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Reflections on a key component of co-producing climate services: Defining climate metrics from user needs

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ABSTRACT

There is increasing recognition of the importance of co-producing climate services to bridge the current "usability" gap in climate information for decision-making – yet understanding precisely how this should take place is less well elaborated. One key stage of the co-production process involves identifying specifically which climate metrics can usefully inform decisions – but methods that can be drawn upon to construct this information are often overlooked. We discuss how the choice and application of four existing social science methods (interview-informed role play workshop, open-ended interviews, prioritised surveys and enhanced surveys) arose out of, and was in turn embedded within, a different epistemological approach characteristic of co-production to identify decision-relevant climate metrics for the water and agriculture sectors in Malawi and Tanzania. In so doing, we reflect on the evolution of our understanding of co-production as our assumptions were challenged, from the expectation that we would be able to "obtain" metrics from users, to a dynamic mutual definition based on better understanding of the decision-making contexts. Such reflections inform emerging experiences of co-production of climate services, as well as having implications for broader contexts beyond the climate change space in which co-production is attempted to improve science-society interactions.

Practical implications

The field of climate services is growing with the intention of providing weather and climate information that is tailored and targeted to specific needs of users and their decision contexts. Climate services can thus ultimately enable users to more effectively reduce climate risk and adapt to changing circumstances. However, the process of developing climate services is not always easy. Typically, relatively more emphasis has been placed on the supply side of climate services than the demand side. This means that, on the whole, producers of weather and climate information have typically not engaged with, or taken into account, user needs for information when generating forecasts and projections. Instead forecasts and projections have been produced in a vacuum and disseminated with little consideration of the diversity of user needs, thus meaning that the information is not always useful or usable.

To generate effective climate services, there is therefore a need to step out of this one way flow of information to rather recognise that users have valuable inputs into the knowledge production

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process. Co-production offers an alternative approach to knowledge production that recognises that knowledge is not just generated from a scientific process, but rather can come from many sources. Whilst the overall aim of the process is well accepted, how it should take place is poorly elaborated. In particular, the process of engaging users and determining their specific information needs is not well defined.

In this paper we present the example of an African climate services project to illustrate how this process of unpacking user needs and defining their decision-relevant climate metrics took place. It highlights how existing social science methods can arise out of, and be embedded within, a different epistemological approach which is characteristic of co-production. It also elaborates how reflexivity and iteration, including on the assumptions around what constitutes knowledge and how it should be generated, are essential at all stages. The practical implications are thus that the process of assessing user needs, which is an essential element of co-producing climate services, can be aided through existing methods applied within a different approach to knowledge production.

1. Introduction

Development activities, strategies and planning will need to take into account changing climate risk in order to reduce the risk of potential losses, and to maximize potential opportunities and outcomes. There is growing interest in improving the availability of weather and climate information for use in decision-making to reduce adverse impacts of climate change (Jones et al., 2015). The climate services agenda has arisen to address this need (Hewitt et al., 2012). Climate services aim to provide users with timely, tailored and targeted climate information that may be used to adapt to climate change and variability (Vaughan and Dessai, 2014). Despite increasing availability of climate information, this has, however, generally not translated into its effective use for adaptation (Lemos et al., 2012). Instead there are a number of challenges that impede the effective use of climate information in decision-making.

Challenges within the climate services arena mainly relate to the gap in the development and delivery of climate information by producers, and usefulness of the information to suit decision contexts of the users (Hewitt et al., 2017). There is often a mismatch in the temporal and spatial horizon, with climate information producers projecting future climate to 2100 and beyond, and usually at relatively low resolution (Sultan et al., 2020). Users, on the other hand, tend to be more concerned with considerably shorter horizons that are consistent with political and budget cycles, or their preferred timescale of planning, and high spatial resolution. Farmers, for example, tend to need timely provision of sub-seasonal or seasonal weather information that is applicable in their particular locations (e.g. Kirchhoff et al., 2019; Nissan et al., 2018). Mismatch of terminology is also common – for example, there is frequent (and well documented) confusion over the term "uncertainty", given that it means different things to producers and users (and, indeed, frequently has different meanings amongst sectors of users). Producers of such information have typically struggled to portray the cascading uncertainty inherent in climate projections, with users often desiring greater confidence in models, whilst overlooking the inherent indeterminacy of the future (Sultan et al., 2020; Otto et al., 2016; McMahon et al., 2015; Spiegelhalter et al., 2011). In one example, mismatch of terminology became apparent when users were requesting downscaled information - when what they were seeking (in the language of the producers) was locally-relevant information (Briley et al., 2015). Part of the way in which the mismatch has arisen stems from differences in how legitimate information is produced, as well as different levels of confidence in each other's knowledge systems (Dilling and Lemos, 2011).

Together, the differences in the supply of information by producers and the demand from users creates a usability gap (Lemos et al., 2012; Buontempo et al., 2014). Addressing this usability gap requires a rebalancing of climate services to increase focus on the demand side (Vincent et al., 2020). There are various modalities to enable this rebalancing, one of which is co-production (Cvitanovic et al., 2015). Despite the growth in co-produced climate services and the opportunities they present, there are few methodological reflections on the experiences of it in practice (Carr et al., 2019; Lemos et al., 2018). The paper aims to help in addressing this gap, discussing how the choice and application of existing methods arose out of, and are in turn embedded within, a different epistemological approach which is characteristic of co-production. We use the example of an African climate services project in which four methods were variously applied (each with slightly different representatives of the broadly identified user groups) to characterise decision-relevant climate metrics. We assess the strengths and weaknesses of each method within our epistemological approach by looking at the nature of the outputs of the process, embedding the discussion within a critical reflection of our assumptions and how challenges played out. Our aim is to add nuanced understanding to the process of assessing user needs, which is an essential element of co-producing climate services.

2. Co-production of climate services and the UMFULA project

Co-production of knowledge challenges the typical narrative that there is an objective reality that is best addressed through scientific hypothesis-testing (Pellizzoni, 2014). Aligned with the participatory turn in human geography (e.g. Chambers, 1983), co-production emphasises that there are many forms of knowledge. Actively embracing these different knowledge systems through collaboration of many different parties in an inclusive and iterative process can allow for analysis of problems and construction of solutions (Hegger et al., 2012; Meadow et al., 2015; van Kerkhoff and Lebel, 2015; Vincent et al., 2018). There are a diversity of approaches to co-production, each associated with varying academic traditions, different aims and therefore criteria for success, which have been conceptualised as a prism of "lenses" (Bremer and Meisch, 2017; Bremer et al., 2019). Among these lenses is a normative type of "iterative interaction", which focuses on addressing the usability gap (Bremer and Meisch, 2017).

Co-production is variously defined, but broadly refers to a different way of producing knowledge that involves partnership of producers, users and (often) intermediaries or "boundary spanners", and challenges the dominant supply deficit model, potentially offering the opportunity to address uneven power relations (Turnhout et al., 2020; Vogel et al., 2019; Wyborn et al., 2019). Co-production between producers and users can, therefore, construct credible, salient and legitimate climate knowledge (Cash et al., 2003; Vaughan and Dessai, 2014). It creates challenges, however, including for institutions such as National Meteorological and Hydrological Services whose core activities have been limited to generating forecasts and projections when to support co-production of climate services they have to adapt and build capacity (Nkiaka et al., 2019; Mahon et al., 2019). It also often creates roles for new partners, such as intermediaries or boundary spanners (Bednarek et al., 2018; Goodrich et al., 2020).

There is growing literature and practice around co-produced climate services to address the usability gap, particularly in the developed world, although there are emerging examples of its application in Africa (e.g. Daly and Dessai, 2018; Steynor et al., 2016). In order to effectively co-produce a climate service, it is critical to identify the climate information needs, as has been identified and elaborated by many studies (e.g. Carr et al., 2019; Carr and Onzere, 2018; Coulibaly et al., 2015; Dilling and Lemos, 2011; Lotter et al., 2018; Ouedraogo et al., 2018; Prokopy et al., 2017; Sultan et al., 2020). The importance of identifying users and their needs has been highlighted as a critical area that is often uncritically or simplistically addressed (Carr et al., 2019). There is growing agreement on the principles of co-production – including a focus on context (and the decision in question), ensuring pluralism of perspectives through a collaborative and flexible approach that is goal-oriented and time-managed (Norström et al., 2020; Vincent et al., 2018). Such principles mean, however, that there is no single established method through which to undertake co-production (Mach et al., 2020).

Determining the climate metrics that are of interest to users is a critical component of co-producing a climate service, as this enables the producers to develop the decision-relevant information. However, the process of eliciting such metrics involves various stages – including identifying the users in question, exploring their decision-making contexts and narrowing down information needs before being able to distil the climate metrics. In many studies the users and their needs are either assumed, or determined through one method, whether a questionnaire, interviews, focus groups, or other participatory tools (Carr et al., 2019). There is rarely reflection upon the epistemology in which the choice of methods was embedded. This gives rise to a research gap to interrogate which methods are effective in different situations, and determine how different approaches can be drawn upon to build on strengths and eliminate gaps (Carr et al., 2019). To address this gap, we critically reflect on the various methods employed as part of co-producing climate services in the UMFULA project to explore the decision-making context and information needs, and co-produce the list of user-informed climate metrics.

UMFULA is a project under the Future Climate For Africa (FCFA) programme[6] which aims to improve the use of medium term (5–40 year) climate information in decision-making in Africa. Embracing the instrumental aim of co-producing usable climate information (Harvey et al., 2019), the UMFULA project has focused on the water, agriculture and energy sectors in central and southern Africa, with case studies in Malawi and Tanzania; as well as a focus on the Southern African Development Community region more broadly (FCFA, 2019). It has done this through a multidisciplinary and international team comprising climate scientists and impact modellers as “producers”, and social scientists investigating the nature of decision-making and planning processes, who are also equipped with facilitation and interview skills to lead the co-production process with users.

As with all climate services projects, a key task within the co-production process of UMFULA was to determine climate metrics of relevance to the decision-making and planning of the different sectors, with the aim of ensuring that climate information produced was useful and usable. Within co-production debates, concern is rightly placed on the way in which users are identified, since it can easily be (inadvertently) exclusive (Carr et al., 2019; Wyborn, 2015). Our main users included the commercial agricultural sector (specifically sugar and tea sectors), and small-scale farmers (through the agricultural extension services and contract farming organisations), as well as other parties concerned with future water availability – for example irrigation and hydropower planning, which largely comprised government technical staff, electricity company representatives and dam operators. In this case, the users were largely pre-defined (for example by their job position in government, or by the small number of commercial agriculture entities that comprise the tea and sugar sectors). All were technical staff with either a tertiary education and/or specific technical expertise, and were able to converse in English, meaning that methods employed did not have to take into account potential exclusion that might be more prominent in a less homogeneous group, for example on the grounds of language, gender, or different worldviews (Porter and Dessai, 2017).

In UMFULA, co-production was carried out as an iterative process, with the approach being adjusted flexibly to accommodate lessons learned through experience. In keeping with the ethos of co-production, particular effort was paid to building trusted relationships with various user groups, ensuring inclusion of a wide variety of relevant parties, and creating a grounded, constructivist approach that involves putting the opinions of users at the centre of analysis (Hegger and Dieperink, 2014; Holt et al., 2019). We did not initially expect to employ multiple methods to elicit climate metrics. Instead, the fact we had to do so reflects the repeated challenging of an underlying assumption with which we approached the process – that users would be aware of their (specific) climate information needs, and be able to elicit or distil metrics that accurately encapsulate those needs for producers to develop climate information. Each time the assumption was challenged, we had to be reflexive and progressively modify our approach by adopting other methods that better suited our evolving understanding of the context and situation. Ultimately we realised that, despite our best efforts to be inclusive and recognise pluralist ontologies, in the initial stages our methodological choices were still embedded in epistemological assumptions that reflected scientific process. Each method was applied with a different group of users from the various target user “pools” and, thus, each group participated in one of the methods.

3. Different methods to determine climate metrics

We broadly define four methods that were used with our user groups to explore climate information needs and, more specifically, define climate metrics of appropriate resolution for producers to generate. We outline them here, including the tools used, outputs generated, as well as the strengths and weaknesses, in order to illustrate the issues we faced with resolution of information needs (Table 1). The first of these, undertaken as part of the pilot phase of the study (working with an earlier set of users, a sub-set of whom continued to be involved) entailed the design of interview-informed role plays used to simulate decision-making contexts in a workshop setting. The second was open-ended

Table 1
Summary of the users, strengths and weaknesses of each of the four methods.

Method	Users	Strengths	Weaknesses
1. Interview-informed role play workshop	Government technical staff and non-government commentators (interviews). Decision-makers from climate-relevant sectors in this case, agriculture, water and disaster management) (workshop)	Exploration of the decision-making context, thinking "outside of the box"	Unfamiliar exercise, time-consuming to prepare, technical staff found it difficult to make parallels between the role play and their daily decisions so remained theoretical
2. Open-ended interviews – “clean slate” approach	Government technical staff within climate-relevant sectors (in this case, agriculture, water and disaster management)	Minimises limitations of being constrained by information availability, exploration of the decision-making context	Poor resolution of information needs-insufficient to enable producers to identify appropriate metrics
3. Prioritised survey – “'multiple option” approach	National and local government technical staff in climate-relevant sectors and private commercial agricultural sector	Enables definition of key variables and thresholds	To avoid constraining users, requires lengthy survey to explore all options
4. Enhanced surveys and guided discussions	Farmers and farm managers in the commercial agricultural sector (tea estates and smallholders)	Survey targeted for specific users and their decision-contexts. Defines highly-relevant metrics with locally-specific thresholds	Requires significant background research (e.g. open-ended interviews) to prepare. Time- and resource-intensive

[6] Future Climate For Africa is a four year programme from 2015 to 2019, funded by the UK Department For International Development (DFID) and Natural Environment Research Council (NERC).

interviews with users. The third comprised a survey of a wide range of potential climate metrics, with prioritisation undertaken as part of the exercise. Finally, the fourth was a mutual problem exploration, where the metrics were ultimately "diagnosed" by the producers to fit the problem context, through enhanced surveys and guided discussions. We explore each of these approaches below.

3.1. Interview-informed role play workshop

Recognising the differences in epistemologies, value systems and priorities, we were wary of using questionnaires of climate metrics of interest, lest they limited the imagination of users. Instead, we made the decision to explore the decision-contexts and planning decisions undertaken by government staff in the climate-relevant sectors, with the aim of using this to create a role play scenario for use in a workshop format. The role play setting - an urban environment - was unfamiliar to all the participants, but had close parallels with their daily jobs, given that the full range of sectors are represented within an urban planning context - and thus the decision-making process was similar (Jones et al., 2013). The aim was to encourage participants to consider the potential risks of climate change to different sectors, to provoke discussion, and to both raise their awareness of the potential use of weather and climate information through prompts (Table 2) – as well as also encouraging them to consider additional information that would also be useful in planning decisions. Having had this prompt, we expected that participants would be better able to draw parallels and differences with their own decision-making contexts, and thereby be better placed to identify climate metrics that would be of interest to them.

The next stage was for small groups (comprising three to four people) to apply the same process – to determine what type of weather and climate information would be relevant – but to inform decision-making in their particular sectors and domains, and the varying timeframes and planning horizons that underlay those decisions (see example in Fig. 1). Ultimately, results from each group were transferred onto a large grid matrix and explained in plenary. In order to keep a competitive game format, each decision was scored by a judge who allocated a certain number of points based on the explanation of how the weather and climate information would be useful. In an attempt to encourage thinking "outside of the box", teams that devised their own weather and climate information, as opposed to relying on the pre-made cards, were given bonus points (for more information on the workshop format and role play, see Vincent et al., 2014).

The interview-informed workshop method had advantages and disadvantages. The interviews enabled exploration of decision-making contexts, which meant that we were able to design role play scenarios that were realistic and feasible. The participatory nature of the workshop and the role play scenarios were effective in encouraging participants to "think outside of the box". However, participants were unable to draw parallels between the role play and their daily decisions, which impeded their ability to identify metrics of interest at the resolution required by producers to be able to generate the information. In addition, the process was very time- and labour-intensive in terms of preparation.

Table 2
Example climate metrics provided to role play participants.

Strong winds and/or hail
Frost
Temperature and rainfall projections for 5 years from now
Flash floods
Multi-year forecast (i.e. temperature and timing/ distribution/ amount of rainfall)
Floods of short duration (<1 week)
Floods of long duration (>1 week)
Intense rainfall of short duration (<1 day)
Intense rainfall of long duration (>1 day)
Drought (less than one season)
Drought (multi-year)
Likely duration of the annual rainy season
Likely start date of the rainy season
Potential for dry periods within the rainy season
Average annual temperature
Average annual rainfall
Temperature and rainfall projections for 10 years from now
Number of extremely hot days
Number of extremely hot nights

3.2. Open-ended interviews – "clean slate" approach

Whilst the workshop role play scenarios were successful in eliciting broad areas of interest, they were largely generic, and there was more interest in short-term (annual) timeframes of potential use (Vincent et al., 2017). Open-ended interviews with representatives from government departments in climate-relevant sectors were then conducted. Again we preferred a "clean slate" approach, so as not to prejudice users with the language of producers, nor with the limitations of climate metrics that are technically feasible. Our implicit assumption, widespread in the climate services co-production literature, was still that users would be able to elucidate their climate information needs (e.g. Kolstad et al., 2019; Briley et al., 2015).

As a result of the direct relationship of agriculture with weather and climate, it was expected that users in the agriculture sector, in particular, would be able to provide more detail on the climate metrics of interest (for example not just "increased temperatures" but "number of days that exceed 35°C"). We did anticipate that the climate metrics of concern to agricultural users are also likely to differ significantly, depending on the particular requirements of crops and different scales of farming operations. The "clean slate" approach had the advantage of not prejudicing users with the assumptions of producers, as would have inherently been embodied in the choices of categories/questions. However, the disadvantage was similar to the previous method in terms of the resolution of information needs, which was still too generic for the climate information producers to be able to take it on board.

Commercial agriculture representatives from the sugar and tea industries take proactive approaches to weather information, in many cases collect their own data, and were more familiar with long-term planning. Together with the highly managed nature of their production systems, they were thus better able to elucidate climate variables of concern to them – for example, river water flow for irrigation demand, or the critical temperature thresholds for production loss and/or failure, or increased pest incidence. This was in contrast to the government extension staff whose primary audience is small-scale farmers producing primarily for their own consumption, who are concerned mainly with the immediate season. Instead, the interviews enabled us to continue and extend our explorations of the decision-making contexts of climate-relevant sectors, and identify critical thresholds and barriers. At the same time, they enabled us to build the relationships and trust necessary for a collaborative co-production process (Vincent et al., 2018).

3.3. Prioritised survey – "multiple option" approach

When the interview-informed role play workshop and open-ended interviews together had still not provided the required level of detail of user needs for climate information producers, a questionnaire was developed. Informed by a survey conducted by a sister project to UMFULA, AMMA-2050 (Rowell et al., 2015), as well as our growing understanding of the decision-contexts and sector-relevant information needs gleaned from the previous two methods (and their limitations), a list of 31 metrics was included in the questionnaire. The list contained metrics relating to rainfall (10), temperature (8), evapotranspiration (4), extreme weather events (5) and water quality (as relevant to irrigation) (4). We were cautious to not limit ourselves to the producer perspective and include only those that currently exist or are possible to develop and, instead, guided by insights into the decision-making contexts, also included some that are relevant but may never exist, and could be used

Building new roads/creating a sustainable public transit system (Transport – long timeframe, 5-20 years)	**Repairing leaks in infrastructure** (Water and sanitation – short timeframe, annual planning)	**Pest management to ensure food availability** (Food security/DRR – medium timeframe, 1-5 years)
Promotion of climate-resilient livelihoods in the formal and informal sectors (Economic planning and development – medium timeframe – 1-5 years)	**New strategies to ensure food security (new crop types, new land availability, storage facilities, processing)** (Food security/DRR – long timeframe, 5-20 years)	**Maintaining resource integrity in existing facilities** (Biodiversity – short timeframe, annual planning)
Improving availability of renewable energy (e.g. infrastructure) (Waste/pollution/energy – long timeframe, 5-20 years)	**Upgrading/re-grading existing roads** (Transport – medium timeframe, 1-5 years)	**Recruitment of new staff/ re-training of existing staff** (Health – medium timeframe, 1-5 years)

Fig. 1. Example of decisions where climate information could play a role, including sector and timeframes.

to inform proxies (Table 3). Where possible, and in order to elicit further detail, respondents were asked to provide thresholds that they would use for relevant metrics to help identify how these metrics were relevant to the decision-making process and to provide a more detailed response. Respondents were asked to prioritise the five metrics of greatest interest, and use the additional space to list other relevant metrics not included in the pre-prepared list. A commercial sugar producer in Tanzania was the only one to make additions (solar radiation and sunshine hours).

The advantage of this method was that it began to elicit more insights from the agriculture sector, with the metrics prompting recognition of key growth parameters and thresholds for different crops. However, as indicated above, very few of our respondents provided additional metrics. When prioritizing, they tended to select variables rather than the metrics (e.g. rainfall or temperature rather than "probability of night-time temperatures exceeding x"). It had been our intention to undertake this exercise in a discussion format, for example through an interview, which would have allowed some flexibility to further probe any responses. However, the preference of some respondents was for us to leave the survey with them for completion in their own time. Although the survey was comprehensive, since we were not there to engage with them, we were unable to ask further probing questions to obtain the specifics of the information required. Another disadvantage was that, in order to not lead respondents, the survey had to be fairly long with many options, making it time-consuming to complete.

Table 3
Example of selected temperature metrics.

Probability of temperatures exceeding x degrees – overall (in a season?)
Probability of daytime temperatures exceeding x degrees
Probability of daytime temperatures exceeding x degrees for y days in a row
Probability of night-time temperatures exceeding x
Probability of night-time temperatures exceeding x for y days in a row
Tmax (maximum temperature) 2 m above ground
Probability of solar radiation (Rs/Rn) exceeding/being less than a threshold amount (please specify threshold, e.g. as relevant to a particular crop)
Probability of sunshine hours exceeding/being less than a threshold amount (please specify threshold, e.g. as relevant to a particular crop)

3.4. Enhanced surveys and guided discussions

Learning from experiences with the prioritised survey, the project sought greater collaboration with the commercial agriculture sector; tea. Initial interactions with the key players in the tea sector showed high levels of detailed knowledge of the crop, and an immediate need for credible future climate information to inform planning. To elicit more detailed insights into the specific needs of tea sector managers and to test a more guided approach, we carried out an enhanced metrics survey in Malawi, and an approach using examples of climate information to guide discussion for tea specific metrics in Tanzania.

The enhanced climate metrics survey was designed to elicit relevant months, seasons, thresholds specifically relevant for the quantity and quality of tea in Malawi. In a workshop setting, the metrics survey was introduced, discussed and feedback was gathered to improve the survey. We found that stakeholders were more enthusiastic and prepared to respond to the revised survey, as it was co-designed with their inputs. In some instances, surveys were directed to tea estate agronomists by the estate managers to provide more useful information for the relevant climate metrics. This approach was time- and resource-intensive – even more so when taking into account the reliance on insights gleaned from earlier methods of co-production. However, the advantage was that it was effective in yielding relevant metrics with locally-specific thresholds.

In Tanzania, time constraints forced a different approach to the enhanced metrics survey, and this allowed us to test a more guided method for deriving specific metrics and details on relevant thresholds to meet climate information needs for tea production, through discussions. In this approach, examples of climate information with thresholds such as number of days exceeding 30°C, were developed and presented in the form of climate briefs. The briefs were prepared by engaging the National Meteorological and Hydrological Services in Malawi and Tanzania, and using state-of-the-art climate models to derive climate projections at the national level (Conway et al., 2017; Mittal et al., 2017). The briefs were presented to tea producers in face-to-face meetings where discussion was enabled.

This approach provided the potential users with a clearer idea of the level of detail and the ways in which climate projections could be tailored to specific climate metrics and thresholds. The briefs presented examples of thresholds and visualisations of detailed metrics for other crops to spark discussion about how the metrics could be varied and/or refined to make them more relevant to tea. This approach honed in quickly on key metrics and variations, providing a springboard for discussion. Equally, having something to work from did not prevent users from identifying different thresholds and offering others metrics for consideration that had not been previously mentioned by other respondents.

4. Reflections and learning going forward

Co-production is a time- and resource-intensive process which can be highly demanding of users, and caution is necessary to ensure appropriate methods are used (Lemos et al., 2018). In the case of UMFULA, we took a reflexive, necessarily adaptive and flexible approach, which led to us ultimately trying different methods and sequencing our activities within the co-production process. Part of this is due to us reflexively realising that, despite our best intention to embrace plural ontologies, we were initially more influenced by our own way of seeing the world and assumptions about what knowledge looks like and how it is produced.

The reason for applying different techniques and methods was that our key assumption was rapidly shown to be false. As with many (although not all) other climate services projects, we assumed that users would easily be able to be specific about what climate information might be useful to them, as well as the way in which it might be useful (e.g. Kolstad et al., 2019; Porter and Dessai, 2017; Wyborn, 2015). When the level of detail arising from the role play workshop was too general, our perspective shifted from an intended unidirectional dialogue in which we would "obtain" climate metrics, to a mutual dialogue, with each party bringing their own perspective to ultimately "define" the metrics. We liken this changed understanding to the analogy of a doctor and patient. A patient does not request the medicine but will describe the symptom felt, and the doctor will evaluate what the patient needs to alleviate that symptom. It became clear to us that, rather than expecting to "obtain" metrics, as the prerequisite for the climate service solution, we rather had to "define" them together by applying our knowledge to the context of the users and the problem that wanted to address). Essential in this process of diagnosing, is the conversation around issues, or to continue the analogy, "@symptoms". This was undertaken in open-ended, "clean slate", interviews.

Providing more meaningful context, as we did through the prioritised surveys, helped users to express their requirements and gauge the relevance of potential climate information. Even in the case of this method, however, it rarely led to a high enough resolution of information specifics. Being able to provide this information was a result of attempting, reviewing and revising our engagement approaches, whilst retaining the knowledge gained on metrics of value from one step to the next.

More information was found to help generate a better level of detailed discussion for the users most familiar with climate information (i.e. those in the private agriculture sector) through the enhanced surveys (Malawi) and guided discussions (Tanzania). We found that commercial agriculture producers were more able than most to identify metrics of concern, possibly as a result of the fact that they take a more 'scientific' or analytical approach to decision-making for production maximization, and have greater clarity of their climate information needs (Vaughan et al., 2018). Their technical training also largely means that they are comfortable with scientific information and language (Porter and Dessai, 2017).

Each of these methods can be used in their own right in co-production of climate services. However, the trial-and-improvement sequencing and multiple methods approach that we adopted enabled us to build on findings of each preceding stage. Moreover, the fact that the methods were embedded within a reflexive and iterative process of co-production is what distinguishes them from use within other epistemological approaches. In the process, we can reflect that, despite succeeding in building trusted relationships and creating the new collaborative spaces consistent with the aims of co-production, we had erroneously assumed we could "obtain" climate metrics of interest from users. Rather than being knowledge that existed, instead the process of co-production enabled us to collaboratively co-produce that knowledge, and thus "define" them. The process of eliciting user-informed climate metrics was thus indeed, as the literature on co-production suggests, a learning process in itself that required an inclusive, participatory and interactive analysis of problems and construction of solutions (Roux et al., 2006; Hegger et al., 2012; Meadow et al., 2015; van Kerkhoff and Lebel, 2015).

5. Conclusion

Normative, "iterative interaction" and instrumental approaches to co-producing climate services always require an element of defining user needs and priorities and metrics of interest. It is rare for the "black box" of this process to be critically assessed. We have here highlighted how methodological reflection is critical, based on our own experience within the UMFULA project, where the co-production process involved a variety of methods and techniques, reflecting emerging insights from the process, and the challenging of assumptions.

Whilst obtaining metrics of interest to climate-relevant sectors was not as easy as anticipated, active reflection on the engagement and willingness to be flexible led to an iterative process of knowledge construction. In particular, throughout the range of approaches, there was a tension between not wanting to lead responses in the spirit of being user-driven, whilst gradually recognising that some guidance was required in order to reach a greater level of detail in metric and threshold specifics. The variation in appropriateness of different methods for different users highlights that the approaches used in co-production need to be adjusted to suit different users and their existing relationships with climate information - and it is not always clear from the outset which users will be able to provide the greater detail. In this paper we have outlined the iterative process that led to us variously adopting different approaches as an indication of what reflexivity in co-production may look like. The particular method(s), or iteration of method(s) of identifying metrics of interest will depend on context and the target user group, and it may well be that in other circumstances a lesser number of methods is required. Indeed it may be the case that use of one sole method will be effective from the start, particularly if the context is very well known to the producers. At the same time, reflexivity and iteration also means that it may be very difficult to predict the evolution and adaptation of methods that will be required throughout the process. Furthermore, after metrics have been "defined", they are likely to need to be refined through further conversations between producers and users as the climate service is trialed and improved.

The experience of defining climate metrics has relevance for the climate services community, as well as more broadly for co-production and the wider suite of options for facilitating science-society interactions. For the climate services community, there is clear need to have a more nuanced and critical approach to these tasks – including moving towards an improved typology of climate information and users, and our experience illustrates the strengths and weaknesses of different approaches (as well as the advantage of taking a multiple methods approach, where feasible). For other science-society relations, where dialogue, engagement and communication between scientists and society is critical, our experiences reiterate the importance of empathy. A critical understanding of decision-making contexts, and user needs and preferences, is essential to generate and communicate useful and usable information. This applies at all levels, whether local, for example in citizen science and the establishment of community warning systems; or global, for example in international assessments such as the Intergovernmental Panels on Climate Change and Biodiversity and Ecosystem Services (IPCC and IPBES).

CRediT authorship contribution statement

Katharine Vincent: Conceptualization, Investigation, Writing - original draft. **Emma Archer:** Conceptualization, Writing - original draft. **Rebecka Henriksson:** Investigation, Writing - original draft. **Joanna Pardoe:** Investigation, Writing - original draft. **Neha Mittal:** Investigation, Writing - original draft.

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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