

Original research article

What can climate services learn from theory and practice of co-production?

Katharine Vincent^{a,b,*}, Meaghan Daly^c, Claire Scannell^d, Bill Leathes^d^a Kulima Integrated Development Solutions (Pty) Ltd, Postnet Suite H79, Private Bag x9118, Pietermaritzburg 3200, South Africa^b School of Architecture and Planning, University of the Witwatersrand, Johannesburg, Private Bag x3, Wits 2050, South Africa^c Department of Environmental Studies, University of New England, 11 Hills Beach Road, Biddeford, Maine 04005, USA^d Met Office, FitzRoy Road, Exeter, Devon EX1 3PB, UK

ARTICLE INFO

Keywords:

Co-production
Climate services
Developing countries
Science-society relations
Post-normal science
Producer-user relations

ABSTRACT

Co-produced climate services are increasingly recognised as a means of improving the effective generation and utilisation of climate information to inform decision-making and support adaptation to climate change, particularly in developing countries. There is a rich literature outlining the theoretical and conceptual evolution of co-production, and experiences of it in a variety of decision contexts – in different sectors and at different scales. However, the extent to which the producers of climate services have engaged with this literature varies. Reflecting the emerging interest and application, particularly in developing countries, this paper reviews the co-production literature to distil some key principles to inform climate services. Whilst we aim to be neither comprehensive nor prescriptive, these principles can inform a normative and pragmatic approach to co-produced climate services. A co-produced climate service product should be decision-driven, process-based and time-managed. The process of co-producing a climate service should be inclusive, collaborative and flexible. Illustrations are also provided of how these principles may be engaged in practice. Evaluation of these emerging examples will help further inform co-production of climate services.

Practical implications

1. Introduction

The field of climate services has arisen in response to the fact that improving climate information has not always translated into effective adaptation. Climate services recognises that useful and usable information should be timely and tailored to improve its likelihood of enabling adaptation. This requires a step further than consultation. Instead, producing climate services requires a shift in the knowledge system – from a one-way “push” of scientific information, to a two-way collaborative process of knowledge construction known as co-production.

2. Co-producing climate services

Co-production of climate services, particularly in developing countries, is still in its infancy. A number of initiatives are emerging that are attempting to co-produce climate services in developing countries. However, they are largely not drawing on the long history and lessons learned from co-

production in other fields, including public services administration, science policy and science and technology studies, and participatory development. Failing to consider these experiences can lead to unnecessary repetition of failures and sub-optimal application. To avoid this, we assess multiple streams of literature to distil several principles to inform the co-production of climate services, and illustrate with some examples of how these principles have been applied in developing countries.

3. Distilling principles of co-produced climate services

To produce a usable, co-produced climate service, from our review of the origins, evolution, and use of the concept of co-production we distilled six principles that can inform climate services. Three of them are relevant to the *product* itself, and the other three are related to the *process*. Together the process and product are part of the cycle of co-production of a climate service that involves identification of stakeholders, co-exploration of the decision need, co-development of the solution, co-delivery of the solution, and evaluation. The cycle is characterised by continuous monitoring, knowledge exchange and learning that enables reflexive review and refinement of

* Corresponding author at: Kulima Integrated Development Solutions (Pty) Ltd, Postnet Suite H79, Private Bag x9118, Pietermaritzburg 3200, South Africa.

E-mail addresses: katharine@kulima.com (K. Vincent), mdaly8@une.edu (M. Daly), claire.scannell@metoffice.gov.uk (C. Scannell), bill.leathes@metoffice.gov.uk (B. Leathes).

<https://doi.org/10.1016/j.cliser.2018.11.001>

Received 3 July 2018; Received in revised form 9 November 2018; Accepted 19 November 2018

2405-8807/ © 2018 Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

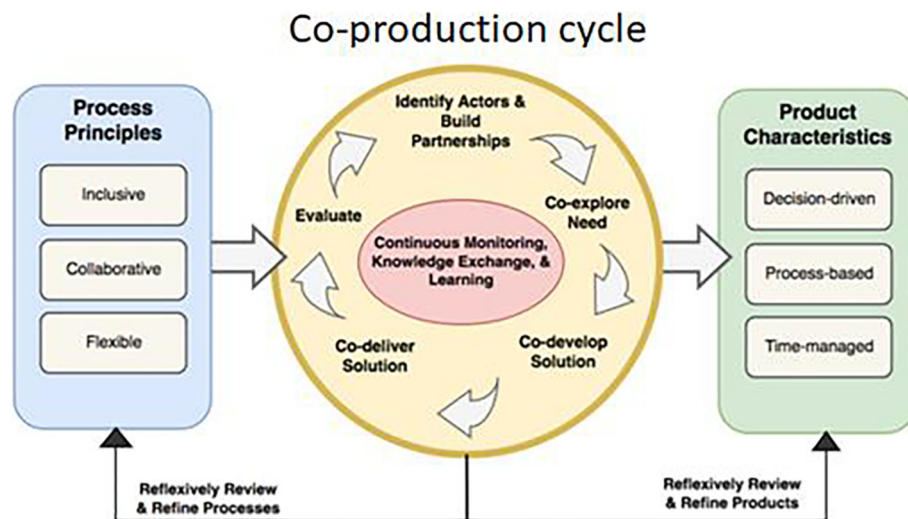


Fig. 1. Product characteristics and process principles of the climate service co-production cycle.

both the process and product as necessary. Product principles include: decision-driven, process-based, and time-managed. Process principles are: inclusive, collaborative, and flexible (Fig. 1).

3.1. Co-produced climate service product characteristics

3.1.1. Decision-driven

Climate services are expressly developed to address identified user needs. Co-exploratory processes between producers and users, for example through workshops or surveys, can unpack the decision-making context to understand the decision that the climate service can address. Around Lake Victoria in Kenya, for example, investigation into user decision contexts led to the production of a daily weather forecast for fishermen and a daily forecast for western Kenya (prior to that only a weekly forecast was available) to inform decisions around when to fish.

3.1.2. Process-based

A process-based approach to co-production recognises the importance of collaboration and trust and relationship-building between the various parties (producers and users). Trust and relationships are built by, and in turn lead to, knowledge exchange between producers and users which are important to co-produce climate services.

3.1.3. Time-managed

Time management of co-produced climate services refers to the management of the process of co-exploration, co-production and co-delivery of a solution such that the ultimate climate product arrives in a timely manner to inform its intended decision. This is particularly important with natural resource-based activities – for example seasonal forecasts need to be delivered in advance of the planting season.

3.2. Co-produced climate service process principles

3.2.1. Collaborative

Identifying the decision context and ensuring development of a timely climate service requires a collaborative process built upon inclusion of different people with different needs and different knowledge systems. This typically requires empathy on the part of both producers and users, together with willingness to embrace new ways of working. The Future Resilience for African Cities and Lands (FRACTAL) project, for example, ‘embeds’ researchers in decision-making environments. This creates improved understanding and empathy, and allows insights into how decisions are made to develop effective climate services.

3.2.2. Inclusive

Inclusion of users, and their partnership in the process of producing a service, can help construct knowledge that is useful and usable. Similarly including non-scientific knowledge can build legitimacy. There is a rich literature on stakeholder engagement from the participatory development field. However, particular care should be taken at the stage of identifying stakeholders as there is the risk of overlooking and excluding marginalised or less powerful groups. This requires particular empathy as producers will often gravitate to those with similar educational backgrounds to them.

3.2.3. Flexible

Flexibility is important in co-production because, as a result of taking a process-based approach to providing a decision-driven service, it is not possible to fully map out the process at the start. As a result of continuous knowledge exchange, monitoring and learning there may be need to refine product and process. In the Uncertainty Reduction in Models for Understanding Development Applications (UMFULA) project, for example, flexibility was necessary to elicit and understand user needs for climate information in the agriculture sector. The initial co-exploration process identified interest in the increased occurrence of extreme events, but did not define the critical threshold for such events. Flexibility is also required on the part of the institutions and individuals participating in the cycle of co-production.

4. Conclusion

Co-production may not always be comfortable, since it requires a different approach to knowledge production and reconfiguration of the hegemony of science. However it offers great opportunities to generate useful and usable climate information, and is increasingly occurring in developing countries. The product and process principles are neither comprehensive nor prescriptive, but rather offer insights from existing co-production literature that may be pragmatic for the rapidly-evolving climate services field. As more evaluations come to light, there will be more evidence of the sustainability of co-produced climate services beyond project lifespans, and the utility and applicability of these principles.

1. Introduction

Knowledge about future climate conditions is considered a key

component of increasing societal capacities to adapt to both climate variability and change (Williams et al., 2015). There have been rapid advances in capacities to provide a range of climate information – from historical data to seasonal forecasts to end-of-century projections – in recent decades. However, this has not always translated into effective risk mitigation and adaptation. Part of the challenge has been that, whilst this information may be potentially useful, it is often not actually usable by decision-makers in practice (Jones et al., 2015; Lemos et al., 2012; Dilling and Lemos, 2011). To address this gap, there is now increasing emphasis on the role of climate services, which differ from climate information in that they aim specifically “to provide people and organizations with timely, tailored climate-related knowledge and information that they can use to reduce climate-related losses and enhance benefits, including the protection of lives, livelihoods, and property” (Vaughan and Dessai, 2014: 588; emphasis is ours). Here we use “climate services” to refer to all timescales, from short-term weather to long-term climate.

Whilst improving the availability of climate information is important, it is not sufficient. Developing usable climate services also requires service producers to take an inclusive approach to the construction of credible, salient, and legitimate climate knowledge (Cash et al., 2003). This requires changes in the way in which the production of science is conceptualised – moving from dominant supply-driven modes of science ‘push’ to a post-normal approach in which demand ‘pull’ is important, and regular and sustained interaction and iterative approaches develop knowledge products (Kirchhoff et al., 2013; Dilling and Lemos, 2011; Roux et al., 2006). As a result, it also calls into question the definitions of, and predominant power relationships between, ‘producers’ (scientists generating information) and ‘users’ (people who then take and apply that information) – recognising that, depending on circumstances, the categories are not mutually exclusive. Whilst not necessarily a prerequisite for a climate service, co-production is increasingly promoted as deliberate approach for increasing the usability of climate services by fostering partnership between producers and users to create a service that is effectively tailored and targeted (Vaughan and Dessai, 2014).

Whilst the need for increased interaction between producers and users in order to increase the uptake and application of climate information has been recognised for over two decades, approaches to co-production of climate services remain largely in their infancy. This can be explained, at least in part, due to varying understandings of, and approaches to, co-production which are often only implicit, lacking clarity, and only now beginning to be classified (Bremer and Meisch, 2017; Steynor et al., 2016). Where co-production approaches have been employed within the climate services field, they have typically been normative and used in a variety of sectors including agriculture (e.g. Prokopy et al., 2017), water resources (e.g. Vogel et al., 2016; Feldman and Ingram, 2009), and energy and transport (e.g. Buontempo et al., 2017).

Most documented examples of co-production specific to climate services have taken place in developed country contexts (Kruk et al., 2017). The availability of climate services there is dependent upon a very different context in terms of observational records, technical capacity, financial resources, and staff availability, typically on the producer side (Georgeson, Maslin, and Poessinouw, 2017; Brasseur and Gallardo, 2016). Nonetheless, there are several examples where co-production has led to development of improved climate services in developing countries (e.g. Kruk et al., 2017; Briley et al., 2015; McKenzie-Hedger et al., 2006; Lemos and Morehouse, 2005). A growing number of international initiatives, among them the Global Framework for Climate Services, FCFA (Future Climate for Africa) and WISER (Weather and Climate Information Services for Africa), aim to address imbalances in access, whilst also addressing the usability gap, by directly targeting and involving users in the co-production of climate services (Hewitt et al., 2012).

Despite the growing interest in co-production of climate services,

there is variability in the extent to which these approaches acknowledge and build upon existing theoretical and conceptual literature in other fields. Here, we aim to bridge this gap and contribute to emerging scholarship on climate services by drawing perspectives from existing co-production literature across several disciplines and theoretical orientations. We distil principles of co-production from multiple streams of literature to inform co-production of climate services, and illustrate some examples of how these principles have been applied in developing countries. Although the principles are relevant to all parties in the co-production cycle for climate services, we implicitly focus on ‘producers’ of climate information (recognising that their application may differ slightly for those categorised in the particular climate service as ‘users’, e.g. Visman et al., 2017).

Section 2 outlines the origins and antecedents of co-production in the field of climate services, drawing on literature from: public services, science policy and science and technology studies, and participatory development. After outlining the methodology, Section 4 highlights six principles of relevance to the co-production of climate services: three relating to the information product itself and three relating to the underlying process. Without being prescriptive, section four further outlines what these principle may look like in the context of climate services and describes their application in emerging initiatives. We conclude by highlighting further research needs that arise to inform the development of sustainable, co-produced climate services.

2. Theory and practice of co-production

Outside of the field of climate services, co-production has a long standing theoretical and conceptual history. In particular co-production has been embraced within the field of public services administration, science policy and science and technology studies, and participatory development (Miller and Wyborn, 2018). In this section we review the origins and theoretical underpinnings, and then summarise different conceptualisations of co-production embodied in the various definitions.

2.1. Origins of co-production

The earliest known use of the term co-production originated in public services administration in the late 1970s (Kiser and Percy, 1980; Ostrom et al., 1978; Parks et al., 1981). The basic idea of co-production was simple, yet had far-reaching implications. Co-production was seen as a means of increasing both the efficiency and effectiveness of public services across various domains (e.g., public safety, education, health) through increased citizen participation and empowerment. Standard approaches to public services relied on a top-down, bureaucratic approach in which producers and consumers of public services remained separate. Co-production argued that successful and responsive public services required the active participation of citizens in both their *production* and *consumption*. This required a shift away from conventional linear service delivery and created new relationships between producers and consumers of services that blurred traditional roles and boundaries (Ostrom, 1996). Over the course of the last decade, the co-production of public services has become widespread in the U.S., the U.K. and Europe (Alford, 2013; Boyle and Harris, 2009) and has also gained increasing traction in developing country contexts (see, for example, Cepiku and Giordano, 2013; Otsuki, 2016).

In parallel to developments within the public services administration, there were growing critiques of ‘top-down’ approaches to socio-economic development starting in the early 1980s, which resulted in widespread calls for participatory models that encouraged the involvement of beneficiaries within development interventions (e.g., participatory rural appraisals, technical ecological knowledge) (Chambers, 1983; Cooke and Kothari, 2001). While these participatory approaches did not use the term ‘co-production,’ they similarly challenged existing power structures, including the dominance of

bureaucratic planning systems and technical expertise, by reversing the roles and relationships between ‘outsiders’ attempting to facilitate development and ‘local people’ who were the intended beneficiaries (Mosse, 2001). The participatory turn in socio-economic development emphasised that local populations possess a vast wealth of proven, experiential knowledge that was equally as valuable as ‘modern’ or scientific approaches.

Applications of the concept of co-production in the field of science and technology studies (STS) can be traced to sociological approaches to understanding the construction of scientific knowledge (e.g. Latour and Woolgar, 1979). However, co-production fully gained prominence in the 1990s when it was comprehensively developed as an analytical lens to understand the mutually constitutive relationship between science and society (Jasanoff, 2004; Jasanoff and Wynne, 1998). In recent years, co-production has also increasingly become an explicit, or instrumental, normative goal of science policy, in which producers and users of knowledge are encouraged to engage in collaborative approaches to address jointly defined problems (Wyborn, 2015; van Kerkhoff and Lebel, 2015). Similar to participatory development, STS interpretations of co-production emphasise the need to address differences in power and prestige between users and producers of knowledge, which otherwise often pose a barrier to building the relationships and trust necessary to enable collaborative knowledge production.

Co-production is increasingly considered a fundamental component of many environmental management processes, particularly within climate change adaptation policy, practice, and climate service development. While we have discussed three major streams of literature that have variously conceptualised co-production, it is important to acknowledge that these literatures have not evolved entirely independently. Rather, there has been interaction and hybridisation across fields, which may be of particular relevance to the field of climate services, itself necessarily an interdisciplinary endeavour. Indeed, current conceptualisations and applications of co-production reflect various elements of the three antecedent streams of literature discussed here (Fig. 1).

There has, however, been a powerful and ongoing critique of

participatory methods that contends that such approaches may not only fail to bring about the positive outcomes that are claimed, but in many instances can serve to perpetuate or worsen conditions of inequality (Cooke and Kothari, 2001; White, 1996; Ribot, 2010). Participation has historically been conceived of as a spectrum – ranging from non-participation, to tokenistic inclusion, to full empowerment (see Arnstein, 1969). However, it has been argued that climate change adaptation will require a shift beyond linear notions of participation toward those that emphasise the importance of processes, the existence of feedback loops, and the dynamic nature of user participation (Collins and Ison, 2009; Tritter and McCallum, 2006).

2.2. Definitions of co-production

It is important to recognize that each of these three fields of literature draws on different theoretical orientations, has different underlying motivations and goals and, as a result, has multiple, and potentially contrasting, interpretations and understandings of co-production. Importantly, despite their differing theoretical bases, these conceptualisations of co-production all require much more than consultation with potential users of scientific knowledge.

Reflecting the various theoretical roots, the term co-production has a multitude of definitions with most of them encompassing certain key elements around forms of knowledge, collaboration and an ongoing process (see Table 1 for examples).

3. Methodology

The principles were distilled based on a review of academic and grey literature and content analysis. Literature was compiled using two search engines (Google Scholar and Ebscohost) to determine a sample of papers focusing on co-production, defined as having the terms “co-production,” “coproduction,” or “co-production of knowledge” in the title, keywords, or abstract between 2005 and 2015 (see Daly, 2016). Because this broad search resulted in a large number of results pertaining to co-production as a chemical process (e.g., within the

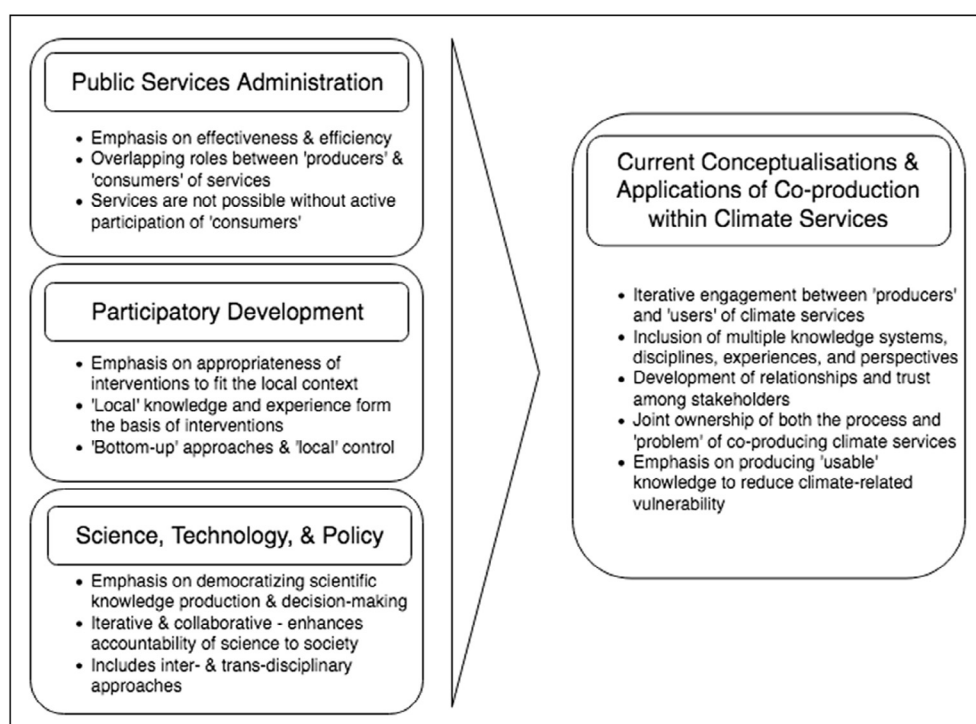


Fig. 1. Theoretical antecedents and related concepts that have contributed to current interpretations and applications of the concept of co-production (source: authors).

Table 1
Characteristics of co-production.

Feature	Elaboration
A means of addressing complex problems	Co-production recognises challenges with the typical approach to the relationship between science and society, and instead takes a different approach to create usable knowledge to address complex problems (Pellizzoni, 2014; Corburn, 2007; Schuttenberg and Guth, 2015; Brugnach et al., 2014).
A means of producing knowledge	Co-production is based on a new understanding of what knowledge is and how it is produced, with users being integral to the production of the knowledge (Enengel et al., 2012; Muñoz-Erickson, 2014; Robinson and Wallington 2012; Cash, 2006; Brandsen and Pestoff, 2006; Meadow et al., 2015; Pellizzoni, 2014; Roux et al., 2006).
A means of producing knowledge and governance systems	By bringing together different parties to address issues, co-production not only involves the construction of knowledge, but simultaneously the construction of the governance systems that use that knowledge (St Clair, 2006; Muñoz-Erickson, 2014).
A means of recognising different knowledges	In being an alternative means to produce knowledge, co-production puts users on an equal footing with producers, with exploration, discussion and negotiation key components of the process (Edelenbos et al., 2011; Nel et al., 2016).
Involves collaboration among various actors	Participants in the co-production process can include multiple disciplines, scientists, citizens, clients, consumers, volunteers, community organisations etc. (Sancino, 2016; Enengel et al., 2012; Cash, 2006; Bovaird, 2007; Hegger et al., 2012; Meadow et al., 2015; Taylor et al., 2017).
Is contingent upon trusted relationships	Given that knowledge is mutually produced by a range of partners who would not normally collaborate, building and maintaining trusted relationships is important (Taylor et al., 2017; Bovaird, 2007).
Is a social learning process	Since co-production involves inclusive, participatory and interactive analysis of problems and construction of solutions, it also needs to be a learning process (Frantzeskaki and Kabisch, 2016; Meadow et al., 2015; Hegger et al., 2012; Pohl, 2008).

biological, biochemical, and medical sciences) and the services management sector, search results were further screened to filter these out. The initial result was 122 publications, which were reviewed and further narrowed according to topical relevance to 50 publications for inclusion in analysis. While this approach is not exempt from omissions, it is sufficiently comprehensive to provide an overview of the variants of co-production that have been put forth within the literature in the last decade, how these have interacted, and to better understand how these have been applied in relation to climate services. Additionally, we compiled a sample of 16 climate services programme documents that had included co-production elements. Literature and programme documents first underwent a preliminary content analysis to ensure that there was a central focus on co-production. Remaining documents underwent a summative analysis of co-production – i.e. systematic examination of the literature in which the context and explicit and implicit uses of the term and concept were identified and analysed (Potter and Levine-Donnerstein, 1999; Hsieh and Shannon, 2005).

Using an inductive approach, three of the authors individually identified principles of co-production based on the results of the summative content analysis. This included compiling various definitions and descriptions of co-production, as well as associated practices, processes, and activities, in order to draw out underlying principles. For example, if an article stated that “co-production begins with decisions to be made,” an underlying principle could be that co-production should be ‘decision-driven.’ The approach also included identifying implicit normative principles. For example, much of the literature described various ways in which co-production efforts include opportunities for continual evaluation, learning, and adjustment. While not directly stated, all of these examples relate to a need for ‘flexibility’ as a foundational principle. This is necessarily a subjective approach, but having three of the authors code independently and then compare results helped to ensure robustness. In the initial analysis, over 20 initial principles were identified by this method. With the intention of providing principles of co-production that are applicable specifically to design and delivery of climate services, these interpretations were then compared, merged where appropriate, and refined.

An initial challenge that hampered the finalisation of the principles related to the nature of climate services. Whilst a climate service incorporates the development of a product, the notion of a service, and co-production itself, necessitates an interactive and iterative process in which the product is embedded – and tested and refined. The poor conceptualisation between process and outcome in co-production has been observed by others (Harvey et al., 2017). To overcome this, we eventually distinguished process principles and product principles,

while recognising that the principles underlying both processes and products necessarily interact with each other in practice and can be difficult to unravel.

4. Co-production principles and application

From our review of the literature, we distilled six principles for producing a usable, co-produced climate service. Three of them are relevant to the *product* itself, and the other three are related to the *process*. Together the process and product are part of the cycle of co-production of a climate service that involves identification of stakeholders, co-exploration of the decision need, co-development of the solution, co-delivery of the solution, and evaluation (Fig. 2). Product principles include: decision-driven, process-based, and time-managed. Process principles are: inclusive, collaborative, and flexible. Table 2 summarises the literature from which these principles were distilled.

These principles are neither comprehensive nor prescriptive. We also recognised that climate services are diverse and the extent to which a co-production approach is applied in their generation is variable: the entire climate service may be co-produced, or a co-production approach may be applied to elements within the service. However, the principles provide a pragmatic framework to normatively inform (elements of) the co-production cycle of the climate service by building on existing knowledge and experience with co-production from other fields, as well as within climate services itself. It is also important to remember that the co-production cycle, whilst embracing the process principles, should be characterised by continuous monitoring, knowledge exchange and learning so that the process and product can be reflexively reviewed and refined (e.g. Visman et al., 2016) (Fig. 2). This is an essential part of the cycle, and provides the opportunity to generate both useful and usable climate information, but is often overlooked (Tall et al., 2018).

4.1. Co-produced climate service product characteristics

4.1.1. Decision-driven

A key difference between a climate product and a climate service is that the latter is expressly developed to address an identified user need, and, thus, should be decision-driven (Dilling and Lemos, 2011; Lemos et al., 2012). This is often a fundamentally different *modus operandi* for producers of climate information. To identify the need for a climate service, it is necessary to understand the decision that the climate service can address. The decision-making context can have a large influence on what is determined to be the most important problem (Steynor

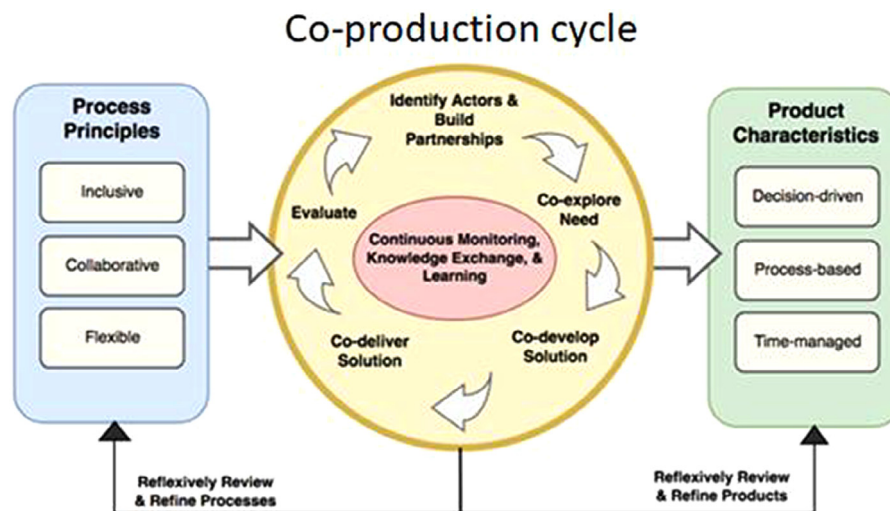


Fig. 2. Product characteristics and process principles of the climate service co-production cycle (source: authors).

et al., 2016). However, identifying user needs can be challenging. Often, users have not explicitly considered what climate information would inform their decision-making processes (Vincent et al., 2017a,b). Both users and producers may identify a climate product that is not necessarily the most appropriate one for the intended decision – and iteration may be required to develop a service that actually addresses the decision.

To identify the decision that a climate service can inform, co-exploratory processes between producers and users are important. Such scoping has variously been undertaken using workshops, town meetings, questionnaires and surveys and described as an “intelligence phase” (McNie, 2007). Different climate-sensitive decisions are taken by different people, which, in turn, affects the nature of individuals’ information needs. For example, in agrarian settings in West Africa and South Asia, the different socially constructed roles of men and women in farming give rise to needs for different information, to be delivered at different times, and in different formats (Carr et al., 2016; Tall et al., 2014). Taking a step back from the product, and instead interrogating the decision context, can facilitate co-production of a more usable climate service. Continuous knowledge exchange, monitoring and learning throughout the co-production cycle helps to identify where such refinement is required and enable course correction as necessary.

An example of where a decision-driven climate service has been produced is around Lake Victoria in Kenya as part of a project under the WISER programme, “Decentralised climate information services for decision making in western Kenya”. Reliance on fishing from open wooden canoes powered by paddles and sails with weather forecasts means that there is a high risk of boats capsizing and drowning should conditions change (Powell, 2016). Investigation into user decision

contexts led to the production of a prototype daily weather forecast for fishermen and a daily forecast for western Kenya (prior to that only a weekly forecast was available). The forecast is issued daily to cover a 48-hour period. It provides information on wind speed and direction, rainfall volume and spatial distribution and visibility, as well as early warning of potential hazards, such as strong winds, high waves, water spouts and thunderstorms. To meet locally-specific conditions, the bulletin forecasts the weather separately for the Gulf of Winam and for an area of open lake to the west up to 60 km from the Kenyan coastline. This prototype service is being further extended in WISER phase 2 as part of the HIGHWAY (High Impact Weather Lake System) project where a decision-driven early warning system for the lake region is being co-produced by climate scientists and lake users, primarily those involved in fishing (Venton, 2018).

4.1.2. Process-based

The idea of a process-based product is to highlight that a climate service is about more than the product itself, but also the process through which producers and users engage to develop, test, and refine a service, while also establishing long-term relationships and trust. A process-based approach to co-production of climate services might take place in various ways. Defining priorities, responsibilities, expectations, and goals can be part of such a process.

There are various models of knowledge exchange and these can contribute to effective co-production of equitable and inclusive climate services on a variety of scales. Cvitanovic et al. (2015) highlight the roles for embedding researchers and using knowledge brokers. Models such as these help to facilitate process-based co-production bringing together different actors. Embedding researchers in decision-making

Table 2
Evidence of principles in the literature.

Principle	Evidence in the Literature
<i>Co-produced product characteristics</i>	
Decision-driven	Beier et al., 2016; Bessembinder et al., 2012; Feldman and Ingram, 2009; Hegger et al., 2012; McNie, 2007; Prokopy et al., 2017; Vogel et al., 2016
Process-based	Akpo et al., 2014; Beier et al., 2016; Feldman and Ingram, 2009; McNie, 2007; Prokopy et al., 2017; Vogel et al., 2016; Wall et al., 2017
Time-managed	Akpo et al., 2014; Armitage et al., 2011; Baldwin, 2000; Harris and Lyon, 2013; Lebel et al., 2015; Lemos and Morehouse, 2005; Meadow et al., 2015; McNie, 2007; Polk, 2015; Wall et al., 2017
<i>Co-production process principles</i>	
Inclusive	Beier et al., 2016; Bessembinder et al., 2012; Diver, 2017; Harris and Lyon, 2013; Feldman and Ingram, 2009; Hegger et al., 2012; Lebel et al., 2015; Lemos and Morehouse, 2005; Meadow et al., 2015; Polk, 2015; Prokopy et al., 2017; Reyers et al., 2016; Vogel et al., 2016
Collaborative	Armitage et al., 2011; Baldwin, 2000; Diver, 2017; Harris and Lyon, 2013; Lebel et al., 2015; Reyers et al., 2016; van Kerkhoff and Lebel, 2015; Adams et al., 2015
Flexible	Dilling and Lemos, 2011; Lemos and Morehouse, 2005; McNie, 2007; Polk, 2015; Harris and Lyon, 2013; Feldman and Ingram, 2009; Vogel et al., 2016; Lebel et al., 2015

environments creates improved understanding and empathy, as well as facilitating knowledge exchange (Cook et al., 2013). Ethnographic research, or participatory action research, in which researchers are embedded within their research context – for example within a rural community – is another example. Knowledge brokers are typically embedded within research teams and act as intermediaries to develop and manage relationships and networks among and between producers and users (Michaels, 2009). These approaches of managing producer–user relationships enable the continuous knowledge exchange, monitoring and learning that is necessary within the co-production cycle to support the evolution of a useful and usable co-produced climate service.

Knowledge exchange is important because it both requires and builds trusting relationships and mutual respect between producers and users, which are essential for the process of producing a climate service. Co-production requires reconfiguring of our dominant modes of knowledge production in which scientific knowledge is considered the only authoritative or valid form of knowledge. Instead the process-based nature of co-production fosters alternative modes of knowledge production based on collaboration and partnership of multiple parties across epistemological boundaries. This requires fundamentally adjusting power relationships to co-construct knowledge through mutually-constituted processes (Djenontin and Meadow, 2018). Thus, the outcome of the process should include reconfigurations of power relationships and new relationships and institutional arrangements that are better suited to knowledge co-production and relevant climate services.

4.1.3. Time-managed

Time management of co-produced climate services is important in the sense that information needs to arrive in a timely fashion in order to inform the intended decision. A potential risk of a process-based service is that the availability of relevant information does not align with the timing of key decisions. Timely availability of information is particularly important for natural resource-based activities, and so has been embraced by co-produced climate services targeting farming, for example through participatory scenario planning and the Participatory Integrated Climate Services for Agriculture project (PICSA) (CARE, n.d.; Dorward et al., 2015; Easterling and Mjelde, 1987). Receiving a seasonal forecast too late, for example, means that farmers may have already had to make a judgement call about their crop choices in order to maximise likelihood of a return. The PICSA case, and others with similar aims, also highlight that timing of the delivery of climate services needs to take into account the cascade of information from producers to users, including the time required to transmit information across institutional scales and structures – including horizontally amongst government agencies and vertically from the national scale to the grassroots.

Producing a timely product is contingent upon a co-production cycle that is time-managed. Since the cycle involves identification of relevant actors, co-exploration of needs, co-development and then co-delivery of the service prior to evaluation, producing a timely product requires appropriate time allocation to each of these key stages. Being decision-driven and process-based requires extensive time for engagement between producers and users and the building of trust (Vogel et al., 2016; Hegger and Dieperink, 2014). This is because a climate service is contingent on exploring the need for climate information, developing the product, using the product, and then evaluating and possibly redefining and refining. The ongoing nature of inclusive collaboration requires regular two-way contact and maintenance of relationships (Kirchhoff et al., 2013). Time for such critical activities is often not built into project proposals and, even if it is, it is often underestimated significantly. Fig. 3 provides an idealised comparison of how the time requirement of different stages in the cycle of development of a co-produced climate service (blue) might differ relative to a more traditional weather and climate product development (orange)

where knowledge generation by scientists is imparted to users in a linear and unidirectional model (Stockmayer, 2013).

4.2. Co-production process principles

4.2.1. Collaborative

Collaboration underpins co-production and related “co-” terms (co-exploration, co-design etc.) that refer to the importance of the process as an end in itself, as opposed to a means to an end. Collaboration is at the very heart of co-produced climate services, which require the building of relationships and partnerships between producers and users throughout the cycle. These collaborations can take multiple forms and can vary significantly in nature depending on the particular context. Identifying the decision context and ensuring development of a timely climate service requires a collaborative process built upon inclusion of different people with different needs and different knowledge systems. When done effectively, collaboration may enable sustainability of climate services beyond the projects that initiate them by enhancing shared ownership of the process and products (Dilling and Lemos, 2011). Collaboration has been identified as critical in emerging discussions on development of ethical climate services (Adams et al., 2015).

To foster meaningful collaboration, there is a need for empathy from producers and users to consider the respective decision-making environments on both sides. Scientists often have a different mode of operation to users, who are typically driven by a range of political, economic and social drivers that reflect, and in turn inform, societal development (e.g. Policansky, 1998). However, scientists similarly face their own constraints, and co-production can be seen as an additional task simply added to existing workloads (Daly and Dilling, submitted). This may mean that the capacity of all partners to actively engage in the co-production process necessarily waxes and wanes depending on demands, which vary depending on their roles, responsibilities, and decision-making contexts. A policy-maker, for example, may encounter an unexpected policy issue or be subject to the demands of changing political interests that determine their focus of activities. At the grassroots level, a farmer's capacity to engage could be affected by changing seasons or the occurrence of livelihood shocks, such as extreme events. Recognizing and actively planning to account for the fact that the development of a climate service will be subject to such ebbs and flows will assist effective collaboration. Considering a role for formalising the collaboration, for example, through Memoranda of Understanding that detail the respective commitments of relevant parties, may also help to build ethical partnerships that cement collaboration. Reflexivity from continuous knowledge exchange, monitoring and learning throughout the cycle ensures that collaboration takes place at all stages, from co-exploration of need, to co-design and co-delivery of the service.

Since it is so pivotal to co-production of climate services, there are many examples of collaboration. In some cases, formalised fora are created. The Strengthening Climate Information Partnerships East Africa (SCIPEA) project, for example, has three service development teams (SDT), comprised of a members from the National Meteorological and Hydrological Services (Kenya, Tanzania, Uganda and Ethiopia), university and end user organizations (Kenya Electricity Generating Company (KenGen), National Red Cross Societies and the East Africa Regional Food Security and Nutrition Working Group). The Future Resilience for African Cities and Lands (FRACTAL) project has taken a different approach to collaboration, relying on embedding researchers in decision-making environments. In addition to creating improved understanding and empathy, embedding researchers facilitates ongoing collaboration and allows insights into how decisions are made to inform the development of usable climate services (McClure et al., 2017; Cook et al., 2013).

4.2.2. Inclusive

Ensuring that the co-production cycle is inclusive is also important

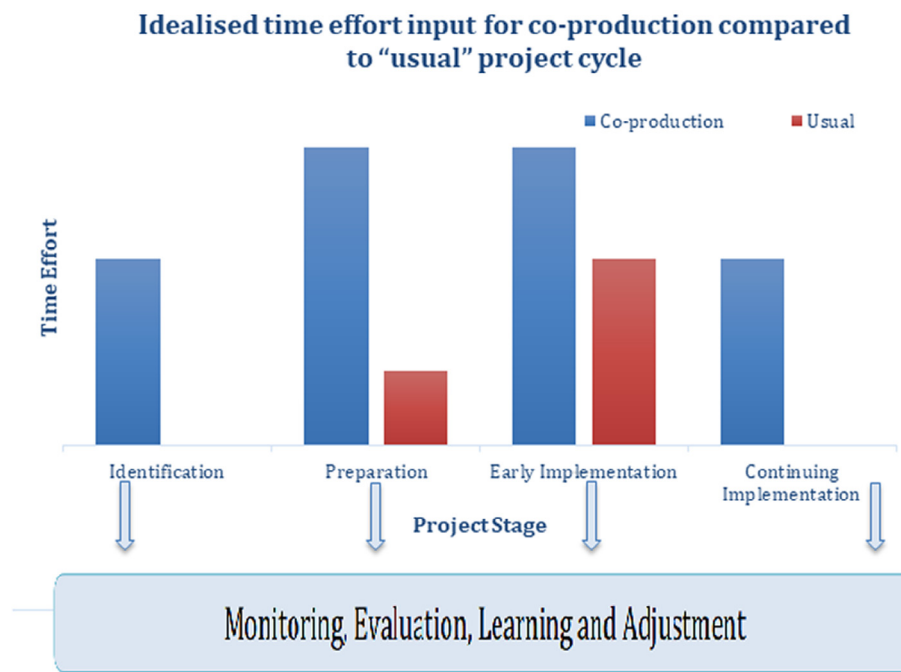


Fig. 3. Idealised time effort input for co-production compared to the “usual” project cycle (source: authors).

to develop an effective decision-driven climate service. Inclusion of users, and their partnership in the process of producing a service, can help construct knowledge that is useful and usable, thus building legitimacy and greater confidence in its use (Jasanoff and Wynne, 1998; Robinson and Tansey, 2006). Inclusion can refer to the two inter-related components: inclusion of people and inclusion of knowledge.

Often the idea to generate a climate service originates from producers, or at least parties who have familiarity with climate science and climate product development. This means that there are often implicit assumptions about the need for climate information, as well as about the users who have a decision that could be informed by that climate information. Similarly, science has typically prioritised knowledge based on theory construction, testing of hypotheses, and refinement of conceptual models based on defensible methodological processes. The co-production cycle brings together and involves a variety of people with differing epistemological and ontological foundations. Through the co-production process, including co-exploration of the information needs, experiential knowledge is created and this, in turn, builds legitimacy and increases the fit of information for decision-making (Fazey et al., 2014). Potential users are diverse and may include planners in the public or private sector across various realms – e.g., in the energy, water, health, and agriculture sectors (Daly and Dessai, 2018; Ouedraogo et al., 2018; Vincent et al., 2017a; Steynor et al., 2016). Users at the grassroots level, such as farmers or fishing communities, have also been directly targeted with climate information (e.g. through participatory scenario planning, ALP, n.d.).

Although substantial literature exists on how to best engage stakeholders, there is much less attention paid to how to identify those stakeholders in the first place, and how to maintain relationships and ongoing collaboration throughout the process (Golding et al., 2017; Colvin et al., 2016; Meadow et al., 2015; Reed et al., 2014). An uncritical analysis of potential stakeholders, or users, within climate service production can lead to subtle reinforcement of existing power structures, and systematic exclusion of groups that are typically marginalised, such as women and the disabled (Goldman et al., 2018; Carr and Onzere, 2018; Smith et al., 2017). Scrutinising one release of the UK Climate Projections – UKCP09 – also shows that climate scientists have narrow perceptions of users, often envisioning them to be technically capacitated and highly numerate (Porter and Dessai, 2017). The

privileged position of deciding who is awarded stakeholder status, and therefore included in the process, ought to be undertaken reflexively and accepted with due responsibility to fully consider the widest potential range of users (Kivits, 2011). Inclusion also may affect the nature of the decision that the climate service is intended to address, as information requirements and communication preferences may vary between different groups of the population (Coulibaly et al., 2015; Archer, 2003). Continuous knowledge exchange, monitoring and learning throughout the cycle can help to identify any biases in inclusion, as well as provide opportunities to rectify them.

4.2.3. Flexible

Flexibility is important in the co-production of climate services. A consequence of taking a process-based approach to producing a decision-driven service, is that it is not possible to fully map out the process at the start. As a result of this, a key element is to clearly conceptualise how co-production contributes to the broader theory of change in the development of a climate service, which is often overlooked (Tozier de la Poterie, 2017). Enabling iterative processes of frequent and sustained interaction between producers and users of climate information requires flexibility to develop usable climate services (Dilling and Lemos, 2011). In the Uncertainty Reduction in Models for Understanding Development Applications (UMFULA) project, flexibility was necessary to elicit and understand user needs for climate information in the agriculture sector. The initial “clean slate” approach did not provide sufficient detail about potential needs to enable the production of meaningful climate information. For example, this approach identified interest in the increased occurrence of extreme events – but did not define the critical threshold for such events. As a result, the process was modified to take a “multiple options” guiding approach, based on a long list of potential climate metrics that were informed by interviews on decision-making contexts (Vincent et al., 2017b). Proactive approaches to monitoring, evaluation, and learning are at the heart of enabling flexible and adaptive programming throughout the co-production cycle (Fig. 2). The need for flexibility is increasingly recognised within a growing number of socio-economic development programmes, which have shifted toward adaptive programming to incorporate learning into activities in real time (see, for example, Villanueva and Gould, 2017).

As well as flexibility in programme design, it is also important to

have the organisational, institutional, and individual flexibility that can enable adjustment to the shifting needs and priorities that may arise throughout the co-production cycle (Fazey et al., 2014). An effective co-production process involves developing new relationships and ways of working. This can sometimes put a strain on organisations and individuals, who have different mandates and modalities for carrying out their work. In this sense, co-production processes are not uniform. It can take significant time to explore and reconcile these different ways of working. Such alignment is better enabled if monitoring and evaluation take into account users' perspectives alongside producers' views (Soares et al., 2009; Tozier de la Poterie and Daly, 2019). However, evaluations also need to account for the complexity that is inherent in the landscape of stakeholders, who necessarily have different capacities, roles, motivations and expectations (Wall et al., 2017).

5. Discussion and conclusion

Co-production requires a different approach to knowledge production and the reworking of relationships at the science-society interface – i.e. moving from supply-driven to demand-driven models. Co-production requires actions that are necessary, but often uncomfortable. This includes reconfiguration of traditional concepts of knowledge and the hegemony of science on the producer side. This can include disruption of well-established organisational roles, practices, and routines, as well as overcoming significant differentials in power between various participants involved in co-production processes (Bremer and Meisch, 2017; Daly and Dilling, submitted). However, there is clearly interest in, and increasing use of, co-production in the field of climate services, including in developing countries, demonstrating potential for generating useful and usable information to inform decisions.

Climate services is an emerging field, and co-produced climate services are growing, particularly in developing countries. However, co-production has a much longer history in other fields. Despite this long history, there is considerable variation in terms of whether and how climate services has been informed by theoretical and conceptual literature on co-production from other fields and disciplines, as well as the growing amount of empirical evidence across various contexts. With continued and growing interest in co-production of climate services, it will be important to draw on extensive theoretical and practical insights from long-standing efforts in other domains – including public services administration, participatory development, and science policy. Based on content analysis, we distilled six principles which, whilst neither comprehensive nor prescriptive, can provide a broad normative framework for the development of co-produced climate services that are useful and usable.

Key principles of the co-production cycle relate to the product (decision-driven, process-based and time-managed) and to the process (inclusive, collaborative and flexible). There are important notes of caution when considering these principles. First, there are various conceptual lenses with which co-production can be approached (Bremer and Meisch, 2017). Here, we apply a normative lens, assuming that the role of co-production in climate services is to produce usable science. Second, it is important to note that existing initiatives are typically project-based. This can constrain more organic or emergent processes of co-production (Chilvers and Kearnes, 2015), as well as impede the extent to which they are able to adhere to some of the principles we propose here, since the scope is predetermined by the funding commitments (Harvey et al., 2017). The principles have been distilled on the grounds that there is a rapid growth of interest in co-production of climate services, particularly in the developing world, but little theoretical and conceptual information that draws on previous literature to inform the practice. Without aiming to be comprehensive or prescriptive, we have thus taken a pragmatic approach, recognising that this growth in interest will likely continue and success is more likely if grounded in existing experience. However, we recognise that normative approaches to instrumental co-production of climate services

should be combined with descriptive analytical approaches that can foster continual reflexivity within these processes.

Questions still remain around co-production of climate services. Systematic evaluations are time-consuming and costly and are lacking with regards to climate services. There is still little proof that co-production of climate services is as effective as is often claimed. There is also only scant evidence of the sustainability of co-produced climate services beyond project lifespans (Scannell et al., 2016). Perhaps more fundamentally, there is no agreement on what constitutes 'successful' co-production. Typical metrics for evaluation are difficult to apply to co-production because of the importance of the process as well as the outcome (Wall et al., 2017). Success criteria that have been proposed consider the credibility, legitimacy and salience of producing usable science (taking into account both the producers and users); the extent to which the process was managed; and the quality of relationships, shared ownership and sustainability (Wall et al., 2017; Polk, 2015; Beier et al., 2016; Hegger et al., 2012). There is still uncertainty with regard to how such principles may be operationalised within practical evaluation of co-production of climate services, as well as whether and how evaluative criteria may be developed to enable comparison across multiple co-production processes and contexts. Furthermore, which aspects of usability are addressed within processes of co-production are not neutral, but also reflect and (potentially) reinforce existing power relations (Daly and Dilling, submitted). Asking such questions will be vital to testing the utility of the six principles proposed here.

Declaration of interest

None.

Acknowledgements

This work was carried out in part under the Weather and Climate Information Services for Africa (WISER) programme, which is funded by the UK Government's Department for International Development (DFID); and in part under the Future Climate for Africa UMFULA project, with financial support from the UK Natural Environment Research Council (NERC), grant ref NE/M020010/1, and the UK Government's DFID. We thank Lindsey Jones, Helen Ticehurst, Andy Dougill, Joe Daron and Joanna Pardoe for comments on an earlier version.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.cliser.2018.11.001>.

References

- Adams, A., Eitland, E., Hewitson, B., Vaughan, C., Wilby, R., Zebiak, S., 2015. Towards an ethical framework for climate services, A white paper of the Climate Services Partnership Working Group on Climate Services Ethics <http://www.climate-services.org/wp-content/uploads/2015/09/CS-Ethics-White-Paper-Oct-2015.pdf>.
- Akpo, E., Crane, T.A., Vissoh, P.V., Tossou, R.C., 2015. Co-production of knowledge in multi-stakeholder processes: Analyzing joint experimentation as social learning. *The Journal of Agricultural Education and Extension* 21 (4), 369–388. <https://doi.org/10.1080/1389224X.2014.939201>.
- Alford, J., 2013. The multiple facets of co-production: building on the work of elinor ostrom. *Public Manage. Rev.* 16 (3), 299–316. <https://doi.org/10.1080/14719037.2013.806578>.
- ALP, n.d. Participatory Scenario Planning for co-producing user based climate services. CARE Adaptation Learning Programme, Nairobi, 4p.
- Archer, E.R.M., 2003. Identifying underserved end-user groups in the provision of climate information. *Bull. Am. Meteorol. Soc.* 84 (11), 1525–1532. <https://doi.org/10.1175/BAMS-84-11-1525>.
- Armitage, D., Berkes, F., Dale, A., Kocho-Schellenberg, E., Patton, E., 2011. Comanagement and the co-production of knowledge: Learning to adapt in Canada's Arctic. *Global Environ. Change* 21 (3), 995–1004. <https://doi.org/10.1016/j.gloenvcha.2011.04.006>.
- Arnstein, S.R., 1969. A ladder of citizen participation. *J. Am. Instit. Planners* 35 (4), 216–224.
- Baldwin, S., 2000. Interactive social science in practice: new approaches to the

- production of knowledge and their implications. *Sci. Public Policy* 27 (3), 183–194.
- Beier, P., Hansen, L.J., Helbrecht, L., Behar, D., 2016. A how-to guide for coproduction of actionable science. *Conserv. Lett.* <https://doi.org/10.1111/conl.12300>.
- Bessembinder, J., Street, R., Themessl, M., Baños de Guisasaola, E., Delecluse, P., Benestad, R., 2012. Guidance to support the identification and assessment of users' requirements. Concept. Available online at: < https://www.climate-services.org/wp-content/uploads/2015/05/jpi2012_assessment_of_users_requirements.pdf > .
- Bovaird, T., 2007. Beyond engagement and participation: user and community coproduction of public services. *Public Administr. Rev.*
- Boyle, D., Harris, M., 2009. The Challenge of Co-production. New Economics Foundation, London, pp. 1–28.
- Brandens, T., Pestoff, V., 2006. Co-production, the third sector and the delivery of public services. *Public Manage. Rev.* 8 (4), 493–501. <https://doi.org/10.1080/14719030601022874>.
- Brasseur, G.P., Gallardo, L., 2016. Climate services: lessons learned and future prospects. *Earth's Future* 4, 79–89. <https://doi.org/10.1002/2015EF000338>.
- Bremer, S., Meisch, S., 2017. Co-production in climate change research: reviewing different perspectives. *WIREs Clim. Change* 2017, e482. <https://doi.org/10.1002/wcc.482>.
- Briley, L., Brown, D., Kalafatis, S.E., 2015. Overcoming barriers during the co-production of climate information for decision-making. *Clim. Risk Manage.* 9, 41–49.
- Brugnach, M., Craps, M., Dewulf, A., 2014. Including indigenous peoples in climate change mitigation: addressing issues of scale, knowledge and power. *Clim. Change.* <https://doi.org/10.1007/s10584-014-1280-3>.
- Soares, M.B., Daly, M., Dessai, S., 2009. Assessing the value of seasonal climate forecasts for decision-making. *WIREs Clim. Change* 9. <https://doi.org/10.1002/wcc.523>.
- Buontempo, C., Hanlon, H.M., Soares, M.B., Christel, I., Soubeyroux, J.M., Viel, C., Calmant, S., Bosi, L., Falloon, P., Palin, E.J., Vanvyve, E., Torralba, V., Gonzalez-Reviriego, N., Doblas-Reyes, F., Pope, E.C.D., Newton, P., Liggins, F., 2017. What have we learnt from EUPORIAS climate service prototypes? *Clim. Serv.* <https://doi.org/10.1016/j.cliser.2017.06.003>.
- CARE, n.d. Decision-making for climate resilient livelihoods and risk reduction: A Participatory Scenario Planning approach. Participatory Scenario Planning Brief, Adaptation Learning Programme.
- Carr, E.R., Fleming, G., Kalala, T., 2016. Understanding women's needs for weather and climate information in agrarian settings: the case of Ngetou Maleck, Senegal. *Weather Climate Soc.* 8 (3), 247–264.
- Carr, E.R., Onzere, S.N., 2018. Really effective (for 15% of the men): lessons in understanding and addressing user needs in climate services from Mali. *Clim. Risk Manage.*
- Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. *Proc. Natl. Acad. Sci. U.S.A.* <https://doi.org/10.1073/pnas.1231332100>.
- Cash, D.W., 2006. Countering the loading-dock approach to linking science and decision making: comparative analysis of El Niño/Southern Oscillation (ENSO) forecasting systems. *Sci. Technol. Human Values* 31 (4), 465–494. <https://doi.org/10.1177/0162243906287547>.
- Cepiku, D., Giordano, F., 2013. Co-production in developing countries: insights from the community health workers experience. *Public Manage. Rev.* 16 (3), 317–340. <https://doi.org/10.1080/14719037.2013.822535>.
- Chambers, R., 1983. *Rural Development: Putting the Last First*. Routledge, Oxford.
- Chilvers, J., Kearnes, M. (Eds.), 2015. *Remaking Participation: Science, Environment and Emergent Publics*. Routledge.
- Corburn, J., 2007. Community knowledge in environmental health science: co-producing policy expertise. *Environ. Sci. Policy* 10 (2), 150–161. <https://doi.org/10.1016/j.envsci.2006.09.004>.
- Collins, K., Ison, R., 2009. Jumping off Arnstein's ladder: social learning as a new policy paradigm for climate change adaptation. *Environ. Policy Governance* 19 (6), 358–373. <https://doi.org/10.1002/etp.523>.
- Colvin, R.M., Bradd Witt, W., Lacey, J., 2016. Approaches to identifying stakeholders in environmental management: insights from practitioners to go beyond the 'usual suspects'. *Land Use Policy* 52, 266–276. <https://doi.org/10.1016/j.landusepol.2015.12.032>.
- Cook, C.N., Mascia, M.B., Schwartz, M.W., Possingham, H.P., Fuller, R.A., 2013. Achieving conservation science the bridges the knowledge-action boundary. *Conserv. Biol.* 27, 669–678.
- Cooke, B., Kothari, U., 2001. *Participation: The New Tyranny?* Zed Books, London.
- Coulbaly, J.Y., Mango, J., Swamila, M., Tall, A., Kaur, H., Hansen, J., 2015. What climate services do farmers and pastoralists need in Malawi? CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) Working Paper no. 112. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark. Available online at: www.ccafs.cgiar.org.
- Cvitanovic, C., Hobday, A.J., van Kerkhoff, L., Wilson, S.K., Marshall, N.A., Dobbs, K., 2015. Improving knowledge exchange among scientists and decision-makers to facilitate the adaptive governance of marine resources: review of knowledge and research needs. *Ocean Coast. Manag.* 112, 25–35.
- Daly, M.E., 2016. Co-production and the politics of usable knowledge for climate adaptation in Tanzania. PhD Thesis. University of Colorado Boulder. https://scholar.colorado.edu/envs_gradetds/56.
- Daly, M., Dessai, S., 2015. Examining the role of the regional climate outlook forums: What role for user engagement? *Weather Clim. Soc.* 10 (4), 693–708. <https://doi.org/10.1175/WCAS-D-18-0015.1>.
- Daly, M., Dilling, L., submitted. The politics of 'usable' knowledge: Examining climate services development in Tanzania. Submitted to *Climatic Change*.
- Dilling, L., Lemos, M.C., 2011. Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy. *Global Environ. Change* 21 (2), 680–689. <https://doi.org/10.1016/j.gloenvcha.2010.11.006>.
- Diver, S., 2017. Negotiating indigenous knowledge at the science-policy interface: Insights from the Xáxli'p Community Forest. *Environ. Sci. Policy* 73, 1–11. <https://doi.org/10.1016/j.envsci.2017.03.001>.
- Djenontin, I.N.S., Meadow, A.M., 2018. The art of co-production of knowledge in environmental sciences and management: lessons from international practice. *Environ. Manage.* 61, 885. <https://doi.org/10.1007/s00267-018-1028-3>.
- Dorward, P., Clarkson, G., Stern, R., 2015. *Participatory Integrated Climate Services for Agriculture (PICSA): Field Manual*. Walker Institute, University of Reading 65p.
- Easterling, W.E., Mjelde, J.W., 1987. The importance of seasonal climate prediction lead time in agricultural decision making. *Agric. For. Meteorol.* 40 (1), 37–50. [https://doi.org/10.1016/0168-1923\(87\)90053-0](https://doi.org/10.1016/0168-1923(87)90053-0).
- Edelenbos, J., van Buuren, A., van Schie, N., 2011. Co-producing knowledge: joint knowledge production between experts, bureaucrats and stakeholders in Dutch water management projects. *Environ. Sci. Policy* 14 (6), 675–684. <https://doi.org/10.1016/j.envsci.2011.04.004>.
- Enengel, B., Muhar, A., Penker, M., Freyer, B., Drlik, S., Ritter, F., 2012. Co-production of knowledge in transdisciplinary doctoral theses on landscape development—an analysis of actor roles and knowledge types in different research phases. *Landscape Urban Plann.* 105 (1–2), 106–117. <https://doi.org/10.1016/j.landurbplan.2011.12.004>.
- Fazey, I., Bunse, L., Msika, J., Pinke, M., Preedy, K., Evelyn, A.C., Lambert, E., Hastings, E., Morris, S., Reed, M.S., 2014. Evaluating knowledge exchange in interdisciplinary and multi-stakeholder research. *Global Environ. Change* 25, 204–220.
- Feldman, D.L., Ingram, H.M., 2009. Making science useful to decision makers: climate forecasts, water management, and knowledge networks. *Weather Clim. Soc.* <https://doi.org/10.1175/2009WCAS1007.1>.
- Frantzeskaki, N., Kabisch, N., 2016. Designing a knowledge co-production operating space for urban environmental governance—Lessons from Rotterdam, Netherlands and Berlin, Germany. *Environ. Sci. Policy* 62, 90–98. <https://doi.org/10.1016/j.envsci.2016.01.010>.
- Georgeson, L., Maslin, M., Poessinouw, M., 2017. Global disparity in the supply of commercial weather and climate information services. *Sci. Adv.* 3 (5), e1602632. <https://doi.org/10.1126/sciadv.1602632>.
- Golding, N., Hewitt, C., Zhang, P., 2017. Effective engagement for climate services: methods in practice in China. *Clim. Serv.* 8, 72–76. <https://doi.org/10.1016/j.cliser.2017.11.002>.
- Goldman, M., Turner, S., Daly, M., 2018. Advancing a critical political ecology of climate change adaptation: epistemology, ontology and ethics. *WIREs Clim. Change* 9, e526. <https://doi.org/10.1002/wcc.526>.
- Harris, F., Lyon, F., 2013. Transdisciplinary environmental research: Building trust across professional cultures. *Environ. Sci. Policy* 31, 109–119. <https://doi.org/10.1016/j.envsci.2013.02.006>.
- Harvey, B., Cochrane, L., Van Epp, M., Cranston, P., Pirani, P.A., 2017. *Designing Knowledge Co-production for Climate and Development*. CARIAA Working Paper no. 21. International Development Research Centre, Ottawa, Canada and UK Aid, London, United Kingdom Available online at: www.idrc.ca/carriaa.
- Hegger, D., Lamers, M., Van Zeijl-Rozema, A., Dieperink, C., 2012. Conceptualising joint knowledge production in regional climate change adaptation projects: Success conditions and levers for action. *Environ. Sci. Policy* 18, 52–65. <https://doi.org/10.1016/j.envsci.2012.01.002>.
- Hewitt, C., Mason, S., Walland, D., 2012. The global framework for climate services. *Nat. Clim. Change* 2, 831–832.
- Hegger, D., Dieperink, C., 2014. Toward successful joint knowledge production for climate change adaptation: lessons from six regional projects in the Netherlands. *Ecol. Soc.* 19 (2). <https://doi.org/10.5751/ES-06453-190234>.
- Hsieh, H.F., Shannon, S.E., 2005. Three approaches to qualitative content analysis. *Qual. Health Res.* 15 (9), 1277–1288.
- Jasanoff, S., 2004. *States of Knowledge: Science, Power, and Political Culture*. Routledge.
- Jasanoff, S., Wynne, B., 1998. Science and decision-making. In: Rayner, S., Malone, E. (Eds.), *Human Choice and Climate Change: Volume 1 The Societal Framework*. Batelle Press, Columbus, Ohio.
- Jones, L., Dougill, A., Jones, R., Steynor, A., Watkiss, P., Kane, C., Koelle, B., Moufouma-Okia, W., Padgham, J., Ranger, N., Roux, J.-P., Suarez, P., Tanner, T., Vincent, K., 2015. Ensuring climate information supports long-term development objectives. *Nat. Clim. Change* 5, 812–814.
- Kirchhoff, C.J., Lemos, M.C., Dessai, S., 2013. Actionable knowledge for environmental decision maker: broadening the usability of climate science. *Ann. Rev. Environ. Resour.* 38, 393–414. <https://doi.org/10.1146/annurev-environ-022112-112828>.
- Kiser, L.L., Percy, S.L., 1980. The concept of coproduction and its implications for public service delivery. *Workshop in Political Theory and Policy*.
- Kivits, R.A., 2011. Three component stakeholder analysis. *Int. J. Multiple Res. Approaches* 5 (3), 318–333.
- Kruk, M.C., Parker, B., Marra, J.J., Werner, K., Heim, R., Vose, R., Malsale, P., 2017. Engaging with users of climate information and the co-production of knowledge. *Weather Clim. Soc.* <https://doi.org/10.1175/WCAS-D-16-0127.1>.
- Latour, B., Woolgar, S., 1979. *Laboratory Life: The Construction of Scientific Facts*. Princeton University Press, Princeton.
- Lebel, L., Wattana, S., Talerngsri, P., 2015. Assessments of ecosystem services and human well-being in Thailand build and create demand for coproductive capacity. *Ecol. Soc.* 20 (1), 12. <https://doi.org/10.5751/ES-06527-200112>.
- Lemos, M.C., Kirchhoff, C.J., Ramprasad, V., 2012. Narrowing the climate information usability gap. *Nat. Clim. Change* 2 (11), 789–794. <https://doi.org/10.1038/nclimate1614>.
- Lemos, M.C., Morehouse, B.J., 2005. The co-production of science and policy in integrated climate assessments. *Global Environ. Change* 15, 57–68. <https://doi.org/10.1016/j.gloenvcha.2004.09.004>.

- McClure, A., Taylor, A., Mwalukanga, B., Lee, J., Lipinge, K., van Rooyen, L., Mamombe, R., Zenda, S., 2017. FRACTAL Embedded Researchers Workshop Report, 36p. Available online at: http://www.fractal.org.za/wp-content/uploads/2017/03/FRACTAL_ER-workshop-report_March-2017.pdf.
- McKenzie-Hedger, M., Connell, R., Bramwell, P., 2006. Bridging the gap: empowering decision-making for adaptation through the UK climate impacts programme. *Clim. Policy* 6 (2), 201–215.
- McNie, E.C., 2007. Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. *Environ. Sci. Policy* 10 (1), 17–38.
- Meadow, A.M., Ferguson, D.B., Guido, Z., Horangic, A., Owen, G., Wall, T., 2015. Moving toward the deliberate coproduction of climate science knowledge. *Weather Clim. Soc.* 7 (2), 179–191. <https://doi.org/10.1175/WCAS-D-14-00050.1>.
- Michaels, S., 2009. Matching knowledge brokering strategies to environmental policy problems and settings. *Environ. Sci. Policy* 12 (7), 994–1011. <https://doi.org/10.1016/j.envsci.2009.05.002>.
- Miller, C.A., Wyborn, C., 2018. Co-production in global sustainability: histories and theories. *Environ. Sci. Policy* in press.
- Mosse, D., 2001. People's knowledge, participation, and patronage: operations and representations in rural development. In: Cooke, B., Kothari, U. (Eds.), *Participation: The New Tyranny?* Zed Books, London.
- Muñoz-Erickson, T.A., 2014. Co-production of knowledge-action systems in urban sustainable governance: the KASA approach. *Environ. Sci. Policy* 37, 182–191. <https://doi.org/10.1016/j.envsci.2013.09.014>.
- Nel, J.L., Roux, D.J., Driver, A., Hill, L., Maherry, A.C., Snaddon, K., et al., 2016. Knowledge co-production and boundary work to promote implementation of conservation plans. *Conservation Biol.* 30 (1), 176–188. <https://doi.org/10.1111/cobi.12560>.
- Ostrom, E., 1996. Crossing the great divide: coproduction, synergy, and development. *World Dev.* 24 (6), 1073–1087. [https://doi.org/10.1016/0305-750X\(96\)00023-X](https://doi.org/10.1016/0305-750X(96)00023-X).
- Ostrom, E., Parks, R.B., Whitaker, G.P., 1978. The public service production process: a framework for analyzing policy services. *Policy Stud.* 7 (s1), 381–389.
- Otsuki, K., 2016. Infrastructure in informal settlements: co-production of public services for inclusive governance. *Local Environ.* 1–16. <https://doi.org/10.1080/13549839.2016.1149456>.
- Ouedraogo, I., Diouf, N.S., Ouedraogo, M., Ndiaye, O., Zougmore, R.B., 2018. Closing the gap between climate information producers and users: assessment of needs and uptake in Senegal. *Climate* 6 (13). <https://doi.org/10.3390/cli6010013>.
- Parks, R.B., Baker, P.C., Kiser, L., Oakerson, R., 1981. Consumers as co-producers of public services: some economic and institutional considerations. *Policy Stud.* 9 (7), 1001–1011.
- Pellizzoni, L., 2014. Construction, Co-production, and beyond. *Academic disputes and public concerns in the recent debate on nature and society. Sociol. Compass* 8 (6), 851–864. <https://doi.org/10.1111/soc4.12180>.
- Polk, M., 2015. Transdisciplinary co-production: designing and testing a transdisciplinary research framework for societal problem solving. *Futures* 65, 110–122. <https://doi.org/10.1016/j.futures.2014.11.001>.
- Pohl, C., 2008. From science to policy through transdisciplinary research. *Environ. Sci. Policy*. <https://doi.org/10.1016/j.envsci.2007.06.001>.
- Policansky, D., 1998. Science and decision-making for water resources. *Ecol. Appl.* 8, 610–618.
- Porter, James J., Dessai, Suraje, 2017. Mini-me: Climate scientists' (mis)perceptions of users and their needs, Sustainability Research Institute Paper No. 104/Project ICAD Working Paper No. 12, 20p.
- Potter, W.J., Levine-Donnerstein, D., 1999. Rethinking validity and reliability in content analysis. *J. Appl. Commun. Res.* 27, 258–284.
- Powell, R., 2016. WISER Western Project Proposal for a Daily Weather Forecast for Kenyan Fishermen on Lake Victoria. Exeter, Met Office, 37p.
- Prokopy, L.S., Carlton, J.S., Haigh, T., Lemos, M.C., Mase, A.S., Widhalm, M., 2017. Useful to usable: developing usable climate science for agriculture. *Clim. Risk Manage.* 15, 1–7.
- Reed, M.S., Stringer, L.C., Fazey, I., Evelyn, I.C., Kruijsen, J.H.J., 2014. Five principles for the practice of knowledge exchange in environmental management. *J. Environ. Manage.* 146, 337–345. <https://doi.org/10.1016/j.jenvman.2014.07.021>.
- Ribot, J., 2010. Vulnerability does not fall from the sky: toward multiscale, pro-poor climate policy. *Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World*, pp. 47–74.
- Robinson, J., Tansey, J., 2006. Co-production, emergent properties and strong interactive social research: the Georgia Basin Futures Project. *Sci. Public Policy* 33, 151–160. <https://doi.org/10.3152/147154306781779064>.
- Robinson, C.J., Wallington, T.J., 2012. Boundary work: engaging knowledge systems in co-management of feral animals on Indigenous lands. *Ecol. Soc.* 17 (2), 16. <https://doi.org/10.5751/ES-04836-170216>.
- Roux, Dirk J., Rogers, K.H., Biggs, H.C., Asher, P.J., Sargeant, A., 2006. Bridging the science-management divide: moving from unidirectional knowledge transfer to knowledge interfacing and sharing. *Ecol. Soc.* 11 (1), 1–20.
- Reyers, B., Nel, J.L., O'Farrell, P.J., Sitas, N., Nel, D.C., 2015. Navigating complexity through knowledge coproduction: Mainstreaming ecosystem services into disaster risk reduction. *PNAS* 112 (24), 7362–7368. <https://doi.org/10.1073/pnas.1414374112>.
- Sancino, A., 2016. The meta co-production of community outcomes – towards a citizens' capabilities approach. *Voluntas: Int. J. Voluntary Nonprofit Organiz.* 27 (1), 409–424. <https://doi.org/10.1007/s11266-015-9596-9>.
- Scannell, C., Corbelli, D., Harrison, M., Taylor, S., Cinco, T., Manalo, M., Il Villafuerte, M., 2016. Building Resilience to Climate Extremes following Typhoon Haiyan in the Philippines: Improving production and uptake of weather and climate information to increase resilience to a changing climate. http://precisrcm.com/DFID_Philippines_Reporting/DFID_Philippines_WP4%20Pilots_final.pdf.
- Schuttenberg, H.Z., Guth, H.K., 2015. Seeking our shared wisdom: a framework for understanding knowledge coproduction and co-productive capacities. *Ecol. Soc.* 20 (1), art15. <https://doi.org/10.5751/ES-07038-200115>.
- Smith, F., Simard, M., Twigg, J., Kett, M., Cole, E., 2017. Disability and climate resilience. A literature review. Report produced by Leonard Cheshire Disability and DFID, 59p. Available online at http://www.ucl.ac.uk/leonard-cheshire-research/research/publications/documents/2017/Disability_and_Climate_Resilience_Lit_review.pdf.
- St Clair, A.L., 2006. Global poverty: the co-production of knowledge and politics. *Global Social Policy* 6 (1), 57–77. <https://doi.org/10.1177/1468018106061392>.
- Steynor, A., Padgham, J., Jack, C., Hewitson, B., Lennard, C., 2016. Co-exploratory climate risk workshops: experiences from urban Africa. *Clim. Risk Manage.* 13 (2016), 95–102. <https://doi.org/10.1016/j.crm.2016.03.001>.
- Stockmayer, S., 2013. Engagement with science: models of science communication. In: Gilbert, J.K., Stockmayer, S. (Eds.), *Communication and Engagement with Science and Technology. Issues and dilemmas.* Routledge, New York.
- Taylor, A., Scott, D., Steynor, A., McClure, A., 2017. Transdisciplinarity, Co-production and Co-exploration: Integrating Knowledge Across Science, Policy and Practice in FRACTAL. FRACTAL Working Paper #3, 19p.
- Tall, A., Kristjansson, P., Chaudhury, M., McKune, S., Zougmore, R., 2014. Who gets the Information? Gender, power and equity considerations in the design of climate services for farmers. CCAFS Working Paper No. 89. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).
- Tall, A., Coulbaly, J.Y., Diop, M., 2018. Do climate services make a difference? A review of evaluation methodologies and practices to assess the value of climate information services for farmers: implications for Africa. *Clim. Serv.* <https://doi.org/10.1016/j.clserv.2018.06.001>.
- Tozier de la Poterie, A., 2017. When Does Information Matter? Roles of Knowledge in Disaster Risk Reduction and Climate Change Adaptation Decision-making. PhD Thesis. University of Colorado Boulder.
- Tozier de la Poterie, A., Daly, M., 2019. Ethical considerations for just climate services. In: Light, A. (Ed.), *The Routledge Companion to Environmental Ethics*, 1st ed. .
- Tritter, J.Q., McCallum, A., 2006. The snakes and ladders of user involvement: Moving beyond Arnstein. *Health Policy* 76 (2), 156–168. <https://doi.org/10.1016/j.healthpol.2005.05.008>.
- van Kerkhoff, L.E., Lebel, L., 2015. Co-productive capacities: rethinking science-governance relations in a diverse world. *Ecol. Soc.* 20 (1). <https://doi.org/10.5751/ES-07188-200114>.
- Vaughan, C., Dessai, S., 2014. Climate services for society: origins, institutional arrangements, and design elements for an evaluation framework. *Wiley Interdiscip. Rev. Clim. Change* 5 (5), 587–603. <https://doi.org/10.1002/wcc.290>.
- Venton, B., 2018. Understanding the Weather Information Needs of Fishermen on Lake Victoria. <https://www.linkedin.com/pulse/understanding-weather-information-needs-fishermen-lake-becky-venton/>.
- Villanueva, P.S., Gould, C., 2017. Routes to Resilience: Lessons from Monitoring BRACED. *BRACED Knowledge Manager*, pp. 1–50.
- Vincent, K., Dougill, A.J., Dixon, J.L., Stringer, L.C., Cull, T., 2017a. Identifying climate services needs for national planning: insights from Malawi. *Climate Policy* 17 (2), 189–202. <https://doi.org/10.1080/14693062.2015.1075374>.
- Vincent, K., Dougill, A., Mataya, D., Mkwambisi, D., Conway, D., Archer van Garderen, E., Tembo Nhlema, D., 2017b. From a clean slate to multiple options – eliciting user needs for climate information in Malawi. Poster presentation at the 5th International Conference on Climate Services, Cape Town, 1st–3rd March 2017.
- Visman, E., Pelling, M., Audia, C., Rigg, S., Crowley, F., Ferdinand, T., 2016. Learning to Support Co-production: Approaches for Practical Collaboration and Learning Between at Risk Groups, Humanitarian and Development Practitioners, Policymakers, Scientists and Academics. Learning paper #3, November 2016, 8p.
- Visman, E., Audia, C., Crowley, F., Pelling, M., Seigneret, A., Bogosyan, T., 2017. Underpinning Principles and Ways of Working that Enable Co-production: Reviewing the Role of Research, KCL/BRACED, Learning Paper #7.
- Vogel, J., McNie, E., Behar, D., 2016. Co-producing actionable science for water utilities. *Clim. Serv.* 2–3, 30–40.
- Wall, T.U., Meadow, A.M., Horganic, A., 2017. Developing evaluation indicators to improve the process of coproducing usable climate science. *Weather Clim. Soc.* 9 (1), 95–107. <https://doi.org/10.1175/WCAS-D-16-0008.1>.
- White, S.C., 1996. Depoliticising development: the uses and abuses of participation. *Develop. Practice* 6 (1), 6–15.
- Williams, C., Fenton, A., Huq, S., 2015. Knowledge and adaptive capacity. *Nature Clim. Change* 5 (2), 82–83.
- Wyborn, C., 2015. Co-productive governance: building relationships between science and governance to connect knowledge with action. *Global Environ. Change* 30, 56–67.