By combining these building blocks and principles with literature and experience from applied projects, a framework of indicators or metrics of success for assessing the contribution of co-production activities is proposed.
   - To demonstrate the applicability of the framework, the paper considers how the more operationally-focused Weather and Climate Information Services for Africa (WISER) Phase 2 programme and the more research-focused Science for Humanitarian Emergencies and Resilience (SHEAR) and Future Climate for Africa (FCFA) programmes, as well as a number of projects undertaken within each of these programmes, have focused on measuring specific elements of co-production and the methods they have employed. Based on these experiences in Africa, the paper considers the extent to which the proposed framework offers indicators relevant to the aims of both operationally- and research-focused co-produced climate services initiatives in all global contexts.
   - The projects of focus illustrate how a range of methods have supported tracking of specific indicators or areas of change. The operationally-focused projects illustrate methods effective in tracking access, use and benefits of new and improved climate services at household level, while the research-focused projects have more closely tracked improvements in the meteorological and climate science informing climate services. Experiences across climate resilience-building initiatives highlight the need to employ a range of methods, due to the complex range of partners, decision making levels, disciplines, sectors and funding sources engaged. Within this complex landscape, the proposed framework can guide consideration of key indicators of co-production that an initiative seeks to impact on, while operational experience indicates a range of methods through which sought for changes may be effectively tracked.
4. **Conclusion**
   - Co-production in climate resilience-building requires tracking of research excellence alongside development impact at all stages of the project cycle, including post-programme evaluation. The elements of MEL need to be planned together, so that monitoring methods can collate the data required to enable evaluation, as well as supporting on-going review and course correction. However, embedding MEL throughout programme or project life cycles requires significant resourcing. Resources are required for the initial framing, baselining, ongoing monitoring, knowledge management and learning, as well as mid-term and/or final evaluation. If implemented as part of the co-production process, these resourcing constraints can be mitigated, to some extent, by MEL being seen as a core project activity, rather than as an extra activity. The framework for monitoring the impacts of co-produced climate services is intended as a working guide, to be developed and revised as further learning emerges.

1. Introduction

Funders have increasingly focused on co-production as a route to developing decision-relevant climate services that can strengthen resilience to increasing climate-related risks (Bremer et al., 2019)[3]. A range of approaches has been employed to support co-production in climate services, whereby producers and users of climate information work together to generate decision-relevant services. There is emerging consensus regarding key underpinning principles and processes through which co-production can be supported (Carter et al., 2019; Vincent et al., 2021). There are well-established frameworks for evaluating the impacts of humanitarian and development assistance (CHS Alliance

[3] While climate services are variously defined, we follow the World Meteorological Organisation in defining these as providing weather or climate information (over timeframes) in ways that assist decision-making by individuals and organizations (WMO, 2018).

et al., 2014; OECD/DAC, 2019). However, despite increased investment in the multi-actor initiatives required to strengthen resilience to climate-related risks, there remains a lack of agreed frameworks for monitoring and evaluating the impacts of co-produced climate services (Jones et al., 2018; Vincent et al., 2018; Bucher et al., 2020). Having such frameworks is important given the need to identify and build on emerging learning regarding those approaches and framings that are proving most effective, particularly in resource-constrained environments and to address increasing climate-related risks (Lemos et al., 2018).

Co-production may be defined as 'the bringing together of different knowledge sources, experiences and working practices from across different disciplines, sectors and actors to jointly develop new and combined knowledge for addressing societal problems of shared concern and interest' (Visman et al., 2018, p3). This builds on recognition that strengthening diversity in decision-making leads to better quality outcomes (Uchegbu, 2020) and the need to enhance equity across climate research (Pearson and Schuldt, 2014). However, although co-production can provide important and wide-ranging benefits, bringing together a breadth of relevant actors demands significant time, effort and support (Vincent et al., 2021).

Co-producing weather and climate services requires a range of key actors (that might include funders, meteorologists and climate scientists, researchers and technical experts across disciplines and sectors, boundary agents and users across decision-making levels and livelihood groups) with the aim of generating useful and useable information (Lemos et al., 2012; Vaughan and Dessai, 2014). Practically speaking, there is variability in the specific nature of the process but, broadly speaking, it is often undertaken through a series of face- to-face and online interactions amongst key actors to together identify and agree on where joint collaboration may effectively address issues of societal concern before continuing to co-design, co-develop and co-evaluate initiatives to address the concerns of focus (see the Build Blocks of co-production in Fig. 1a). Given the range of actors and potentially varied views of what constitutes "success", monitoring and evaluation of co-production in climate services needs to consider the different priorities of the various actors involved, taking into account research quality and development impact (Vincent et al., 2020a).

Consideration of how to monitor and evaluate co-production of climate services has encompassed a range of foci reflecting the range of parties and interests in the process and the mode of knowledge production (Harvey et al., 2021). Fazey et al. (2014) noted that, to evaluate knowledge exchange in multi-actor environmental change research, it is necessary to consider the way knowledge exchange is conceptualised, why it is considered necessary, how it is to be implemented and why a particular knowledge exchange process is believed to deliver desired outcomes. This recognises that both process and outcome are important considerations, with others highlighting the extent to which co-production has supported collaboration and social, systemic and transformative learning (Armitage et al., 2008; Pahl-Wostl, 2009), uptake and use in decision-making (Lemos et al., 2012) and its impact on partnering researchers and the scientific merits of 'joint knowledge production' (Hegger and Dieperink, 2015).

In addition to differences over the scope of what is evaluated, there is likewise diversity in approaches on how to assess the extent of impacts. Single loop learning, or learning to do the same things better, may, for example, be supported by ongoing improvement of existing forecast products. Double loop learning, or learning to do things differently, may, for example, be present where changes in those engaged in knowledge co-production impacts on resulting decisions (Mach et al., 2020). More transformative or triple loop learning may be identified through assessing the extent to which co-production enables reflection on the underpinning principles, rules and norms governing the credibility of knowledge (Wall et al., 2017; Mach et al., 2020), whose knowledge counts and the shared aims of bringing together different sources of knowledge.

Enabling equity also requires review of the way research priorities are established and how progress in achieving intended aims is measured (Vincent et al., 2020a). The way that research is framed can have significant impacts on the use of the resulting science (Arnott et al., 2020). Research funding policies that fail to support inclusion of all voices and ideas (including local needs and priorities) can have negative impacts on society (Vogel et al., 2019; Vincent et al., 2020a). A number of recent climate resilience building initiatives have focused more on either societal or scientific impacts, or impacts for only some of the actors involved in co-production (Visman et al., 2019). This may, for example, result in tracking changes in partnering decision-making institutions and the at-risk people they seek to support but insufficiently considering the impacts of co-production on partnering researchers (Visman and Tazen, 2019). Likewise the framing of important climate-resilience investments has incorporated inequities across timeframes by insufficiently addressing the need to balance consideration of emerging and future climate-related challenges with meeting existing

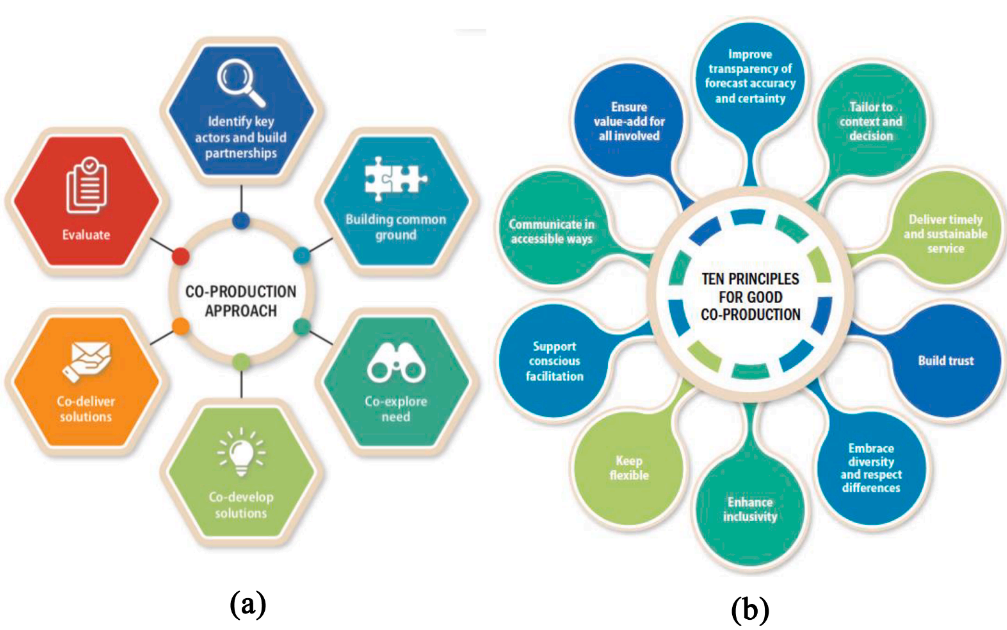

Fig. 1. The building blocks (a) and principles of good co-production (b) introduced in Carter et al. (2019) (reproduced with permission from the authors).

challenges in resource-constrained contexts (Audia et al., 2021).

Given the emerging consensus regarding the need to integrate underpinning principles across the process of co-producing climate services (Carter et al., 2019), this needs to be reflected in combined principles- and process-focused monitoring and evaluation in assessing the impacts of such initiatives (Mach et al., 2020; Vincent et al., 2021). In response, we propose a framework for combining these principle and practice dimensions, populated by indicators drawn from the literature (Section 2). The framework seeks to reflect the priorities of, and track changes amongst, the audiences an initiative seeks to support, partnering researchers and decision-makers, and the institutions of which they are part. We then use case studies of co-produced climate services in Africa to demonstrate the saliency and relevance of and extend this framework for both research- and development-focused projects in global contexts (Section 3). This is achieved by considering the extent to which project-based case studies have been able to monitor and further build on the indicators outlined in the framework, and the methods they have employed to support this process. We conclude (Section 4) with reflection on the usefulness of the proposed framework for combining principles- and process-focused monitoring and evaluation of climate-resilience building initiatives, and the ways this may be further developed and strengthened.

2. Theoretical basis for a new indicators framework to track the processes and principles of co-production

Given the dispersed nature of the discourse on developing indicators to measure the impact of climate services co-production, there is a need to draw together the existing rich theoretical understanding into a single action-oriented framework. With inclusive evaluation of co-production entailing recognition of the differing perspectives and value systems of the multiple actors engaged, drawing on academic research alone is unlikely to result in a holistic representation of indicators that work in practice (Fazey et al., 2014). To this end, we draw on and collate several sources of information to propose and test a single framework (Table 2). This framework draws on the work of Carter et al. (2019) (Section 2.1) as a conceptual framing of the process and principles of co-production, and is populated with indicators drawn from a variety of both academic and operationally- oriented sources, including Fazey et al., 2014, Wall et al., 2017, Hegger and Dieperink, 2015 (Section 2.2), Dinku et al., 2018a (Section 2.3) and the 2019 InterGovernmental Authority on Development (IGAD) Climate Predictions and Applications Centre (ICPAC) peer-review learning workshop reflecting on the range of co-produced climate services developed for the Greater Horn of Africa region within the Weather and Climate Information Services for Africa (WISER) programme and related climate services initiatives (Section 2.4). All of these studies or processes are further described below to highlight their relevance for inclusion in the proposed framework.

2.1. Conceptual framework for co-production of climate services

The 2019 WISER/Future Climate for Africa (FCFA) manual on co-production in weather and climate services outlined a series of six building blocks and ten principles (Fig. 1 and Table 1) identified as vital for underpinning effective co-production of climate services (Carter et al., 2019). These building blocks and principles were developed by building on research and drawing together operational experiences from across a wide range of climate services projects in East, West and Southern Africa (including Patt and Gwata, 2002; Mendler de Suarez et al., 2012; Visman et al., 2012; Visman, 2014; Visman et al., 2018; Koelle et al., 2019; Araujo et al., 2020; Vincent et al., 2020b).

While the building blocks and principles outlined in Carter et al.'s (2019) manual (Fig. 1) provide a useful foundation, the manual insufficiently highlights the need for ensuring that climate services address climate-related risks across timeframes. There is a need to meet current concerns while also factoring in emerging understanding regarding longer-term climate extremes, variability and change (Evans et al., 2020), hence the proposed framework promotes consideration of process over timeframes. Employing a framework that monitors steps in the process enables identification of changes that co-production efforts may have contributed to, even in advance of identifying their impacts on longer-term resilience to climate-related risks (Visman et al., 2016). That said, it is increasingly recognised that assessing the impact of climate resilience-building initiatives requires an extended period (Lemos et al., 2018). For example, it takes time to strengthen the capacities of forecasters to produce forecasts with sufficient skill and communicate these in accessible ways, as well as to build the confidence required to enable people to act on probabilistic forecasts. More fundamentally, many major economic sectors, including agriculture and pastoralism, are dependent on principal annual rains. High impact weather events occur infrequently but are also often seasonally associated. Realising the potential benefits of acting on co-produced climate services therefore is often dependent on efforts continuing over multiple annual cycles. While this is clear with regard to efforts to support longer-term adaptation, it is also true of efforts to strengthen resilience at shorter timeframes. While the probabilistic nature of weather and climate information necessarily means that the most likely outcome may not always occur, if the forecast is of sufficient skill and co-production has enabled the identification of appropriate thresholds for action, forecast-based action will prove effective in the long-term (Carter et al.,

Table 1
Summary of ten underpinning principles of co-production in climate services from Carter et al. (2019).

Principle	
Tailoring climate services tocontextand decision	Ensuring good understanding of the decision that the climate service is intended to inform
Providing timely and sustainable services	Providing timely, consistent services to meet decision-makers' timeframes.
Building trust and equitable relationships	Ensuring trust is built between the various actors in the process
Embracing diversity	Appreciating differences in knowledge, value systems, practice, language and learning, including consideration of local and traditional knowledge and communication preferences across livelihoods, sectors, disciplines and decision-making levels. Strengthening such appreciation increases users' trust and ownership and meteorological agencies' understanding of users' forecast needs.
Enhancing inclusivity	Promoting active participation of marginalized groups, including women, children, youth, older people and those with disabilities, promotes ownership and applicability across stakeholders.
Keeping the entire process flexible	Enabling emerging lessons to continuously inform review and improve services, while responding to changing concerns and priorities.
Supporting conscious facilitation	Employing approaches and creating spaces that enable the active participation of all stakeholders.
Communicating in accessible ways	Identifying the most effective channels, formats and language for ensuring climate services reach specific audiences, and combining forecasts with information about potential impacts and guidance on relevant preparedness actions.
Ensuring value-added benefits for all involved	Transparent discussions of stakeholders' differing priorities and identification and agreement on respective benefits from engaging in co-production of climate service.
Transparently communicating forecast accuracy and certainty	Ensuring that providers and users of weather and climate products and services are working from a shared understanding of the possibilities and limitations of current scientific capacities.

2019).

2.2. Indicators in the academic discourse

The academic discourse includes previous efforts to develop frameworks for measuring the impact of co-production in climate resilience-building initiatives. These efforts are important for underpinning the basis for a new and updated framework as proposed here. This framework seeks to bridge differences in how impact has been measured in recent research-focused and operationally-focused climate services initiatives. The framework is novel in proposing a combined framework, bringing together impact indicators from across theory and practice to support principles- and process-based monitoring and evaluation of the scientific and socio-economic impacts of co-production in climate services on the part of all stakeholders at both individual and institutional levels.

Three studies (namely Fazey et al., 2014; Wall et al., 2017, Hegger and Dieperink, 2015) were chosen for the purpose of informing our framework. Recognising the minimal focus and lack of established best practice to assess the impact of climate services (Findlater et al., 2021), these studies are amongst the limited number to have systematically drawn together existing literature into a framework for evaluating the impact of knowledge exchange/joint-knowledge production/co-production in relation to climate and environmental change research.

Fazey et al (2014) conducted a meta-analysis of 135 peer-reviewed studies focused on evaluating knowledge exchange in environmental change research to draw out broad outcome dimensions and a series of categories common across evaluation of knowledge exchange. They proposed five overarching principles that should be applied in the evaluation of knowledge exchange. These included: i) taking into account multiple perspectives on what constitutes valuable outcomes of knowledge exchange, ii) being explicit about why knowledge exchange is expected to produce a specific outcome, iii) considering a diversity of outcomes of knowledge exchange, iv) including the evaluation process as part of the knowledge exchange process and v) using various methods (quantitative and qualitative) to evaluate the success of knowledge exchange. While Fazey et al.'s (2014) review was not specifically focused on knowledge exchange in climate services, their work has ready transferability to this field.

The work of Wall et al. (2017) was more specifically focused on evaluation or assessment of co-production of usable climate research. Their study was informed by drawing together metrics used to evaluate climate research through reviewing theoretical literature and existing performance metrics on co-production practice, and undertaking in-depth interviews with funders, experienced researchers and practitioners. Based on coding and distillation of the resulting data, they proposed 45 indicators to support assessment against context, process, output, outcome and impact of co-produced climate services. The efficacy of their proposed framework was demonstrated through two case studies. Both studies encompassed significant stakeholder engagement in assessing the impacts of climate change, with one undertaken at a community level and the other at multiple sites on the US West Coast.

Finally, Hegger and Dieperink (2015) developed a framework that has utility for assessing the added value that joint knowledge production in climate adaptation projects provide for science. Through a review of the literature combined with qualitative interviews with environmental science researchers, they proposed a set of 21 hypotheses and developed a survey to assess how joint knowledge production may impact on changes in knowledge production, scientific outputs and outcomes of climate change adaptation endeavours. The survey was completed by 144 climate adaptation researchers to test these hypotheses and demonstrate their applicability for evaluation of joint knowledge production efforts.

2.3. Indicators for monitoring progress in achieving user engagement within the National Frameworks for Climate Services

Attempts to monitor co-produced climate services are also reflected in emerging international standards. In 2009 the World Meteorological Organisation (WMO) established the Global Framework for Climate Services (GFCS) (Hewitt et al., 2012), intended to strengthen climate risk management through the development and incorporation of climate information and prediction into planning, policy and practice on the global, regional and national scales. One pillar of the GFCS is the User Interface Platform (UIP), a mechanism for 'improving co-production' and 'a structured means for users, researchers and climate service providers to interact in order to ensure that user needs for climate services are met' (Hewitt et al., 2012). This recognises that feedback from users of climate services is essential in ensuring their relevance and accessibility, as well as in demonstrating value to decision makers in managing climate risk.

Many countries in Africa are in the process of developing and implementing National Frameworks for Climate Services (NFCS) to complement National Adaptation Plans and Nationally Determined Contributions (NDCs) under the Paris Agreement (Article 4, paragraph 2). A set of objective criteria for tracking National Meteorological and Hydrological Services' (NMHS) progress towards achieving each of the five GFCS pillars has been established (Dinku et al., 2018a). Through self-assessment surveys, the capacities of NMHS are graded according to whether they provide basic, essential or full climate services. The proposed criteria and metrics to assess progress under the UIP pillar are 'designed to ensure that the NMHS has developed procedures, partnership agreements, and the communication infrastructure needed to maintain an engagement with users that includes a two-way flow of communication' (Dinku et al., 2018b, p18).

2.4. Indicators from operational partners identified within an ICPAC peer-learning workshop

The underpinning principles outlined by Carter et al. (2019) recognise that co-production of climate services is context-specific. Each initiative may seek to address the guiding principles in different context-specific ways. In recognition of this and linked with the WISER Phase 2 Support to ICPAC (W2SIP) project, ICPAC hosted a peer-learning workshop in 2019, with more than 60 representatives from across the Greater Horn of Africa region who were participating in co-production of climate services. The aim was to reflect on and synthesise regional experiences in co-production of climate services and, in doing so, consider the extent to which they aligned with and illustrated the steps and principles outlined in the Carter et al. (2019) manual.

This engagement informed the development of the 2021 ICPAC Guide for engagement in co-producing climate services (Percy et al., 2021). While largely aligned with the Carter et al. (2019) manual, the regional participants identified the need to encompass the additional principles of ownership and accountability. While these additions could be considered as encompassed within the existing principles of 'enhancing inclusivity and 'ensuring value-add for all involved', they illustrate how contextualisation of the Carter et al. (2019) manual's guiding framework can strengthen the relevance of co-production process and principles at a regional level (ICPAC, 2021, p23). During the workshop participants also proposed indicators to monitor each step in the process of co-producing climate services (W2SIP, 2019). A number of these are drawn on in the proposed framework.

2.5. Proposed framework of metrics for co-produced climate services

Building on the academic discourse, GFCS and operational partner inputs, Table 2 outlines a new proposed framework for tracking changes across the process and principles of co-production. This framework is based on Carter et al.'s (2019) building blocks and principles as a

Table 2
Collated indicators for measuring the process and principles of climate services co-production, drawing on recent literature and practice.

	Across Timeframes					
Process/ Principles	**Identify key actors and build partnerships**	**Build common ground**	**Co-explore need**	**Co-develop solutions**	**Co-deliver solutions**	**Monitor and Evaluate**
Tailor to context and decision	1.0 Necessary scientific disciplines included in research team (W). 1.1 Sufficient research time devoted to project (W).		1.2 NMHS assessment of user information requirements across sectors and ministries, including availability, interpretation and usefulness of its forecasts and other information products (D). Identifying needs through an ongoing process of dialogue and reflection (Vin).	1.3 NMHS mechanisms to co-produce climate information products tailored for specific sector (D).	1.4 NMHS has produced tailored climate information products to meet specific users' needs, including for national policy and National Action Plans (D).	1.5 Partnering decision-makers perceive climate information as salient to their needs - *user satisfaction with climate services* (W, *N*). 1.6 NMHS documents user feedback in writing (D). 1.7 NMHS procedure for incorporating user feedback into the redesign of information products and services (D).
Embrace diversity and respect differences	4.0 Range of stakeholders involved. (I) 4.1 Gender balance (I). 4.2 Efforts to engage actors and users not typically involved or who have specific barriers to engaging (I).	4.3 Agreeing principles to guide co-production (I).				4.4 Quality of relationships (F). 4.5 Individual and institutional attitude and behaviour change (F).
Enhance inclusivity	5.0 Point at which host/target agency enters or participated in project: vision, problem definition, research design, data collection + analysis, knowledge/ meaning making, testing results, sharing knowledge, evaluation (W).				5.1 Number of new stakeholders having access to relevant climate information (I, *N*). 5.2 Open access to national observations and forecast information (D).	5.3 Satisfaction in equitable engagement in the process: - Number and depth of participant engagement (F) - Degree of cohesiveness among actors (W/F/I). -Challenges within project are resolved in mutually agreeable ways (W). -Researcher and user representative perceive project goals achieved (W). 5.4 Support ongoing learning amongst and beyond partners (F/W) through a range of media easily accessible to intended users (W).

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Table 2 (*continued*)

Deliver timely and sustainable service	2.0 NMHS has strategic plan and procedures for user engagement (D),			2.1 NMHS has implemented or started the process for National Framework for Climate Services (NFCS) (D). 2.2 Use of new technology or tool (F). # 8.1	2.3 Quality of services (F) delivered in a timely manner (W), in agreed format, through agreed channels (I). 2.4 Capacity built to sustain new and improved services (F/W). 2.4 NMHS has signed MOUs with key sectors (D).	2.5 Affordability and sustainability of KE approach (F/W). 2.6 Leadership in KE process and political will (F/W). 2.7 Ownership by key players (I). 2.8 Change in organisational process or decision-making (F). # 9.14 + 10.1 2.9 Plans and strategies for mobilising resources for sustainability of climate services (I).
Build trust	3.0 NMHS/ research team and agency representative have pre-existing working relationship (W+D). 3.1 Partners indicate commitment through contribution of services, funds, time and a specific point person (W+I).	3.2 Research team's motivations for participating in the project (W+H). 3.3 Participants perceive that the process of producing the science is legitimate (W).				#3.3 3.4 Continuity of staff in partnering institutions (W).
Keep flexible				6.0 Resources to revise proposed co-production initiatives as new and additional needs emerge (V and B).		6.1 #9.12 Identification of emerging additional needs (F).
Support conscious facilitation	7.0 Proposals includes a clear plan for communication, engagement and/or collaboration between research and management team (W).	7.1 NMHS and research team have training or experience in collaborative research approaches (W/D). 7.2 NMHS has conducted training that explains to users how to access and/or use climate information products (D) 7.3 Roles of each stakeholder are developed and agreed (I).				7.4 Quality of Knowledge Exchange (KE) including: - frequency and medium of communication between research and management teams (W/I) - KE Strategy. - Effectiveness of KE approaches employed and ways to improve. (F) #9.10 - Partners accomplish assigned roles (I). - Quality of the MEL system (A). 7.5 Inclusive feedback mechanism (I)
Communicate in accessible ways		8.0 NMHS website shares basic climate information products (D).		8.1 # 2.2 Use of new technology or	8.2 NMHS website has advanced	8.3 Quality of communication (F), reach of communication

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Table 2 (*continued*)

				tool to communicate with users (F/D).	climate information products (D).	to those people most directly impacted through trusted channels, using accessible language and formats (P and C).
Ensure value-add for all involved	9.1 Total funding for project compared to total amount allocated for engagement/ collaboration activities (W). 9.2 Sufficient resourcing of decision maker time to actively participate in coproduction (C).	9.3 Establishment of mutual objectives (I) 9.4 Increased knowledge, awareness, understanding and skills acquired by partners and participants (F/W). *Number of individuals who know how to use weather and climate information to anticipate and reduce climate-related risks (N).*	9.5 User partner can articulate a need for the co-produced research (i.e. they have a problem they want to solve through the research project) (W). 9.6 Better understanding of particular problems (W) on part of both researchers and users (H).	9.7 User agency perceives a path to use/application of the research findings (W).		9.4 # 9.8 Achievement of project goals assessed through objective evaluation and researcher and user perceptions (W). 9.9 Mutual interest in longer-term collaboration (W). 9.10 #7.4 Efficiency of KE in achieving aims (F) 9.11 Quality of information exchanged (F) meets useability standards (W). 9.12 #6.1 Identification of emerging additional needs (F), including new/ improved research questions (H). 9.13 Support ongoing learning amongst and beyond partners (F): - Number of peer-reviewed articles, technical reports and other grey literature (W). - Workshops or meetings to share findings (W). 9.14 Use & benefits - Number of *at risk people, policy-makers and researchers / decision-making institutions or research institutions* using + benefiting from new and improved knowledge (B, W, I, *N, A*) *- Types of decisions that coproduced outputs are informing and resulting impacts.*(V, B, *Fo, N*) - Co-produced outputs explicitly used in agency planning, resource allocation or policy decisions (W/I). - Change in institutional standards (F). #2.8 + 10.1 - #4.5 Attitude, behaviour and motivational change (F) - Ecological benefit (F).
Improve transparency in forecast accuracy and certainty		10.0 New skills acquired by researchers (F), *including in forecast evaluation* [Fo) , communicating probability (M, Vi) and *forecast skill* (Fo) and producing new and improved products (C, *N*), and by users, in appropriate use and onward communication of forecast skill and probability (Vi),				10.1 #2.8 and 9.14 Changes in organisational process and standards (F) 10.2 #3.3 +3.4 Participants perceive science as credible (W).

Key: Indicators drawn from Literature informing Section 2.0: A = Araujo et al. 2020; B = Bahadur et al. 2015, C = Carter et al., 2019; D = Dinku et al., 2018a; F = Fazey et al., 2014; H = Hegger and Dieperink, 2015; I = 2019 ICPAC peer-learning workshop (unpublished); K = Koelle et al., 2019; M = Mendler Suarez et al, 2012; P = Patt and Gwata; Vin = Vincent et al., 2020a,b; Vi = Visman et al., 2012 and Visman, 2014; V = Visman et al., 2018; W = Wall et al., 2017.
Areas in italics extend indicators based on the case studies presented in Section 3.0, where A = AMMA-2050, Fo = ForPAc, N = NIRAS, 2021b. # = cross referencing of indicators across principles or building blocks.
Many of the indicators for NMHS are also relevant to partnering research institutions.

conceptual structure, populated by indicators drawn from relevant elements of the literature and emerging learning from operational practice described in sections 2.1 to 2.4. A reference to the original source of each of the indicators in the framework is provided in following brackets in order to ensure transparency and source attribution in the development of the new framework.

Using this proposed framework, we now determine its relevance for assessing the impact of co-production within a series of operationally-focused and research-focused climate resilience building projects (Section 3). Through a process of reflective learning, these case studies are then used to augment the framework where appropriate. The additional indicators resulting from the case studies are denoted in italics in Table 2.

3. Testing the framework and identifying methods for data collection

To assess the extent to which the framework of indicators (Table 2) provides a useful tool for supporting process- and principles-based monitoring and evaluation of co-production within climate services, we applied it to a series of projects undertaken within three multi-partner programmes. While all three programmes sought to strengthen resilience to climaterelated risks, they varied in the extent to which they were research- or operationally-focused and the weather or climate timescale (from hourly early warning information to 40 years climate information) of focus. Likewise there were differences in the co-production approaches employed across projects supported through these programmes.

Section 3.1 provides an overview of the context and co-production aims of the three programmes and four projects of focus. Section 3.2 considers the methods employed to track co-production indicators of

Table 3
Summary of the programmes and projects of focus, outlining overall aims, geographic focus, decision-making timeframe of focus and principal project partners.

Programme (aims and timeframe)	Project	Aim	Geographic focus	Principal partners in the co-production process
FCFA: Strengthening climate resilience of African people and infrastructural development over 5–40 year timeframes. Applied research focus	AMMA-2050 https://www.amma2050.org/	Enhancing understanding about High Impact Weather events to inform medium-term (5–50 year) decision-making in West Africa.	West Africa with pilot studies on flood-resilient urban planning in Ouagadougou, Burkina Faso and climate-resilient agriculture in Senegal.	Climate, agricultural and hydrological research institutions, together with operational forecasting and climate modelling centres, from across West Africa, UK and France.
SHEAR: Co-producing demand-led, people-centred science and solutions to improve risk assessment, preparedness, early action and resilience to natural hazards in Africa and Asia over seasonal to hourly timeframes. Applied research focus.	ForPAc https://sites.google.com/view/forpac-shear/home	Developing new and improved forecasts to strengthen forecast-based preparedness for flood and drought hazards.	Three case studies in Kenya: i) the national drought early warning system (DEWS) as operationalised in Kitui County, ii) urban flooding in Nairobi and iii) the flood early warning system in the Nzoia river basin.	Kenya Meteorological Department (KMD), the IGAD Climate Predictions and Applications Centre (ICPAC), the National Drought Management Authority (NDMA) and Kenya Red Cross Society (KRCS), as well as the Met Office and a number of UK universities.
WISER Phase 2: Strengthening the quality, accessibility, uptake and use of weather and climate information services at all levels of decision making over seasonal to hourly timeframes. Operational focus, with the majority of the supported projects situated in East Africa.	CRISPP Coastal Resilience and Improving Services for Potato Production in Kenya) – Met Office	Enhancing forecasting capacities and co-developing tailored weather and climate services for residents, private sector and principal livelihood groups, including fisherfolk, small-scale farmers and livestock keepers.	Four Counties in Kenya's coastal region, Taita Taveta, Mombasa, Kwale and Kilifi.	KMD, the Met Office, KRCS, the communications experts Inforkomm and the monitoring and evaluation consultancy NIRAS.
	The WISER national Rwanda project 'Iteganyagihe Ryacu' (https://www.metoffice.gov.uk/about-us/what/working-with-other-organisations/international/projects/wiser/rwanda)	Enhancing access to improved co-produced climate services through online maprooms and other communication channels to manage seasonal climate-related risks for small-scale farmers, as well as supporting multi-sectoral coordination of weather and climate services at national and local levels.	Rwanda	Météo Rwanda (Rwanda Meteorological Agency), disaster risk reduction and agriculture sector stakeholders

focus across these programmes and projects. Section 3.3 then examines the relevance of our proposed framework and the principal methods each project employed to monitor and evaluate the impact of its co-production investments. Through a process of reflective learning, this assessment also enabled identification of supplementary indicators that can be usefully added to the framework.

3.1. Case study programmes and projects for co-produced climate services

Initiatives considered in this process were part of the Science for Humanitarian Emergencies and Resilience (SHEAR) programme, the Future Climate for Africa (FCFA) programme and the second phase of the WISER programme (WISER Phase 2). All three programmes were funded by the UK Foreign, Commonwealth and Development Office (FCDO) with SHEAR and FCFA receiving joint funding from the UK Natural Environment Research Council (NERC). They all included commitment to developing scientifically-robust and decision-relevant climate information, increasing the capacity of decision makers to access and use climate information and building understanding of the approaches that support co-production of decision-relevant climate information. As outlined in Table 3, WISER was an operational programme focused on demonstrating increased resilience amongst at-risk groups, while SHEAR and FCFA were applied research programmes focused on enhancing forecasting and climate information development and use.

To inform this section we have drawn lessons from four projects within these programmes, selected because the author team have familiarity with their approaches to co-production and MEL. This includes two projects under the research-oriented programmes: namely the 'African Monsoon Multi-disciplinary Analysis-2050' (AMMA-2050) under FCFA, and 'Towards Forecast-based Preparedness and Action' (ForPAc) under SHEAR; and two projects under the more operationally-focused WISER Phase 2 programme: 'Coastal Resilience and Improving Services for Potato Production' (CRISPP) project in Kenya and the 'Itegayagihe Ryacu' project in Rwanda. Alongside overviews of their supporting programmes, the aims, geographic focus and principal partners of these projects are outlined in Table 3.

3.2. Methods for monitoring: indicators and data collection

Given its focus on operationalising uptake and use of new and improved co-produced climate services and ensuring development impact, MEL was embedded within WISER Phase 2. Guidance was available to project teams on how to design and monitor their projects to ensure inclusive co-production, value for money and transformational benefits (WISER, 2017a,b,c,2019). WISER Phase 2 projects had to report progress under the International Climate Finance (ICF) Key Performance Indicator (KPI) 4, on the number of people with improved "capacities to adapt, anticipate and/or absorb climate-related shocks and stresses" (Climate Change Compass, 2019). The programme supported the development and piloting of a methodology on how to report under this, considering individual and institutional access to and use of improved weather and climate services, and resulting impacts on their climate-related resilience (LTS International, 2019).

The resulting resilience methodology outlined a series of steps for projects to identify intended beneficiaries, how they are impacted by weather- and climate-related risks, and factors affecting resilience that the projects sought to address, with monitoring focused on administering household surveys with five key questions designed to track key indicators of anticipation and preparedness (Table 4). The methodology was piloted through eight projects undertaking households surveys, either face-to-face, or via social media or digital platforms, at base- and end-line (LTS, 2019; NIRAS, 2021a).

Methodologies for monitoring co-production in the FCFA and SHEAR programmes were less clearly articulated and evolving. The development research framing of both programmes, created through

Table 4
WISER indicators for reporting under ICF KPI4 (LTS International, 2019). Here the acronym CIS denotes 'climate information services'. Reproduced with permission of Met Office, WISER Fund Manager.

WISER indicators to measure levels of anticipation & preparedness amongst direct beneficiaries
1. Number of households using the new or improved CIS supported by your WISER project.
2. Number of households who are satisfied with your project supported CIS.
3. Number of household individuals able to anticipate climate events and disasters to reduce risks to their livers and/or property. Disaggregated per female/male.
4. Number of household individuals with improved preparedness mechanisms in place outlining forecast based actions in anticipation of the climate events and disasters. Disaggregated per female/male.

partnership of NERC and FCDO, was a new departure. Many of the partnering researchers were used to being assessed on indicators such as research funding secured and number of papers accepted by high-ranking journals (framework indicator 9.13), rather than the programmes' requirements to also monitor development impact indicators related to use and benefits of improved climate services, including increased understanding of climate-related risks amongst partnering decision makers (indicator 9.4) and use of new and improved climate services to inform policy and infrastructural investment (indicator 9.14). FCFA programme evaluation and critical learning reviews experienced difficulties in collating cross-programme impacts given the disparity and lack of focus on monitoring the processes through which research consortia had contributed to changes related to these development-focused indicators (Vaughan et al., 2021; Araujo et al., 2020).

Each of the four projects employed a variety of methods to monitor co-production indicators of focus, as outlined in Table 5. While Theory of Change (ToC) and Participatory Impact Pathways Analysis (PIPA) are used to identify the changes that an initiative seeks to achieve and the indicators relevant for tracking these changes, Key Informant Interviews (KII), Focus Group Discussions (FGD) and Household Surveys (HHS) enable collection of data on the selected indicators. While often a proposal requirement, ToC and PIPA can also be extremely valuable in supporting ongoing MEL and planning, but are less commonly employed in this way. Most of the methods can be tailored to collect data that enables tracking of the full suite of indicators outlined in the framework. Although they are not yet routinely required within climate-resilience building initiatives, MEL frameworks can support coherent and targeted deployment of the range of methods that tracking of impact in co-production often requires.

3.3. Assessing indicators and methods for data collection against the framework

3.3.1. AMMA-2050 and ForPAc

While participation in proposal development of the ToC in both ForPAc and AMMA-2050 was limited, review with partnering decision-makers during project inception enabled their reshaping *(entry point of co-production partners, Indicator 5.0)*. Using PIPA, the ToCs were subsequently contextualised for case studies of focus within each project, enabling agreement on specific challenges, shared aims and respective institutional benefits (*user-needs assessment, indicators 1.2; user-assessed relevance, indicator 1.5; ownership, indicator 2.7; establishing mutual objectives, indicator 9.3*).

Review of the ToC and PIPA formed part of each project's annual review, enabling partners to consider progress in achieving intended aims and, where changes in assumptions required, revision to proposed pathways to impact. These activities supported reflection, particularly where research and decision-maker priorities were not clearly aligned, while also highlighting limitations in flexibility to reorientate research priorities *(resource flexibility, indicator 6.0)*.

Both ForPAc and AMMA-2050 also integrated elements of climate

Table 5
Methods employed to track co-production indicators in programmes and projects of focus. The indicators are numbered and summarised here, while the broader scope of each is available through reference to the indicator framework, Table 2. Section 3.3 considers the extent to which the methods projects employed enabled tracking of framework indicators.

Monitoring and evaluation method	Framework indicators supported through this method	Description	Example of use
Theory of change (ToC)	ToC can support consideration of the full range of framework indicators and are particularly relevant to co-production indicators 2.7 (stakeholder ownership) , 4.3 (agreeing co-production principles), and 9.3 (establishing mutual objectives).	A core tool for humanitarian and development work and increasingly used in development research, a ToC maps out the outcome, outputs, assumptions and often complex web of activities and stakeholders required to bring about change. While often a proposal or business case requirement, ToC are less frequently used in their originally intended role of supporting planning and ongoing monitoring.	Programme level ToC were undertaken for SHEAR, FCFA and WISER Phase 2. ToC were undertaken at inception and used to support ongoing review and project management within the ForPAc, AMMA-2050, CRISPP and Iteganyagihe Ryacu projects.
Participatory Impact Pathways Analysis (PIPA)	Supporting strategic planning to address agreed co-production indicators of focus, specific components of PIPA are particularly relevant to co-production indicators as follows: indicators 9.3 (establishing mutual objectives), 9.5 (user-identified need for co-produced research), and 9.6 (improved user and researcher understanding of problem context) (through Problem Tree); indicators 2.7 (stakeholder ownership) and9.3 (establishing mutual objectives) (through Visioning); 4.0 (range of stakeholder involvement) and 4.2 (Inclusion) (through Stakeholder mapping); and indicators 2.8 (change in organisational process or decision-making), 2.9 (sustainable resourcing), 4.5 (behaviour change), 7.3 (clarification of roles), 9.7 (useability of research), 9.14 (use and benefits from co- produced climate services) (through Outcome Logic Model).	An adaptable project management tool that enables stakeholders affected by research to jointly identify a shared vision of the intended impact of the collaborative research and co-develop pathways to achieving it (Audia et al., 2021). Through undertaking a series of activities, including problem trees, visioning and stakeholdermapping, partners develop an Outcome Logic Model (OLM) identifying the changes in practice, knowledge, attitudes and skills required to achieve the shared project aim.	PIPA were undertaken for pilot studies in both ForPAc and AMMA-2050.
Key Informant Interview (KII) and KII Score card:	Can be developed to track co-production indicators of focus. In AMMA-2050 KII scorecards focused on tracking indicators 1.2 (user needs assessment), 1.5 (user-assessed relevance), 2.8 (organisational change), 3.2 (researcher motivation),4.5 (behaviour change) , 9.4 (improved knowledge and skills), 9 .8 (objective and stakeholder evaluation), 9.11 (useability) and 9.14 (use and benefits from co-produced climate services) and 10.0 (new skills to support co-production) ,as well as triangulating findings from PIPA.	KIIs provide a way of collecting data from key post holders within partnering institutions. Undertaken at baseline and repeated over the course of and at the end of the project with the same post holders, the KII provides a way of tracking changes in project indicators and key areas of change.	Building on the Institute for International Environment and Development (IIED) Tracking Adaptation and Monitoring Development (TAMD) framework (Brooks and Fisher, 2014), AMMA-2050 developed KII scorecards designed to collect quantitative and qualitative data across a panel of partnering decision-makers and researchers on key areas of change that the project sought to inform.
Household Survey (HHS):	Can be developed to track co-production indicators of focus. WISER Methodology to track ICF KPI4 focused on tracking indicators 1.5 (user-assessed relevance), 9.4 (improved knowledge and skills) and 9.14 (use and benefits of co-produced climate services) (LTS, 2019).	Questionnaires designed to collate detailed information from a representative sample of households within the intended population of focus	Through existing analytics and commissioned services, WISER Phase 2 piloted the Resilience Guide with 8 projects administering household surveys (HHS) encompassing five agreed questions. HHS were undertaken either face-to-face or through social media and digital platforms.
Socio-Economic Benefits (SEB) assessment	Can be developed to track co-production indicators of focus. The methodology piloted in CRISPP focused on monitoring indicators 1.5 (user-assessed relevance),9.4 (improved knowledge and skills) and 9.14 (use and benefits of co-produced climate services).	Identifying and evaluating the social and economic benefits and avoided losses resulting from use of new and improved climate services.	The WISER Coast CRISPP project commissioned a study to establish the socio-economic benefits resulting from co-produced decision-relevant climate services for households in Kilifi County, Kenya (NIRAS, 2021b).
Focus Group Discussion (FGDs):	Can be developed to track co-production indicators of focus. In WISER Phase 2 projects piloting the methodology to track ICF KPI4, FGDs focused on indicators 1.5 (user-assessed relevance), 9.4 (improved knowledge and skills) and 9.14 (use and benefits co-produced climate services).	FGDs enable discussion amongst a selected group of individuals, with participants selected to be representatives of specific groups with which the project or initiative is seeking to engage. FGDs offer an opportunity to gauge consensus and differing perspectives on key issues, as well as enabling triangulation of findings from KIIs.	FGDs were used in CRISPP and the national WISER Rwanda project to triangulate findings from HHS and KIIs.

(continued on next page)

Table 5 (*continued*)

Monitoring and evaluation method	Framework indicators supported through this method	Description	Example of use
MEL frameworks:	Related to indicator 7.4 (quality of knowledge exchange), MEL frameworks provide an overall strategy for enabling monitoring of all co-production indicators of focus.	MEL frameworks can assist in supporting coherent and targeted deployment of the range of methods employed. They bring together the range of methods through which a project plans to monitor progress in achieving intended aims, clarifying partners' respective roles and ensuring that emerging learning informs project development and is regularly shared within and beyond the project.	All the focus projects developed MEL plans. While increasingly recognised as vital to ensure trust of all partners throughout the coproduction of climate services (Wall et al., 2017), MEL plans or frameworks are not routinely required of climate-resilience building research.

information training alongside the PIPA. The training comprised a series of participatory exercises designed to build common ground: strengthening decision-makers' understanding of key climate concepts, including forecast skill and probability, while simultaneously building the capacities of the partnering researchers in risk communication *(user climate training, indicator, 7.2 and new skills to support co-production, indicator 10.0)* as well as their appreciation of the complex decision-making processes which climate information seeks to support *(improved user and researcher understanding of problem context, indicator 9.6)*.

Both projects developed MEL frameworks outlining the suite of methods - including ToC, PIPA, policy and scientific review, KII scorecards, training needs assessment, workshop and training evaluation questionnaires, and regular partner reporting – employed to baseline and monitor changes to which the projects sought to contribute (*quality of knowledge exchange, indicator 7.4*). Whilst there were many commonalities between AMMA-2050 and ForPAc, we now consider the differences between the two projects in the indicators of focus and the methods employed to track these.

3.3.1.1. AMMA-2050. PIPA workshops undertaken to shape the project's pilots highlighted the need to appoint focal points to support ongoing engagement with key stakeholders *(partner contribution, indicator 3.1)* and that, while AMMA-2050 was focused on strengthening medium-term decision-making, to ensure relevance for decision-makers, there was a need for the engagement to also address more immediate weather- and climate-related risks *(improved user and researcher understanding of problem context, indicator 9.6*). In Ouagadougou, this resulted in the development of a flood risk preparedness awareness raising pamphlet (Audia et al., 2021), while project learning regarding drought-resilient millet varieties informed ongoing applied agricultural research in Senegal. Within programming constraints, the project sought to address new and emerging needs *(flexible resourcing, indicators 6.0; identification of emerging additional needs, indicators 6.1 and 9.12)* and invest in capacities for ongoing dialogue *(user climate information training, indicator 7.2; increased understanding, indicator 9.4; and new skills to support co-production, indicator 10.0)*.

AMMA-2050 KII Scorecards gathered quantitative and qualitative data with partnering decision-makers and researchers to measure the relevance of the project's scientific outputs to supporting climate risk management, changes in researcher attitude and capacities for engaging with decision-makers, as well as frameworks and capacities to support sustained engagement between researchers and decision-makers post-project *(user-assessed relevance, i ndicators 1.5; organisational change, indicator 2.8; behaviour change, indicator 4.5; increased understanding, indicator 9.4; use and benefits, indicator 9.14)*. Employed at base-, mid- and endline, the KII scorecard has been used to meet project reporting requirements, as well as to inform project planning, activities and learning outputs.

Baseline KII scorecards made clear the constraints to operationalising existing policy frameworks for integrating climate change in Senegal, as well as the lack of systematic frameworks for researcher-policy maker dialogue in Burkina Faso *(user-engagement procedures, indicator 2.0)*. As illustrated in Fig. 2, baseline data highlighted differences between decision makers and scientists concerning the degree to which decision makers recognised that their decisions were sensitive to climate change, the relevance of currently accessible climate information and the degree to which uncertainties in this information constrained its use. KII data thus enabled the project to appropriately situate its co-production efforts and strengthen researchers' appreciation of decision-makers' perceptions, understanding and use of existing climate information and how climate information could better meet their needs *(user needs assessment, indicator 1.2; tailored climate products, indicator 1.4; and improved user and researcher understanding of problem context, indicator 9.6)*.

Mid- and end-line KII scorecards enabled tracking of changes in decision makers' capacity to integrate climate information *(increased understanding, indicator 9.4; and use and benefits, indicator 9.14*). While there remained a recognised need for more sustained engagement between climate researchers and decision-makers to strengthen decision-makers' understanding and confidence in using available climate information, respondents noted that the project had raised 'understanding that climate change has already changed the frequency of intense storms' and 'sensitised decision-makers to climate change issues such that they are asking for specific products, such as Intensity, Duration, Frequency (IDF) curves and flood maps' (Visman and Tazen, 2019, p7).

The KII scorecards were also able to track individual and institutional capacities of researchers for engaging with decision-makers and delivering research that could advance responses to climate variability and change *(experience in collaborative research, indicator 7.1; and new skills to support co-production, indicator 10.0)*. A number of key informants noted that their institutions had recognised the need to strengthen stakeholder engagement, committing to ensure dedicated capacity for science-policy and training for researchers to effectively engage with decision-makers *(organisational change, indicator 2.8)*. This engagement has also resulted in indirect benefits for some researchers, including career promotion (Visman and Tazen, 2019).

The KII scorecard also evidenced attitude change amongst partnering researchers *(behaviour change, indicators 4.5 and 9.14)*. For many partnering researchers, despite extended periods focused on African climate science, the project was their first opportunity for direct engagement with decision makers. Researchers repeatedly noted significant changes in understanding of their role in supporting climate-resilient development. One researcher highlighted that 'The project has completely changed me… I directly see the difficulties of communicating, to simplify some messages without losing the complexities…My perspectives are completely different through engaging with AMMA-2050' (Visman and Tazen, 2019, p14). Another researcher described how through projects like AMMA-2050 you can 'start to see you can have an impact with your research'. They recognised that 'You have to change your way of doing science. You need to stay a good scientist but develop other competencies', noting 'scientists also need to be aware of the ethics of undertaking this kind of work' and 'learn to do it properly'. (Visman and Tazen, 2019, p14-15).

Climate resilience-building initiatives have, to date, afforded limited consideration of monitoring changes amongst partnering researchers, instead focusing on the outward impacts on research objects. The KII scorecard, undertaken with a panel of researchers and decision makers over the course of the five-year AMMA-2050 project, provides a methodology for collating quantitative and qualitative data that considers internal impacts on the project team. Recognising the value of AMMA-2050′s KII scorecard, its questions were adopted as the basis for the FCFA internal evaluation endline survey.

3.3.1.1. ForPAc. In ForPAc, an adapted PIPA workshop was undertaken to contextualise the project's overall ToC for the project's drought case study in Kitui County. This process made clear that forecasts were not aligned with the national Drought Early Warning System (DEWS). Forecasts were not fully integrated within the drought contingency planning process, the monthly bulletins or the biennial seasonal assessments. The process also made clear that skill analysis of existing forecast products and inclusion of forecast probabilities were not routinely undertaken. The PIPA process identified entry points for providing new and enhanced forecasts, aligned with the existing DEWS, that could activate earlier drought mitigation and preparedness actions and be systematically included within the monthly bulletin (Audia et al., 2021). Repetition of elements of the adapted PIPA over the course of the pilot enabled tracking of partnering decision-makers' perceptions of the relevance of climate information *(user-assessed relevance, indicator 1.5)* and how these could strengthen the DEWS *(user-assessed useability, indicator 9.7)*, while the project also monitored and invested in building of capacity within the NMHS to sustain project-initiated services *(sustainability strategies, indicator 2.4)*.

The PIPA workshop also made clear the need to strengthen decision-makers' appreciation and confidence in interpreting forecast probabilities and the implications of these for different climatic zones, the skill associated with different forecast lead times, and approaches for integrating forecasts within drought preparedness planning (*new skills to support co-production, indicator 10.0*). To enable active engagement of County decision-makers in the co-production of new and improved forecast products, ForPAc developed a climate information training for its pilots in both Kitui and Nairobi (Mwangi and Visman, 2020). Combining the PIPA and climate information training enabled tracking of new understanding acquired by all partners in the co-production initiative: decision makers perceived the forecasts as credible *(perceived legitimacy of science, indicator 3.3)*, while researchers had a better understanding of the issues concerning use of climate information in specific decision- making processes *(increased understanding, indicator 9.4; and improved appreciation of problem context, indicator 9.6)*.

Identifying changes in the knowledge, attitude, practice and skills required to achieve agreed aims, the PIPA's Outcome Logic Model (OLM) provides an opportunity to concretely track changes envisaged in a ToC (Table 6). Re-running and reviewing elements of the ToC and PIPA enables identification of changes to which a project is contributing, as well as supporting project management, where changes in assumptions, external factors or key stakeholders require course correction. PIPA outcomes thus shaped annual project meetings, with dedicated time also afforded for reviewing specific elements of the project's ToC. In 2020, for example, the annual project meeting was centred around a joint learning review with key stakeholders to maximise opportunities for partnering research institutions to receive direct feedback and together identify relevant opportunities for ensuring project legacy. Here PIPA and ToC tracked ongoing dialogue, learning and review amongst project partners, as well as changes in organisational practises (*organisational change, indicator 2.8; entry point of co-production partners, indicator 5.0; and use and benefits, indicator 9.14*).

While use of KII scorecards in ForPAc was limited to establishing the project baseline, alongside the PIPA and policy review they did support the tailoring of co-production initiatives to focus on addressing specific challenges constraining decision-makers' use of current climate information *(tailored climate products; indicator 1.4)*. Data from both KII scorecards and PIPA highlighted that stakeholders required high levels of forecast skill to use them in justifying preparedness action, given the high competition for limited resources. KII data also established decision-makers' perceptions of forecast accuracy and relevance, highlighting that lack of systematic communication of forecast probability and skill prevented their routine use *(user-assessed relevance indicator 1.5; and new skills to support co-production, indicator 10.0)*.

3.3.2. CRISPP and the national Rwanda WISER project

Conscious that the duration of a number of projects supported under WISER Phase 2 was initially less than two years, offering limited time to fully assess strengthened climate-resilience, the programme piloted a methodology to track key indicators of anticipation and preparedness, as outlined in Section 3.2.

WISER Phase 2 projects piloting this methodology undertook household surveys to collect information about use of and satisfaction with new and improved climate services (*user-assessed relevance, indicator 1.5; and use and benefits, indicator 9.14)*, capacity to anticipate climate-related risks *(increased understanding, indicator 9.4)*, types of preparedness actions individuals undertook as a result of receiving and acting on new and improved climate services, and the socio-economic benefits of these actions *(use and benefits, indicator 9.14)*. The

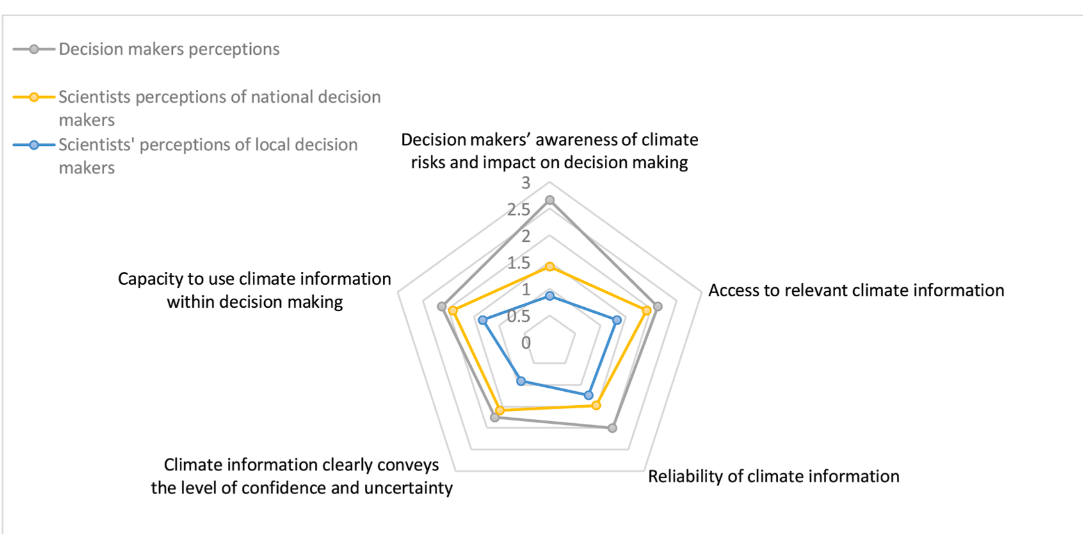


Fig. 2. Comparison between decision-makers' perceptions of their engagement with climate information and scientists' views of decision-makers' engagement at national and local levels. (Visman et al., 2017).

methodology also sought to enable tracking of benefits amongst indirect beneficiaries, collating information via the intermediary organisations supported through the programme. WISER Phase 2 also trialled a socio-economic benefit (SEB) assessment methodology designed to provide more detailed quantification of the socio-economic benefits of weather and climate services (NIRAS, 2021b) *(use and benefits, indicator 9.14)*.

These methodologies highlighted the limits to which weather and climate services can, by themselves, strengthen resilience. While new and improved climate services can support preparedness, resilience in most cases remains dependent on combining weather and climate information with sector-specific expertise to develop tailored advisories and, more fundamentally, address the underlying structural vulnerabilities that place people at risk of the impacts of weather-related hazards.

3.3.2.1. CRISPP. Framing of MEL for CRISPP was led by the organisation coordinating overall MEL for the WISER Phase 2 programme. The base- and end-line were conducted together with Kenya Red Cross Society staff, while ongoing monitoring was integrated into the responsibilities of the County Directors of Meteorological Services (CDMS), supported by a partnering communications organisation. Employing a combination of methods, including KIIs, FGDs and HHS, as well as monitoring feedback through social and mass media and piloting a SEB assessment (LTS, 2019, NIRAS, 2020), the project was able to document tangible benefits of the new and more accurate, accessible, localized and relevant climate services for fishers, farmers and the urban populations living in flood-prone areas *(use and benefits, indicator 9.14)*.

Project-initiated services were also able to support planning across the agriculture, disaster risk reduction, maritime and mining sectors. Project-initiated MEL enabled CDMS to track the extended reach and use of climate services amongst the principal user groups in each County, as well as to mainstream climate information within County Integrated Development Plans *(inclusive communication, indicator 8.3; and use and benefits, indicator 9.14)*. Co-production of climate services was seen to have built trust and increased demand and uptake *(legitimacy of science, indicator 3.3)*. Aligned with the development of County Climate Information Service Plans *(user-engagement procedure, indicator 2.0; and sustainability strategies, indicator 2.9)*, the project also enabled CDMS to more fully appreciate the link between effective communication of weather and climate information, use and recognition of its benefits by the County's population and government *(meeting useability standards, indicator 9.11)*.

KMD appreciated the value of monitoring and feedback achieved within CRISPP, while recognising that this was dependent on project partners. To ensure the sustainability of project-initiated MEL, KMD plans to draw on project learning within development of Kenya's National Framework of Climate Services *(organisational procedure for incorporating user- feedback into climate services development, indicator 1.7; and NFCS development, indicator 2.1)*. There remains a wider need to develop a rigorous and scalable methodology for SEB of climate services. Extending the approach adopted in CRISPP, strengthening research capacities of locally-embedded development actors, offers potential for sustainable scale-up of the trialled SEB methodology.

3.3.2.2. National WISER Rwanda project. The project developed a five question (5Q) tool to administer a digital survey of the WISER resilience methodology questions with nearly 10,000 farmers (Kagabo et al., 2019). Through digital Interactive Voice Recording or Short Message Services, 5Q enabled monitoring of project impact and two-way communication between climate and weather suppliers and consumers *(documentation of user-feedback, indicator 1.6; new tool or technology used, indicators 2.2 and 8.1; inclusive feedback mechanism, indicator 7.5)*. The communication platform also enabled the provision of localized agro-climatic advisories through engaging with the high penetration of mobile telephones in Rwanda and ability to thus geo-locate farmers (*tailored climate products, indicator 1.4*). Findings from 5Q were triangulated with village-level FGDs.

The methodology enabled fast and cost-effective monitoring of farmers' access to and use of weather and climate services, providing detailed understanding of the ways in which the information is used to prepare for weather and climate related risks *(use and benefits, indicator 9.14)* (Fig. 3).

4. Discussion and conclusion

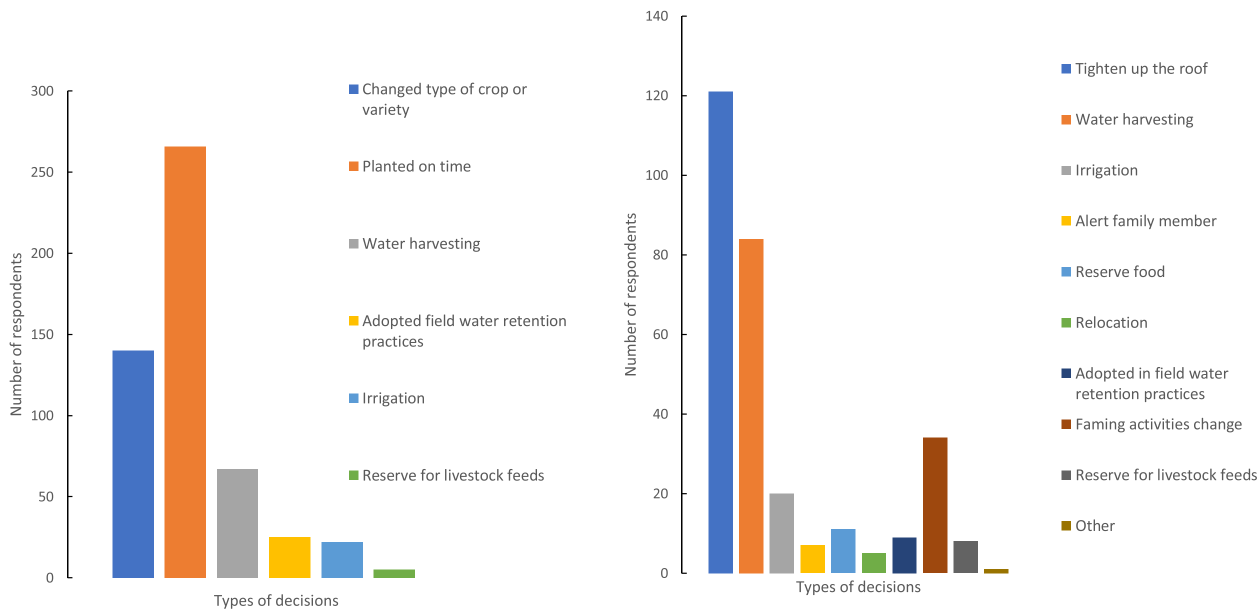
There is growing interest in co-produced climate services, recognising the role they can play in informing decisions that promote climate resilience (Vincent et al., 2018). At the same time, while there is emerging consensus on the process and principles of climate services co-production (Carter et al., 2019), there has been no agreement on how to monitor and evaluate progress. MEL is an essential part of the co-production process, recognising the value of ongoing dialogue and feedback – not just to meet donor reporting requirements and support project management, but to maximise impact for the people at risk that an initiative seeks to support, as well as informing social and physical science research (Visman, 2014). Monitoring the steps in the process of co-production enables tracking of incremental change, even in advance of more fundamental or transformational change to which climate-resilience building initiatives can contribute.

This paper proposed a framework to advance the practice of MEL in climate services co-production through metrics and methods that can be used to collect the necessary data. It has done this by drawing on existing standards and principles practised in the humanitarian, development and climate adaptation sectors, as well as within academia and research.

These metrics should be embedded within a MEL framework that is integrated within the project lifecycle and appropriately resourced. MEL is considered to be a building block of co-production of climate services, given its essential role in forming the evolution of the process (Carter et al., 2019). Closer consideration of the metrics by which co-production impact is assessed redoubles consideration of the aims, spaces and methods through which it can best be focused. Rooting these metrics in the principles and building blocks for co-production of climate services

Table 6
Outcome Logic Model from ForPAc PIPA workshop in Kitui County (Mwangi and Visman, 2020).

Actor	Change in Practice required to achieve the Project's Vision	Change in Knowledge, Attitude, Skills (KAS) required to support this change
KMD	• Strengthened provision of timely, accurate, reliable and credible climate information • Routine communication of forecast skill to forecast-users. • Systematic inclusion of probabilities within forecasts. • Create a feedback channel and routinely seek users' feedback. • Provide information on temporal distribution of rainfall.	• Acceptance that policymakers and practitioners need probabilities to enable forecast-based actions • Where feasible, enhance skill to meet decision makers' requirements • Enhance research on temporal distribution of rainfall
NDMA	• Systematic integration of climate forecasts across Drought Preparedness Planning	• Strengthened capacities to interpret climate forecasts and effectively integrate them within preparedness decision-making processes
NDMA and KMD	• Alignment in timing of forecast production and use across drought preparedness processes • If feasible increase the forecast period to 6 months to cater for food security prognosis	• Enhance mutual recognition of the need for strengthened collaboration in policies and practice



a: Baseline **b**: Endline

Fig. 3. Data collected across 30 districts in the 2020 baseline and March 2021 endline surveys of the Rwanda WISER national project.

ensures that they effectively capture the respective priorities and requirements of the varied range of participants in the process, and the different incentive structures in which they are embedded. There is, likewise, a need to monitor and evaluate the metrics themselves – and the process, methodologies, capacities and resources required to measure them – to ensure ongoing fitness for purpose across development and research institutions, government ministries and funding agencies, as well as amongst users.

We have also reviewed some of the methods through which these metrics may be tracked. Given the complex range of partners, decision-making levels, disciplines, sectors and funding sources, monitoring and evaluation of co-production in climate services may best be supported through using a combination of methods to triangulate and support more inclusive engagement. It should also be noted that the methodologies employed have the potential to shape project implementation as well as tracking impact. Further, the degree and form of co-production, as well as the method employed to measure resulting change, may impact on the extent to which indicators are assessed as having been met.

Operationalising a MEL framework for co-production of climate services requires appropriate resourcing. This should cover the development, piloting and translation (where relevant) of monitoring protocols, as well as the identification of, establishment and undertaking of meetings with participants over the course of a project or programme, together with the collation, analysis and sharing of resulting findings. Experiences also underline the need for flexibility in resourcing MEL given it can be difficult, at the outset, to identify all relevant key areas of change and indicators, together with the most effective ways of monitoring and evaluating these within and beyond project timeframes.

National Frameworks for Climate Services and linkage within existing national monitoring and evaluation frameworks offer important opportunities to ensure sustainable and integrated monitoring of climate services (Percy et al., 2021). However, part of the resourcing requires building of capacity to develop core MEL capacities and systems among the broad range of actors involved in co-production, including national meteorological agencies and key partnering institutions (WMO, 2019). This is essential to enable sustainability and evolution of the co-produced climate services, including beyond project lifecycles (Visman et al., 2018). Sustainability also requires more strategic consideration of MEL and the metrics by which co-production in climate-resilience building research are assessed. Given that the majority of co-produced climate services start from projects, funders also have a critical role to play in providing an enabling environment that supports application of metrics and methods within a comprehensive MEL framework.

CRediT authorship contribution statement

Emma Visman: Conceptualization, Writing – original draft, Methodology, Writing – review & editing. **Katharine Vincent:** Conceptualization, Methodology, Writing – review & editing. **Anna Steynor:** Conceptualization, Methodology, Writing – review & editing. **Irene Karani:** Conceptualization, Writing – review & editing. **Emmah Mwangi:** Conceptualization, Writing – review & editing

Funding acknowledgement

This work was supported through the following funding sources: the Future Climate for Africa programme, with financial support from the UK Government Department for International Development (now the UK Foreign, Commonwealth and Development Office (FCDO)) and UK Natural Environment Research Council (NERC), grant references: NE/M020428/1 and NE/M020428/2 (AMMA-2050, UK Centre for Ecology and Hydrology), NE/M020010/1 (Kulima) and NE/M020347/1/(UCT); the FCDO- and NERC-funded Science for Humanitarian Emergencies and Resilience (SHEAR) programme support for the Towards Forecast-based Preparedness Action (ForPAc) project, grant reference NE/P000673/1; and the FCDO-funded Weather and Climate Information Services for Africa (WISER) Phase 2 programme support for the 'Piloting a methodology for measuring the contribution of weather and climate services to resilience' project, Contract No. P105513 and TRANSFORM Project, Contract No.P104414.

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.

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