Climate Services 34 (2024) 100492

Contents lists available at ScienceDirect

Climate Services

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

Original research article

Principles for co-producing climate services: Practical insights from FRACTAL

Alice McClure [a], Joseph Daron [b,c,*], Sukaina Bharwani [d], Richard Jones [c,e], Lena C. Grobusch [d], Jessica Kavonic [f], Tamara Janes [c], Mary Zhang [g], Erin Hill [f], Murisa Mzime [h]

[a] Climate System Analysis Group, Environmental and Geographical Science Department, University of Cape Town, Private Bag X3, Rondebosch 7701, South Africa
[b] Faculty of Science, University of Bristol, BS8 1UH, the United Kingdom of Great Britain and Northern Ireland
[c] Met Office Hadley Centre, FitzRoy Road, Exeter, Devon, EX1 3PB, the United Kingdom of Great Britain and Northern Ireland
[d] Stockholm Environment Institute, Oxford Eco Centre, Roger House, Osney Mead, Oxford OX2 0ES, the United Kingdom of Great Britain and Northern Ireland
[e] School of Geography and the Environment, University of Oxford, South Parks Road, Oxford, OX1 3QY, the United Kingdom of Great Britain and Northern Ireland
[f] ICLEI - Local Governments for Sustainability (ICLEI) Africa Secretariat, Unit 1, 2nd Floor, South Tower, Sable Park, 14 Bridge Boulevard, Century City, Cape Town, 7441
[g] Oxford School of Global and Area Studies, University of Oxford, Oxford, the United Kingdom of Great Britain and Northern Ireland, OX2 6LH
[h] International Start Secretariat, Washington, DC, USA

HIGHLIGHTS

- Co-produce climate services through collaborative transdisciplinary learning.
- Engage participants emotions.
- Facilitate equitable engagements.
- Engage the past and future but avoid centring climate information.
- Long-term in-depth engagement promotes effective climate service co-development.

ARTICLE INFO

Keywords:
Co-production
Climate services
Transdisciplinarity

ABSTRACT

Co-production is increasingly acknowledged as the preferred mode for producing climate services, especially in complex and information-limited decision contexts. This paper contributes knowledge on practices and processes that can enable effective climate services in such contexts, through sharing experiences from the Future Resilience for African CiTies And Lands (FRACTAL) project.

FRACTAL focused on informing actions to tackle climate-related issues in nine cities in six southern African countries over a six-year period and, in parallel, developing research findings and insights. Principles for effectively co-producing climate services were collaboratively identified by the project team, after which practical insights were detailed by analysing the body of evidence produced during FRACTAL using qualitative methods. This analysis helped to understand how principles were engendered, as well as associated challenges.

While many principles identified resonate with the growing body of relevant knowledge, practical insights from this study contribute to understanding 'how' principles can be engendered. Experiences emphasise the importance of engaging participants' emotions, avoiding centring on climate information, using a "third space" to facilitate equitable engagements, directing resources towards having fun and learning actively, process-driven iteration, focusing on contemporary issues with which stakeholders can connect, introducing a pathways framing, and embedding researchers in decision-making contexts. This constitutes a more comprehensive set of principles than was previously available in the literature. Application of these principles and the

* Corresponding author at: Faculty of Science, University of Bristol, BS8 1UH, the United Kingdom of Great Britain and Northern Ireland.
E-mail addresses: alice@csag.uct.ac.za (A. McClure), joseph.daron@bristol.ac.uk (J. Daron), sukaina.bharwani@sei.org (S. Bharwani), richard.jones@metoffice.gov.uk (R. Jones), jkavonic@c40.org (J. Kavonic), tamara.janes@metoffice.gov.uk (T. Janes), mary.zhang@area.ox.ac.uk (M. Zhang), mmurisa@start.org (M. Mzime).

https://doi.org/10.1016/j.cliser.2024.100492
Received 28 July 2023; Received in revised form 14 May 2024; Accepted 15 May 2024
Available online 30 May 2024

transdisciplinary framing, which was core to FRACTAL, supports a shift away from a focus on 'products' to knowledge co-production 'processes' where collaborative learning is the defining characteristic of climate services.

Practical Implications

The IPCC recognizes the value of transdisciplinary knowledge co-production processes, reflexive dialogue, and collaborative social learning to support the integration of climate information into decision-making (IPCC, 2022). This is particularly the case in complex and information-limited decision contexts. An opportunity was provided to add knowledge on the principles of co-producing climate services by reflecting on the transdisciplinary 'Future Resilience for African CiTies And Lands' (FRACTAL) project. At the end of this six-year intervention, key guiding principles for transdisciplinary knowledge co-production, which supported significant outcomes and impact, were elicited by the FRACTAL team, building on and extending previous characterisations of climate service co-production principles. These principles are summarised below, grouped into four broad categories, with real-world examples of how their application supported different city engagements.

Underlying principles.

1. Bigger picture (systems) thinking.

FRACTAL engagements embodied a systems thinking approach. To illustrate, Climate Risk Narratives for Lusaka were co-developed by all Learning Lab[1] participants, by simplifying complex climate information specific to the local context in a meaningful way for city-level decision-makers, while appreciating links with global interconnections.

2. Treating in context.

'Burning issues' were situated within the local context and embedded in the local stakeholder landscape. Simultaneously, the FRACTAL cities and their challenges and opportunities were considered in relation to their regional and national contexts.

3. Catalysing (local/African) agency.

African-owned solutions were championed, and local agency was strengthened by addressing capacity development and training needs identified during Learning Labs, conducting city-specific research, and holding city-to-city visits to exchange best practices.

Enabling principles.

4. Respect and trust.

FRACTAL city engagements were held in the form of 'Learning Labs', which are inclusive, open, transdisciplinary and participatory by design. The Learning Labs brought together diverse interest groups (from city planners to community representatives) to co-produce knowledge, while building trust and respect through the sharing of their different perspectives and the creation of a shared understanding of challenges, priorities and 'burning issues'.

5. The social element.

The Learning Labs were supplemented with informal and fun social activities that encouraged bonding among stakeholders, such as fireside chats where learning lab participants could approach climate scientists and ask questions in a relaxed space.

6. Inclusivity and collaboration.

An inclusive and collaborative learning environment was fostered by bringing together a genuine representation of stakeholders who co-explored solutions by appreciating all input and creating common ground.

7. Networks and relationships.

Interpersonal relationships and human networks were at the core of all FRACTAL engagements, forming the basis for the exchange and strengthening of skills and expertise.

Process Principles.

8. Neutral space and enabling process.

The Learning Labs were designed to provide neutral, safe and enabling learning spaces.

9. Process-driven iteration.

Processes were designed to be open and facilitate flexibility and spontaneity, with some explicit overarching goals being set but with methods and outcomes being generated and taking shape through iterative processes.

Practical principles.

10. Transdisciplinarity and (un)comfortable differences.

Constructive dialogues were created by fostering open-mindedness between different interest groups and embracing (un)comfortable differences and diverse views to bridge silos.

11. Linking the current with the past and the future.

Future visions of development pathways were grounded in reflections of present and past development, realities, experiences, and expectations.

12. Embedded researchers.

FRACTAL pronounced the role of early career researchers in city governments, as they are key for building bridges between the science-policy interface in the local context.

Many of these principles align with the growing body of knowledge on principles for co-producing climate services. The application of principles such as these supports a major shift away from a focus on 'products' to a transdisciplinary knowledge co-production 'process' in which co-design and collaborative learning is the defining characteristic. Additionally, in this process, both stakeholders and modellers alike build their capacity to understand the decision context and the potential of climate information in urban planning processes. It is important to note that the simultaneous implementation of all the principles can be challenging in a developing country context in light of relatively restricted resources. However, because aspects of the individual principles are interconnected, improvement in the implementation of one or a few principles can generate many of the positive impacts of the other principles.

1. Introduction

Co-production[2] is increasingly acknowledged as the preferred mode

[1] (City) Learning Labs were widely used in FRACTAL, based on the principles of social learning labs: processes that engage a variety of stakeholders in finding solutions for a specific question or problem that they all perceive as relevant and urgent.

[2] Co-production: bringing together different knowledge sources and experiences to jointly develop new and combined knowledge which is better able to support specific decision-making contexts (Carter et al., 2019).

for producing climate services,[3] especially in complex and information-limited decision-making environments such as southern African cities (Taylor et al., 2021a). Partnerships and mutual learning between stakeholders are key in such contexts (Vincent et al., 2018). There is a growing body of knowledge related to principles that enable effective co-production of climate services between different stakeholders. We aim to contribute to this body of knowledge with practical insights about engendering principles for effective co-production of climate services, particularly by reflecting on and sharing experiences from the Future Resilience for African CiTies And Lands (FRACTAL) project (https://www.fractal.org.za).

FRACTAL was implemented from 2016 to 2021 in nine southern African cities as part of the Future Climate for Africa (FCFA) programme funded by the UK's Department for International Development (now part of the UK Foreign, Commonwealth and Development Office) and the National Environmental Research Council. The main aim of FRACTAL was to tackle fundamental knowledge frontiers in (and inform options for) climate-resilient urban development. In particular, the project aimed to: i) alter how African cities include climate change in development planning; ii) increase understanding of regional climate information through co-exploration with decision makers; iii) fundamentally change key decision pathways to increase the resilience of its focus city-regions; and iv) generate a legacy of new knowledge and learning exemplars along with capacity in these city-regions. At the heart of FRACTAL was the aspiration to put climate information at the service of these cities to solve contextual issues related to climate change.

Pursuing these aims in the context of these issues required a large and very diverse project team which is visualised in Fig. 1. This demonstrates the size of the core team, 28 institutions (including city administrations, non-governmental and humanitarian organizations, universities and research centres) and around 70 individuals, including city officials, consultants, humanitarian actors and researchers. Fig. 1 also includes representation of the level of co-production agency of individuals and the decision-making power of institutions and individuals in designing and the initial stages of the project. Decision-making power evolved significantly through the project and co-production agency, which is more equitably spread across the team, was more relevant in shaping the project outcomes. Finally, Fig. 1 does not include the many other stakeholders engaged at city level, from local NGOs to city-level or national institutions and utilities.

Delivering the climate service described above required the integration of existing knowledge types and co-production of new knowledge that could contribute to decision-making in nine southern African cities. FRACTAL learning processes were therefore founded on transdisciplinarity,[4] which introduced new emphases in climate services processes (see Daniels et al., 2020). For example, climate research and climate services engagements were rooted in real-life problems to support decisions associated with "policy-making", administration, business and community life" (Polk, 2015, pg. 111). The FRACTAL team took an approach to considering these real-life problems and designing solutions through active and flexible participation from diverse stakeholders.

Building on the growing body of relevant knowledge related to principles for co-producing climate services, the aim of this study was to offer practical insights based on FRACTAL experiences. These practical insights were gleaned near the end of the project by collaboratively identifying principles (with the team) that underpinned effective engagement and knowledge co-production during FRACTAL. Qualitative methods were then used to analyse the large body of evidence produced during FRACTAL to understand the enablers and challenges related to engendering these principles, and to identify concrete actions and examples of how the principles were engendered.

The body of knowledge that exists relevant to principles for co-producing climate services is summarised below. The methodology used in this analysis is then presented before discussing the results and wider implications for applying these principles to broader activities in the climate services area.

1.1. Principles for co-producing climate services

Sustainable, climate-resilient and equitable development must consider climate variability and change, and therefore requires usable climate information to guide development, along with mechanisms and capabilities to integrate this information into planning, investments, and decisions (Taylor et al., 2021a; Vincent et al., 2018). The landscape of climate services is complex and includes a multitude of processes, including research and decision processes, different types of information and a variety of stakeholders who engage in producing climate information (including scientific, traditional, experiential, etc.) and who might use this information in decision-making (Hewitt and Stone, 2021). Climate services vary depending on many factors, including the decision in question (e.g., policy updates, infrastructure investment decisions, strategic planning), the stakeholders involved, the potential climate hazards and risks considered, as well as the broader material and social environment in which the climate services process is situated (Vincent et al., 2018; Wall et al., 2017). Several types of engagements and activities can occur as part of a climate service, including sharing climate information through documents, websites or web-based tools, presentations, engagements, and ongoing relationships (Hewitt et al., 2017). In many cases, effective climate services include a combination of these engagements and activities.

Several studies have shone light on principles that enable effective co-production of climate services. Key insights from reviewing literature on co-producing climate services are shared below according to three themes, which emerged during the review, namely: i) capacities and expertise of actors and organisations involved; ii) process design; and iii) systemic and environmental features. It is important to note that this review was bound by a focus on studies that have reported on principles for co-producing climate services. Literature on principles of co-production, more generally, is vast and was not included in this study.

1.1.1. Capacities and expertise

The literature suggests that several types of capacities are important for supporting effective co-production of climate services. Since greater time and resource investments are required to support co-production processes when compared with traditional modes of science-society engagement for climate services, adequate material (including financial) and time resources are required to support such processes (Steynor et al., 2020; Wall et al., 2017). Vincent et al., (2020b) draw attention to the need for fair and equitable management of these resources across stakeholder groups involved to mitigate power imbalances.

Stakeholders involved in co-production require cognitive capacities such that they can engage in these learning processes (Wall et al., 2017). The capacity of stakeholders to take a normative stance in collaborative co-production processes is also important, particularly to work towards a shared understanding of a problem across groups, and a common goal (i.e. a climate service product) (Wall et al., 2017). Learning capacities of stakeholders (i.e. social learning, learning how to learn) supports collaborative, flexible and iterative co-production processes (Bremer

[3] Climate services: Climate services involve the provision of climate information in such a way as to assist decision-making. The 34 service includes appropriate engagement from users and providers, is based on scientifically credible information and expertise, has an effective access mechanism, and responds to user needs. (IPCC, 2022).

[4] Transdisciplinarity: Researchers from different disciplines work interdependently to develop and apply conceptual frameworks, theories, methods and measures that both synthesize and extend beyond discipline-specific approaches to create new approaches to address the scientific problem (Hall et al., 2017).

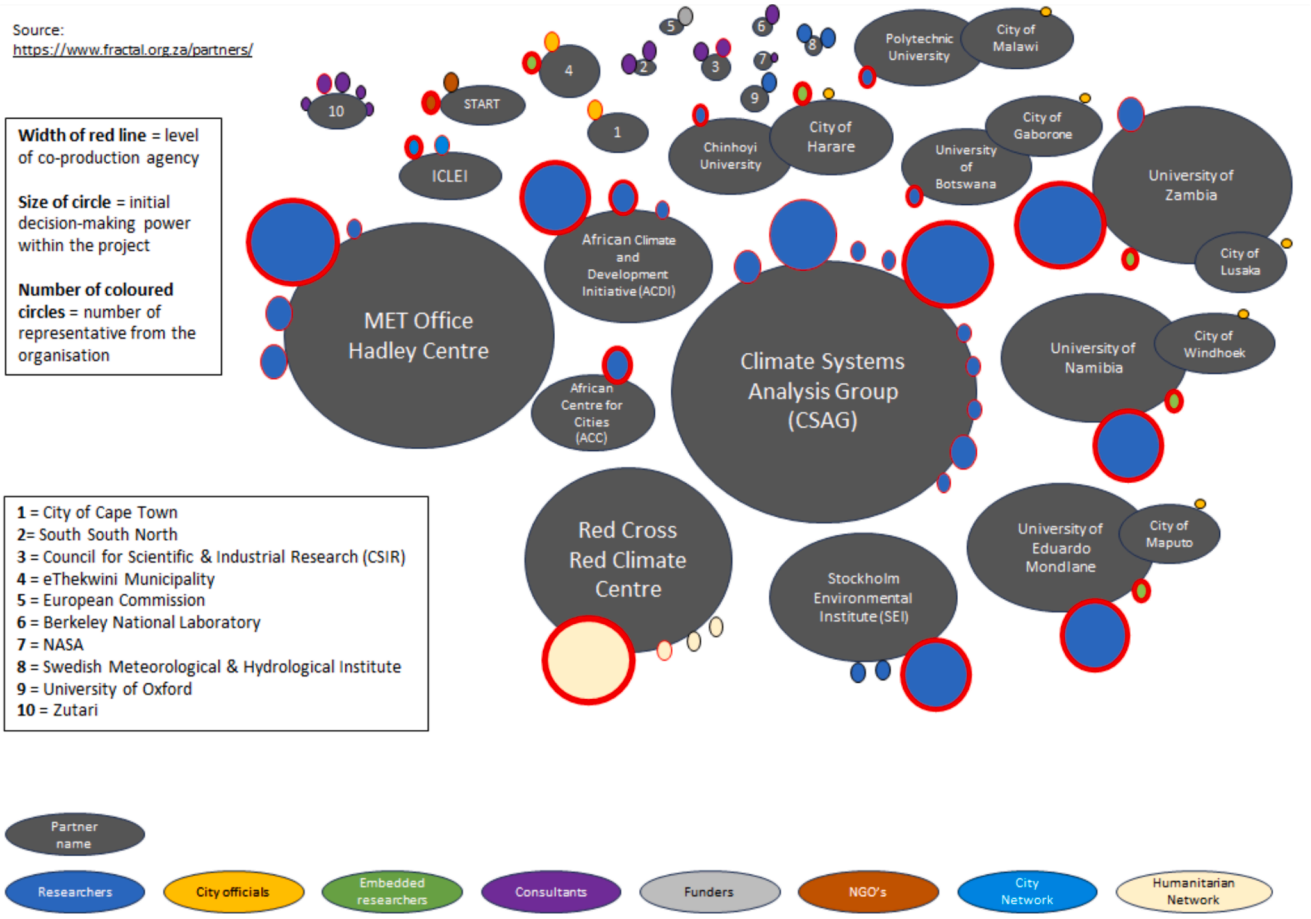

Fig. 1. The FRACTAL project team, the institutions and numbers of individuals involved including details on their co-production agency and initial decision-making power.

et al., 2019). Stakeholders can support effective co-production by exercising capacities that help to better understand and work with a diversity of stakeholders towards this goal. This includes making an effort to strengthen relationships, and communicate effectively across various stakeholder groups (Carter et al., 2019; Hewitt et al., 2020; Meadow et al., 2015; Lemos and Morehouse, 2005; Steynor et al., 2020; Vincent et al., 2018; Wall et al., 2017). Vincent et al. (2018) note the importance of empathy, particularly to understand the perspectives and experiences of diverse stakeholder groups involved in co-production of climate services. Related to empathy, a stance of reflexivity can help participants to interrogate their own assumptions on what constitutes knowledge and knowledge production (Daly and Dilling, 2019; Vincent et al., 2020a).

Climate researchers or scientists participating in co-production processes should practice accountability, along with other participants, for the information that they produce and share during these processes (Bremer et al., 2019; Wall et al., 2017). Scientists should also practice transparency with regards to the accuracy/certainty of such information (Carter et al., 2019). The expertise of boundary organisations or intermediaries can be useful to support relations and translation of information across stakeholder groups (Singletary and Sterle, 2020). Harvey et al. (2019b) note the importance of NGOs, in particular, as potentially filling roles associated with interpretation and translation of climate information. Steynor et al. (2020) single out "embedded researchers" as effective intermediaries.

1.1.2. Process design

There is increasing acknowledgement that co-production of effective climate services involves an iterative, interactive process that unfolds over time (Bremer et al., 2019). As such, a "process-centric" approach to transdisciplinary collaboration of climate services is important to support "complex, real-world decision-making" (Daniels et al., 2020). Several authors note the importance of conscious facilitation and explicit learning objectives during these processes (Carter et al., 2019; Daniels et al., 2020).

Climate services that aim to support decision processes should be timely (i.e. available for key decisions) and should be driven by context or decision needs (i.e. defined by user needs) and information should be tailored to these contexts (Carter et al., 2019; Daniels et al., 2020; Vincent et al., 2018). It is therefore important that associated learning processes are flexible and iterative to respond to context needs (Carter et al., 2019; Lemos and Morehouse, 2005; Vincent et al., 2018; Vincent et al., 2020a; Vincent et al., 2020b). Scientific climate data should be co-explored to distil relevant information for climate services (Carter et al., 2019; Vincent et al., 2018). Reflecting on the state of climate services in Africa, Vogel et al. (2019) call for a "re-imagining" of participatory, bottom-up, polycentric approaches with deep consideration of the hearts and minds of Africans. These authors argue that climate services need to be reframed and informed by the "daily realities" in Africa to shift from being an obligation, which is externally created and owned, to a locally owned and valued service.

Many studies highlight the importance of inclusivity to co-produce climate services, particularly in terms of participants involved, the types of knowledge that are included, as well as processes for monitoring the efficacy of outputs to understand impact (Carter et al., 2019; Golding et al., 2019; Vincent et al., 2018; Vincent et al., 2020b). A careful design and conscious facilitation of co-production processes can support such inclusivity, active engagement of various stakeholder groups, and

respect across these groups (Cater et al., 2019; Daniels et al., 2020; Vincent et al., 2020b; Wall et al., 2017). Activities should be designed and implemented to help participants work towards a common goal regardless of these diverse backgrounds (Wall et al., 2017). Importantly, co-production should be designed so that stakeholders can recognise value in their participation instead of feeling as though such processes are extractive (Carter et al., 2019).

Co-production processes should contribute to socially-robust and legitimate knowledge in the face of uncertainty, which is consolidated in recommendations, ways forward and tangible outcomes (Bremer et al., 2019; Carter et al., 2019; Daniels et al., 2020; Hewitt et al., 2020; Lemos and Moorehouse, 2005; Meadow et al., 2015). Bremer et al. (2019) argue that co-production of climate services should help to redefine local understandings of climate and climate action, to which participants can connect. If possible, co-production processes for climate services should support effective provision of public services and other long-term benefits (Bremer et al., 2019; Daniels et al., 2020; Steynor et al., 2020).

Vincent et al., (2020c) draw attention to the need to address power imbalances in the co-production of climate services. These authors call for a "transformation" of the paradigm that reinforces existing inequalities and suggest that co-production should be designed with equitable inclusion of all participants from the very beginning. This means establishing equitable decision-making on funding and governance arrangements, as well as expectations and incentives at the beginning. Co-production processes have the potential to support renegotiation of social and political processes that shape climate services, and to elevate marginalised groups and voices (Bremer et al., 2019; Vincent et al., 2020a).

1.1.3. Systemic and environmental features

Several studies emphasise the influence of environmental, social and decision context features on co-producing climate services, and on the integration of climate services outputs into planning and policy processes. Such features include institutional structures and cultures, appropriateness of policy and legal frameworks, agency of individuals (linked to the section on capacity above), and values and power asymmetries (Singletary and Sterle, 2020; Vincent et al., 2020a). Activities that allow for co-exploration and for building an understand of these features can thus support better integration of climate knowledge and information into planning (Daniels et al., 2020; Steynor et al., 2016; Vincent et al., 2020a). Core to effective co-production of climate services is established (longer term) relationships between academic and non-academic actors (Meadow et al., 2015).

Daly and Dilling (2019) suggest that normative co-production can challenge traditional modes of knowledge production but that it is "fundamentally shaped by contested processes, existing power structures, and the social, historical, institutional, and cultural contexts" (pg. 64). If practised in an uncritical way that does not explicitly identify and challenge social orders and embedded power structures, normative co-production can "further entrench linear modes of science production" (pg. 64). Daly and Dilling (2019) suggest that to adequately grapple with the power inequities embedded in normative co-production, all participants should examine their own "practices and perceptions" so that they might engage more productively with the perspectives of other participants. This is particularly important for scientists involved in these processes.

2. Study approach

To contribute to the growing body of knowledge summarised above, this study aimed to identify principles that supported the co-production of climate services in FRACTAL and to better understand how these principles were engendered across the African cities in which FRACTAL worked. To achieve the first aim, an inductive and collaborative reflection process was facilitated with the broader FRACTAL team (Fig. 1) to identify principles that supported significant outcomes and impact during the project. The second aim was achieved by analysing the vast qualitative material that was produced during FRACTAL using the collaboratively identified principles as an analytic framework. An inductive-deductive approach to reasoning was adopted during these analytic steps; while the material was analysed using the initial principles as a framework to understand how they were engendered, the principles were also iterated based on insights gleaned from the FRACTAL material, as was the understanding of relations between these principles.

The overall study approach is presented below graphically (Fig. 2). The approach is then detailed (Section 2.2) after the FRACTAL case study is described (Section 2.1).

2.1. FRACTAL case study

Many people living in rapidly growing and dynamic African cities experience issues associated with infrastructure and public service deficits, high unemployment rates and weak local economies alongside climate variability and change (Kareem et al., 2020; Taylor et al., 2021a). Recent studies indicate that African cities will continue to be hotspots of climate-related risks, which will exacerbate non-climatic stressors (Herslund et al., 2016; Trisos et al., 2022).

FRACTAL (2016–2021) aimed to increase understanding of climate-related sensitives of southern African cities through a transdisciplinary approach. Researchers from different disciplines across Botswana, Malawi, Mozambique, Namibia, South Africa, Zambia, Zimbabwe, Europe and the United States worked alongside non-academic stakeholders in these cities to co-produce knowledge to respond to contextual needs. This knowledge took the form of that directly relevant to specific city issues but also, as exemplified by this paper, information more broadly applicable in a climate service context. Two core approaches anchored transdisciplinarity during FRACTAL, namely the city learning labs (hereafter learning labs), which incorporated several already established principles (e.g. flexible iterative processes, conscious facilitation, diversity of participants/knowledge, building trust and understanding context) and the Embedded Researcher (ER) approach, one of the new principles evidenced by FRACTAL.

Learning labs brought together different stakeholders to explore patterns of African urbanization intersecting with climate variability and change, with a long-term view up to 2040. While the learning labs differed across cities in terms of learning processes and outcomes, 'burning issues' were collaboratively identified at the beginning of labs in all cities. These were pertinent issues facing urban communities, which will likely get worse under conditions of climate change. Issues of water quality and security were identified as important across cities. These issues were then explored from multiple perspectives through transdisciplinary activities. Between 2016 and 2019, five learning labs took place in Lusaka (Zambia), four in Windhoek (Namibia) and four in Maputo (Mozambique). They generally lasted for 2–3 days, included all key stakeholders and relevant project partners and were co-designed and co-facilitated by FRACTAL city and other project partners.

ERs were core to FRACTAL as disciplinary, organisational and sectoral boundary spanners (Taylor et al., 2021a). Six early career researchers were contracted to universities within FRACTAL cities and spent their time split between these institutions and government organisations. These researchers helped to cultivate trust-based relationships, facilitate reciprocity across stakeholder groups, enable collaborative agenda setting, remain flexible and navigate multiple accountabilities (Taylor et al., 2021a).

More than 80 institutions across six countries (mainly those illustrated in Fig. 1 but with other city or related national institutions involved also) engaged in transdisciplinary learning processes during FRACTAL, which resulted in notable contributions to climate services in cities. For example, learning labs culminated in the co-development of policy briefs on water in Lusaka, and FRACTAL was mentioned as a supporting partner in the updated Strategic Plan for Lusaka

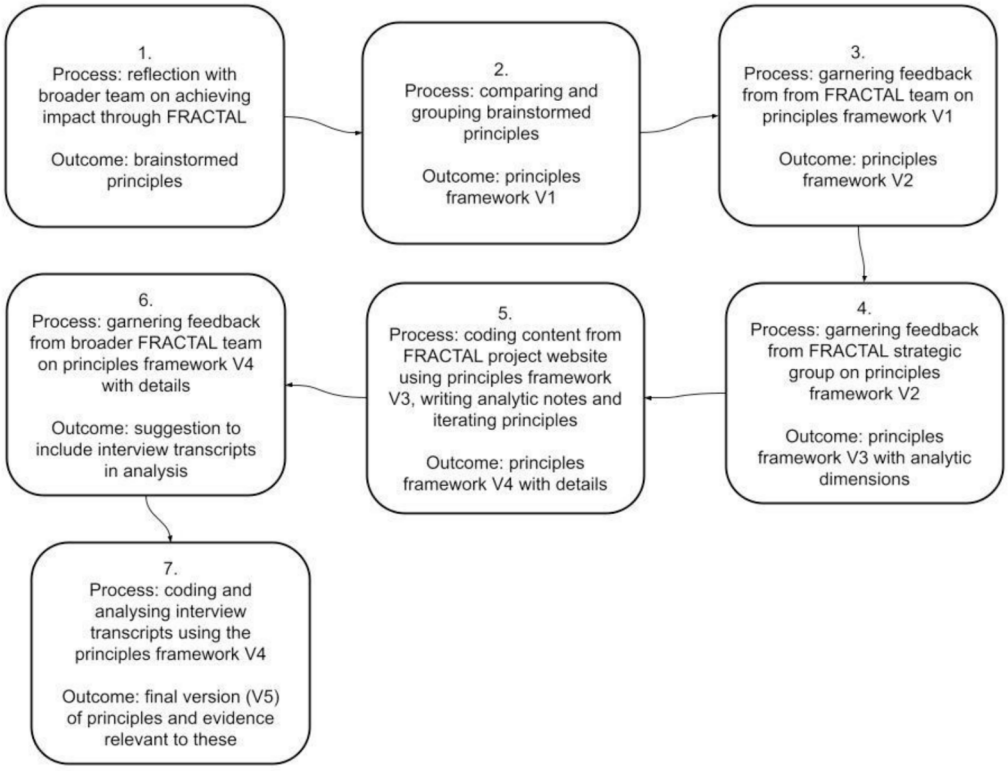

Fig. 2. Graphic showing the methodology followed in the study.

(2017–2021), which includes climate considerations (Taylor et al., 2021b). In Windhoek, the learning lab process supported the development of the Windhoek Integrated Climate Change Strategy and Action Plan (ICCSAP). FRACTAL engagements supported planning relevant to cholera and malaria outbreaks in Maputo. Transdisciplinary engagements in Blantyre, Harare and Gaborone supported mainstreaming of climate considerations into ongoing planning processes. These are all examples of where co-production has resulted in usable knowledge (Harvey et al., 2019a). Stakeholders participating in FRACTAL also reflected on improved communication between a wide variety of stakeholders in cities (Mamombe et al., 2019) and longer-term partnerships between academic and non-academic stakeholders particularly through the establishment of long-term Memoranda of Understanding (MoUs) in Gaborone, Harare and Windhoek. In these cases the outcomes of co-production were in transforming relationships and mindsets.

2.2. Data generation and analysis

2.2.1. Identifying principles

This sub-section describes steps 1 to 4 in Fig. 2.

Near the end of FRACTAL (2020), a reflective process was facilitated by a member of the authorship team to collaboratively identify principles that were important for achieving impact and notable outcomes through co-production. Initially, a brainstorming webinar was convened (September 2020), during which members of the FRACTAL team (Fig. 1) were invited to identify principles that underpinned FRACTAL impacts/success across cities. In total, 14 team members from different organisations participated in this webinar. Participants spent time brainstorming ideas on what they (individually) thought had contributed to impact and added sticky notes to a virtual whiteboard based on these reflections. Once they had added their sticky notes, participants were provided an opportunity to reflect on the whiteboard (Fig. 3).

The ideas that were generated during the brainstorming webinar were compared and grouped into 13 principles. These principles were shared with the full FRACTAL team through email (October 2020) and a project newsletter (December 2020) to allow for broader feedback and iteration of the principles. Two extra principles were proposed based on feedback from the team (see below).

1. Meets emotional needs: feelings of support and connection across the team
2. Having adult, respectful conversations (not overly critical or overly emotional)
3. Humbly presenting knowledge as one piece of a much bigger picture
4. Socialising and having fun
5. Building trust
6. Africa owned solutions, based on local research and capacity building
7. A well-designed, neutral third space and process with clear objectives and boundaries
8. Emergence, iteration, flexibility, and spontaneity
9. Open-mindedness, letting go, being okay with discomfort
10. Inclusivity, a genuine representation of stakeholders, and a real appreciation of all input (voice equity)
11. Allowing differences (ideas, insights, values etc.) and contradictions to emerge
12. Ongoing reflection, learning and adapting (learning from mistakes)
13. Building networks across skills, expertise, spaces etc., which are rooted in human relationships
14. The value of including early career researchers (added during follow-on engagements)
15. The need to acknowledge/address the complexity of the systems involved (added during follow-on engagements)

2.2.2. Understanding practical dimensions and iterating principles

This sub-section describes steps 5 to 7 in Fig. 2.

The activities involved in this step helped to understand how principles were engendered, and to iterate the principles based on evidence

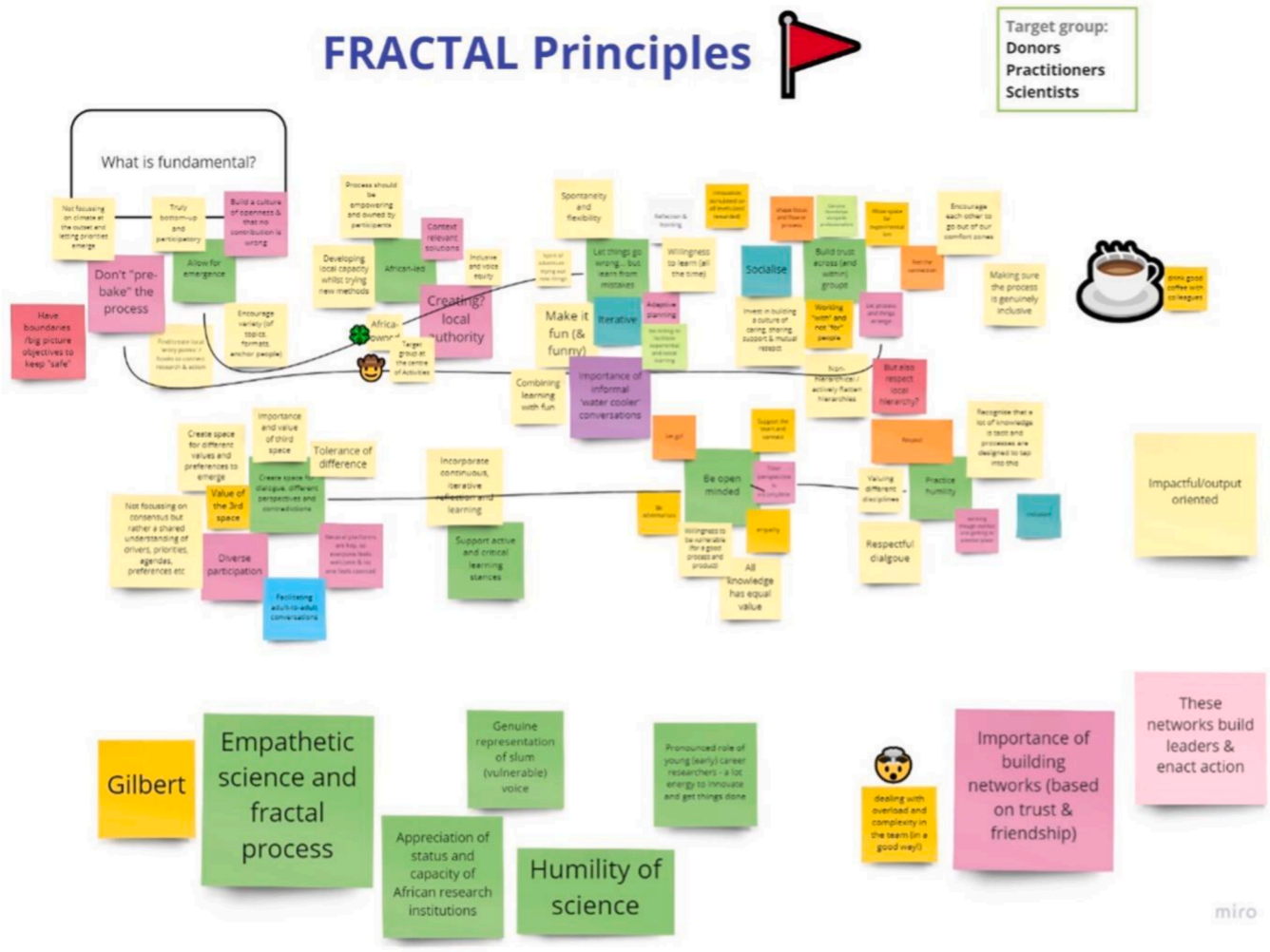

Fig. 3. Outcome of the brainstorming webinar on principles that were important for achieving impact and notable outcomes through transdisciplinary co-production during FRACTAL.

that was generated during FRACTAL. Initially, the updated list of principles was presented to the FRACTAL strategic management group in November 2020 as the "framework" for analysis of material. This group included representatives from all FRACTAL partner organisations (Fig. 1 and https://www.fractal.org.za/partners/). During this meeting, the framework was updated to include extra analytic dimensions, namely: i) examples of how principles were engendered; ii) notes on principles; and iii) enablers and barriers relevant to principles.

Material that had been generated during FRACTAL and was available on the project website was then collated to create a database of content for qualitative analysis. This included: five briefing notes, three reports from dialogues, one training report, one technical brief, one think piece, 10 FRACTAL impact stories, two journal articles that had been produced with a process/learning focus, 10 learning lab reports, three project meeting reports, one concept note, one exercise explainer, five working papers and 16 workshop reports. This amounted to nearly 60 documents.

A member of the authorship team coded the content of these documents using the 15 principles as themes while writing detailed analytic notes. The data that were generated from the initial coding process were read in combination with the analytic notes to iterate the principles and add information on the dimensions of the principles, i.e., how they were engendered, examples of efforts to engender principles, as well as challenges faced while trying to engender principles. The results from this analytic process were translated into three knowledge products to share initial findings with the broader FRACTAL team and provide an opportunity for additional feedback. These knowledge products included: i) an excel table with information about each principle; ii) an online prezi presentation; and iii) a 6-minute animaker video.

An open webinar was hosted (March 2021) to gather feedback on knowledge products from the broader FRACTAL team. During this webinar, a FRACTAL team member suggested to include transcripts from interviews with academic stakeholders (i.e., FRACTAL research team) and non-academic stakeholders (i.e. transdisciplinary participants in Lusaka and Windhoek) in the qualitative analysis. These transcripts had been developed in 2019 based on interviews that were undertaken to document general learnings and insights from a variety of stakeholders who participated in FRACTAL and thus were a rich source of evidence for the development and demonstration of the principles and their relevance. The interviews were semi-structured and were guided by general questions on lessons learned. In line with this suggestion, the transcribed interviews with researchers ($n = 21$) and non-academic stakeholders ($n = 18$) were coded and analysed using the methods described earlier to further refine the principles and to add information on how principles were engendered, as well as challenges faced.

In summary, developing the principles started with a reflective process amongst project team members towards the end of the main FRACTAL project. This was followed by analysis of the wide range of FRACTAL documents to understand how the principles were engendered from which knowledge products were developed for further feedback,

complemented by a qualitative analysis of 39 semi-structured interviews. Results from these steps were then used to refine both the principles and provide contextual information about dimensions of these principle, including how they applied in the various city contexts. This generated a set of 12 final principles, outlined in the next section.

3. Findings from the study

The findings from the study are presented first as the set of and evidence for the FRACTAL principles, and then secondly identifying the contributions of these findings to the growing body of literature.

3.1. FRACTAL principles

A final set of principles was developed after reflective, collaborative processes with the FRACTAL team and iteration of principles while analysing the material that was produced and published during FRACTAL. The following text elaborates how each principle was identified, how it contributed to improved processes and outcomes and which key challenges were faced. See the table in the Supplementary material to this study for detailed information on how principles were applied in FRACTAL through various practices and processes, as well as more detail on challenges.

3.1.1. Underlying principles

1. **Bigger picture (systems) thinking** was engendered by having climate scientists presenting climate information as connected to a wider picture of local challenges and opportunities (for example co-developing Climate Risk Narratives of future storylines) and in a humble way (recognizing there is no "right answer" in contexts of such complexity). Moreover, knowledge exchange exercises were designed to bring together the different perspectives and lived experiences of a wide variety of stakeholders and to connect co-production processes to city goals and decision-making processes. Engendering this principle required extra effort from both citizens and from the climate scientists who learned new perspectives and terminology and critically reflected on how the added value of climate (change) information could fit into this bigger picture and be simplified in a way that is meaningful at the local scale.
2. **Treating in context** was considered central as FRACTAL pioneered context-driven climate research to explore problems and potential solutions together with diverse stakeholders in the different cities. The context-led approach entailed hosting immersive, multi-day stakeholder learning labs where understandings of contextual issues were co-produced, and field trips were undertaken to understand different components of the complex city systems (such as treatment plans, power stations and water supply dams). The uncertainty of the novel context-led processes caused some challenges as real-world decision-making is not linear, and the co-discovery of city specific needs and "getting somewhere" took time.
3. **Catalysing local agency** is about developing locally-owned solutions based on local research and capacity. FRACTAL's flexible iteration processes allowed for contextual needs to emerge from the bottom up, while supporting local climate champions, embedded researchers and local government focal points to take the ideas forward in their own work and support the institutionalization of considerations into planning processes. Budget was allocated for city stakeholders to design and implement city-specific research, and to undertake city-to-city learning activities to showcase African solutions. It was sometimes challenging to navigate a lack of decision-making power at the city level, as well as political changes, financial constraints, and frequent staff turnover.

3.1.2. Enabling principles

1. The principle of **respect and trust** entailed listening to one another and strengthening emotional connections. This principle was engendered by making transdisciplinarity a foundational value throughout FRACTAL, which fostered an openness to framing issues in various ways that make sense to different people. As such, participants were able to engage in active dialogue, interpersonal exchange and transdisciplinary learning processes, which created common ground e.g. the "burning issues" for exploring what could or couldn't be achieved. One challenge in this domain was the amount of time required for people to build the expertise to work in this novel way.
2. **The social element** was foundational to the trust and rapport developed between partners and city stakeholders in FRACTAL and was enabled by way the budget was designed and managed. This allowed events including breakfasts and social evenings to take place in the different cities. It was also helped by participants often staying in the same lodgings and usually being deliberately hosted outside the city so they could break away from their daytime roles and be present and engaged. As time went on, the increase in confidence of participants to ask questions was a marked outcome of these social processes during less formal interactions such as "fireside chats", co-exploring language, talk show simulations, and drama skits, all of which incorporated humour and fun, and triggered different modes of thinking and learning. Challenges however were still present in Maputo where language remained a barrier.
3. **Inclusivity and collaboration** were prioritized to honour the importance of different stakeholders and ensure that their respective voices were heard. This was achieved by explicitly valuing stakeholder diversity and creating platforms for stakeholders to come together in different ways. Conversations were grounded in real-world relevance and the value of collaboration was continuously demonstrated. A key challenge for the implementation of this principle was a difficulty to ensure a strong representation of people from *peri*-urban areas and informal settlements.
4. Building **networks and relationships** across organizations and knowledge domains was a collaborative and transdisciplinary learning process. Participants were encouraged to collaborate on a common problem (i.e. the burning issue) and through the creation of city-to-city learning processes that fostered a learning community. Experiences and activities (such as field trips and city exchanges) also helped people to "walk in each other's shoes". Those who participated in the learning labs and met others face-to-face formed deep relationships and became part of such networks, but it was challenging for those who could not participate face-to-face.

3.1.3. Process principles

1. A **neutral space and enabling process** contributed to shared objectives, learning boundaries and carefully managed programmes at project and city scales. This was created through reflexive and adaptive planning at the project level e.g., co-designing Learning Lab agendas and continually updating these in response to emerging needs on the days of the labs, and reflections after every event to learn for the next one etc. A core agenda of producing robust and useful knowledge for informing effective decision making remained at the heart of Learning Labs. Embedded researchers played a key role in the design and implementation of labs, and local participants were also invited to facilitate exercises or dialogues. Facilitators worked to create a 'third space' (i.e. neutral space outside of participants "home" spaces) where people could safely challenge ideas/inefficiencies and contribute to what are often exclusionary processes e.g. producing climate science. Complexities remained in challenging the power dynamics that exist everywhere. The level of

flexibility described also creates challenges in creating time for the full programme and for all activities.

2. **Process-driven iteration** meant that while some overarching project goals were set, methods and outcomes were generated through iterative transdisciplinary learning processes. This enabled spontaneity in response to participant needs, due to recognition in the team for the need for flexibility, and iteration. It was important the funder did not require outputs to be defined at the outset and supported this iterative and flexible reflexivity. Challenges to this included high staff turnover risking "process memory", understanding and explaining uncertainty, involving a greater diversity of stakeholders and keeping those who were involved engaged when a clear output was not defined.

3.1.4. Practical principles

1. **Transdisciplinarity and (un)comfortable differences** must be integrated very early into the process to be successful, e.g. in proposal development and agreements between partners, to ensure a diversity of knowledges, disciplines, methods, evidence, ideas, values, inputs and processes. Often breaching 'uncomfortable' differences and 'third spaces' it requires humility from researchers who recognize that there is no "right answer" in contexts of such complexity. One mechanism facilitating this approach was the emergence of project governance that included transdisciplinary city "task teams" and "working clusters". these cluster meetings were open for anyone to join, which helped connections across research themes, different disciplines and city learning processes. There are many challenges associated with this principle (see table in Supplementary material) including the fact that academic and government institutions are often not conducive to facilitating transdisciplinary work due to their structure and generally discrete mandates. For this reason, careful consideration of the design of transdisciplinary projects is required early on.
2. **Linking the current with the past and the future** was important in all aspects of FRACTAL, from learning, adapting and future visioning of the city to ongoing reflection within the FRACTAL team about learning processes. Participants connected with the climate change challenge in ways that were meaningful to them, by acknowledging the contribution of history to the current context (i.e., challenges) and locating the learning processes in current issues while planning for the future, e.g. through visioning and backwards mapping exercises. This allowed for inclusive and extensive problem solving, though it was still difficult to explore the nuanced impacts of climate change for future city planning.
3. **Embedding researchers** through their placement in local governments, ERs developed their "capacity to undertake collaborative and impactful research on climate-related issues that is guided by and feeds directly into urban policy and practice". Their role was supported by: dedicated physical spaces at research institutions and government organizations; an ER coordinator who created a space for connecting and reflecting across ERs; and, PIs in the city and municipal representatives to liaise with and create and identify windows of opportunity for the project to engage with. However, this presented its own challenges as there were expectations placed on ERs from both the government and research organizations.

3.2. Contributions to the growing body of literature

The findings presented above provide practical guidance on engendering principles, which is needed within the growing body of literature on principles for co-producing climate services. This section discusses the findings from this study in relation to the growing body of literature more broadly. Many of the principles that emerged from the study echo principles that have been documented prior to this study (see Table 1), thus providing additional evidence for their relevance. Reflecting on

Table 1
Principles for co-producing climate services based on a review of literature.

Principle	Example references
Capacities and expertise	
Adequate material and time resources available (with equitable management of these resources)	Steynor et al. (2020); Vincent et al., (2020b); Wall et al. (2017)
Participants possess cognitive capacities	Wall et al. (2017)
Participants practise normative capacities	Wall et al. (2017)
Participants possess and practise learning capacities	Bremer et al. (2019)
Participants practise relational capacities: building/strengthening relationships, communicating effectively	Carter et al. (2019); Hewitt et al. (2020); Lemos and Morehouse (2005); Meadow et al. (2015); Steynor et al. (2020); Vincent et al. (2018); Wall et al. (2017)
Participants practise and grow empathy	Vincent et al. (2018)
Participants adopt a reflexive stance	Daly and Dilling (2019); Vincent et al., (2020a)
Researchers (and other participants) practise accountability for information shared	Bremer et al. (2019); Wall et al. (2017)
Researchers are transparent re: accuracy and certainty of information shared	Carter et al. (2019)
Intermediaries practise expertise to support relations and translation of information (e.g. NGOs and Embedded Researchers)	Singletary and Sterle, (2020); Harvey et al. (2019); Steynor et al. (2020)
Process design	
Co-production is "process-centric"	Bremer et al. (2019); Daniels et al. (2020)
Facilitation of processes are conscious and explicit learning objectives are set	Carter et al. (2019); Daniels et al. (2020)
Co-production processes are timely to support relevant decisions and climate information is tailored to needs	Carter et al. (2019); Daniels et al. (2020); Vincent et al., (2018)
Processes are iterative and flexible to respond to contextual needs	Carter et al. (2019); Lemos and Morehouse (2005); Vincent et al. (2018); Vincent et al., (2020a); Vincent et al., (2020b)
Climate information is co-explored and distilled	Carter et al. (2019); Vincent et al. (2018)
Co-production allows for "re-imagining" bottom-up, polycentric approaches	Vogel et al. (2019)
Co-production is inclusive in terms of participants, types of knowledge, and monitoring/MEL processes	Carter et al. (2019); Golding et al., (2019); Vincent et al. (2018); Vincent et al., (2020b)
Activities allow for working towards a common goal across participants	Wall et al. (2017)
Processes are designed so that stakeholders can see the value of their participation	Carter et al. (2019)
Co-production contributes to socially robust and legitimate knowledge in the face of uncertainty (consolidated as tangible outcomes)	Bremer et al. (2019); Carter et al., (2019); Daniels et al. (2020); Hewitt et al. (2020); Lemos and Moorehouse (2005); Meadow et al. (2015)
Processes allow for redefining local understandings of climate and climate action	Bremer et al. (2019)
Processes support public services and long-term benefits	Bremer et al. (2019); Daniels et al., (2020); Steynor et al. (2020)
Co-production explicitly address power imbalances	Vincent et al., (2020c)
Processes support renegotiation of social and political processes, and elevate marginalised voices	Bremer et al. (2019); Vincent et al., (2020a)
Systemic and environmental features	
Shared understandings are built amongst participants of institutional structures and cultures, appropriateness of policy and legal frameworks, agency of individuals, values and power asymmetries.	Singletary and Sterle (2020); Vincent et al., (2020a)
Long-term relationships between academic and non-academic actors are established/grown	Meadow et al. (2015)
Critical co-production is practised, to grapple with power inequities and examine practices and perceptions of participants	Daly and Dilling (2019)

FRACTAL experiences does, however, offer several important contributions to this body of knowledge, which are described below.

While a trusting environment that is respectful of differences has been noted as important by several authors, the findings from this study add a new dimension, namely the importance of engaging the emotions of participants during transdisciplinary learning processes. The 'bigger picture' framing encouraged climate scientists to present scientific information (e.g., forecasts and projections) in a humble way. This was enabled through context-led (in contrast to context-informed) and immersive transdisciplinary learning processes that were situated in cities (i.e. during the learning labs). The transdisciplinary teams explicitly avoided centring engagements on scientific climate information. Instead, this information was introduced once the city contexts had been deeply explored with a variety of stakeholders. These insights have methodological implications for co-exploring the context through bottom-up processes that enable effective co-production of timely and usable climate services, which have been emphasised by several authors prior to this study (e.g. Daniels et al., 2020; Vogel et al., 2019).

Another key contribution is the employment of the 'third space' concept, which was introduced by social scientists during FRACTAL. The learning labs were considered third spaces, in which voice equity was encouraged to discuss issues of climate risks, and participants were provided with an opportunity to critically reflect on practices in their 'home spaces' (i.e. work environments). This voice equity supported the development of respect and trust, the comprehensive co-exploration of issues and solutions and generating shared ownership of outcomes. This insight builds on several studies, which note that co-production spaces should be carefully designed, and that facilitation needs to be "conscious" to invite multiple perspectives and knowledge (e.g. Carter et al., 2019; Wall et al., 2017). Principles associated with flexibility and process-driven iteration within this space were core to FRACTAL and team members developed a mantra to "trust the process", assuming this process was well designed (e.g., according to other principles). Several other authors emphasise the importance of flexibility and iterativity (e.g. Vincent et al., 2018).

FRACTAL's transdisciplinary framing, which was written into the proposal, is in line with calls to employ transdisciplinary collaborations for climate services (e.g. Daniels et al., 2020). Within FRACTAL, this framing influenced the design of many activities, from learning labs and the ER approach in cities through to climate science frameworks and processes such as Climate Risk Narratives and the concept of 'distillation' (e.g., see Jack et al., 2020; Jack et al., 2021). The transdisciplinary framing expanded the arena of i) what was considered valid and important evidence for understanding decision contexts; ii) who was considered to be an expert in the process of producing usable knowledge; and iii) who was invited into conversations about producing climate change information (e.g., including on the assumptions that were made). In some cases, scientific climate information contrasted with other types of evidence – these contradictions were surfaced and discussed.

Inclusivity was considered a core principle in FRACTAL, which is not new to the growing body of knowledge on principles for co-producing climate services (e.g. Carter et al., 2019; Vincent et al., 2018; Vogel et al., 2019). The findings from FRACTAL also echo the importance of relationships and networks, which have been considered foundational for effectively co-producing climate services by several authors (e.g., Daniels et al., 2020). A novel insight based on the FRACTAL experience is the importance of socialising and allowing participants to have fun while learning. Specific effort was directed at organising activities that allowed transdisciplinary participants to engage in serious games and participate in activities that helped them to understand one another as people. These efforts are particularly important to support relationships across stakeholders. Findings from the study also contribute methodological insights on enabling inclusivity, particularly on centring dialogue and learning on 'burning issues', with which a variety of participants could connect to meaningfully interrogate climate risks now and into the future. Findings from the study also emphasise the importance of the ER approach (itself a new principle as noted in 2.1) for fostering relationships and closing divides between different groups of people.

Another methodological contribution for co-producing climate services relates to the importance of a pathways approach (linking past, current and future), which helps to frame current decision options based on an in-depth understanding of the past and interrogates the consequences of these decisions on the future. While the pathways framing is widely applied in sustainability sciences more broadly (e.g., Leach et al., 2007, Beland Lindahl et al., 2016) and scientific climate research more specifically (e.g., IPCC WG II Chapter 18: Climate Resilient Development Pathways; Werners et al., 2021), it is a novel methodological consideration for co-producing climate services. It was important in establishing the context and understanding of the system, and supporting local agency in the development of solutions.

Finally, as is evident from the previous paragraphs, application of one of more principles are important for establishing the value of other principles, i.e., their greatest potential is in their interaction and application together. This is a critical overarching methodological finding, which is a consequence of and thus further strengthens the need for transdisciplinarity, systems thinking, enabling and iterative processes and trust/inclusivity.

4. Summary and conclusions

It is now well established that co-production, and processes to enable effective co-production, are important for successfully delivering climate services in many contexts. Given the vast range of contexts in which climate information is relevant, the concept of designing a universal 'climate service' that can cater for these is not practical. However, given the rate of climate, socio-economic and ecological change, and the ambitions for climate resilient development and adaptation, the need for effective climate services across this vast range of contexts continues to grow. Thus, it makes sense to focus on principles that ensure climate services are effective (in any given context) rather than considering what a climate service should comprise of (i.e. a recipe for climate services). With principles established, the requirements for a particular climate service in the given context will follow.

FRACTAL was a transdisciplinary project that chose to focus on decisions and actions to tackle climate-related issues in southern African cities. Given the complexity of the situations with which it engaged, and its mandate not only to deliver useful outcomes for city stakeholders but also to generate relevant and significant knowledge on climate resilient development in southern Africa, a significant component of research focused on the latter. In pursuit of these twin mandates, the project team, which initially involved the academic partners and embedded researchers but soon was enhanced by a wide range of partners in each city (which became known as the "FRACTAL family"), focused both on exploring the causes and possible solutions to burning issues in the cities, and on reflecting on and documenting how this was successfully achieved. The results presented in this study are drawn from this second focus area and specifically relate to how the team's activities provided effective climate services to the cities and the principles which underpinned the co-development of these services.

As described in section 2.2, the process of identifying the principles involved several (iterative) stages and drew on a diverse range of expertise and documentation (thus itself embodying many of the principles). It is important to note that key enablers for this process to succeed were the scale of FRACTAL, both geographically (multi-city/country) and temporally (multi-year) and its (achieved) ambition to also pursue the first mandate of identifying causes and solutions to burning issues in the cities. Thus, the scale and ambition not only provided the opportunity to identify a more comprehensive set of principles than was apparent from previous literature but to clearly demonstrate (as noted in the examples in section 2.1) their relevance in ensuring the delivery of effective climate services.

Findings from the study resonate with, and thus support, the existing literature on principles for co-producing climate services while providing much practical guidance and examples of activities that help to engender principles. In addition, it has generated many key new insights on principles. These include the importance of engaging participants' emotions ("Respect and Trust"), avoiding centring on climate information ("Treating in context"), using a "third space" to facilitate equitable engagements ("Neutral spaces/enabling processes"), directing specific effort and resources towards having fun and learning actively ("The social element"), trusting the process ("Process-driven iteration"), focusing on contemporary issues ("Inclusivity and collaboration"), introducing a pathways framing ("Linking the current with the past and the future") and, possibly most importantly, embedding researchers in decision-making contexts ("Embedded researchers").

The application of these principles supports a major shift away from a focus on 'products' to a transdisciplinary knowledge co-production 'process' in which co-design and collaborative learning is the defining characteristic. It can therefore be argued that a transdisciplinary framing, which was core to FRACTAL from the very beginning, underpins all or most other principles for co-producing climate services. During the FRACTAL transdisciplinary learning process, all stakeholders (including researchers) built their capacity to understand: i) the decision context; ii) the potential of climate information to inform urban planning processes; and iii) arguably most importantly, the roles that stakeholders can play on pathways towards resilience (i.e., catalysing agency). It is important to note that the simultaneous implementation of all the principles can be challenging, especially in a developing country context considering relatively restricted resources. However, because aspects of the individual principles are interconnected, improvement in the implementation of one or a few principles can generate many of the positive impacts of the other principles.

CRediT authorship contribution statement

Alice McClure: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Joseph Daron:** Writing – original draft, Conceptualization. **Sukaina Bharwani:** Writing – original draft, Methodology, Conceptualization. **Richard Jones:** Writing – original draft, Methodology, Formal analysis, Conceptualization. **Lena C. Grobusch:** Writing – original draft, Formal analysis. **Jessica Kavonic:** Writing – original draft, Formal analysis. **Tamara Janes:** Writing – original draft. **Mary Zhang:** Writing – original draft. **Erin Hill:** Writing – original draft. **Murisa Mzime:** Writing – original draft, Formal analysis.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: All authors reports financial support was provided by Natural Environment Research Council. All authors reports financial support was provided by Foreign Commonwealth & Development Office.

Data availability

Data will be made available on request.

Acknowledgements

First and foremost, the authors would like to acknowledge all the participants of FRACTAL learning processes, in cities and across the world. These stakeholders contributed invaluable knowledge and participated actively to ensure mutual learning across all groups and it has been a great privilege to work with them and analyse and synthesise this learning in order to establish these principles.

This work was supported by the Natural Environment Research Council (NERC) and the Foreign Commonwealth and Development Office (FCDO) [grant numbers 2021COPA&R37Daron; NE/M020347/1].

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cliser.2024.100492.

References

Beland Lindahl, K., Baker, S., Rist, L., Zachrisson, A., 2016. Theorising pathways to sustainability. Int J Sust Dev World 23 (5), 399–411. https://doi.org/10.1080/13504509.2015.1128492.

Bremer, S., Wardekker, A., Dessai, S., Sobolowski, S., Slaattelid, R., van der Sluijs, J., 2019. Toward a multi-faceted conception of co-production of climate services. Clim. Serv. 13, 42–50. https://doi.org/10.1016/j.cliser.2019.01.003.

Carter, S., Steynor, A., Vincent, K., Visman, E., Waagsaether, K., 2019. A Manual for Co-Production in African Weather and Climate Services. In: Future Climate for Africa and Weather and Climate Information Services for Africa, p. 156 pp..

Daly, M., Dilling, L., 2019. The politics of "usable" knowledge: examining the development of climate services in Tanzania. Clim. Change 157 (1), 61–80. https://doi.org/10.1007/s10584-019-02510-w.

Daniels, E., Bharwani, S., Swartling, Å.G., Vulturius, G., Brandon, K., 2020. Refocusing the climate services lens: Introducing a framework for co-designing "transdisciplinary knowledge integration processes" to build climate resilience. Clim. Serv. 19, 100181 https://doi.org/10.1016/j.cliser.2020.100181.

Golding, N., Hewitt, C., Zhang, P., Liu, M., Zhang, J., Bett, P., 2019. Co-development of a seasonal rainfall forecast service: Supporting flood risk management for the Yangtze River basin. Clim. Risk Manag. 23, 43–49. https://doi.org/10.1016/j.crm.2019.01.002.

Hall, K., Stipelman, B.A., Vogel, A.L., Stokols, D., 2017. Understanding Cross-Disciplinary Team-Based Research: Concepts and Conceptual Models from the Science of Team Science. In: Frodeman, R. (Ed.), The Oxford Handbook of Interdisciplinarity, 2nd edn,. Oxford Handbooks. https://doi.org/10.1093/oxfordhb/9780198733522.013.28.

Harvey, B., Cochrane, L., Van Epp, M., 2019a. Charting knowledge co-production pathways in climate and development. Env Pol Gov. (1–11) https://doi.org/10.1002/eet.1834.

Harvey, B., Jones, L., Cochrane, L., Singh, R., 2019b. The evolving landscape of climate services in sub-Saharan Africa: What roles have NGOs played? Clim. Change 157, 81–98. https://doi.org/10.1007/s10584-019-02410-z.

Herslund, L.B., Jalayer, F., Jean-Baptiste, N., Jørgensen, G., Kabisch, S., Kombe, W., Lindley, S., Nyed, P.K., Pauleit, S., Printz, A., Vedeld, T., 2016. A multi-dimensional assessment of urban vulnerability to climate change in Sub-Saharan Africa. Nat. Hazards 82, 149–172. https://doi.org/10.1007/s11069-015-1856-x.

Hewitt, C.D., Stone, R., 2021. Climate services for managing societal risks and opportunities. Clim. Serv. 23, 100240 https://doi.org/10.1016/j.cliser.2021.100240.

Hewitt, C.D., Stone, R.C., Tait, A.B., 2017. Improving the use of climate information in decision-making. Nat. Clim. Chang. 7 (9), 614–616. https://doi.org/10.1038/nclimate3378.

Hewitt, C.D., Allis, E., Mason, S.J., Muth, M., Pulwarty, R., Shumake-Guillemot, J., Bucher, A., Brunet, M., Fischer, A.M., Hama, A.M., Kolli, R.K., 2020. Making society climate resilient: International progress under the global framework for climate services. Bull. Am. Meteorol. Soc. 101 (2), E237–E252. https://doi.org/10.1175/BAMS-D-18-0211.1.

IPCC. 2022. Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

Jack, C.D., Marsham, J., Rowell, D.P. and Jones, R.G., 2021. Climate information: towards transparent distillation. *Climate Risk in Africa: Adaptation and Resilience*, pp.17-35. https://doi.org/10.1007/978-3-030-61160-6_2.

Jack, C.D., Jones, R., Burgin, L., Daron, J., 2020. Climate risk narratives: An iterative reflective process for co-producing and integrating climate knowledge. Clim. Risk Manag. 29, 100239 https://doi.org/10.1016/j.crm.2020.100239.

Kareem, B., Lwasa, S., Tugume, D., Mukwaya, P., Walubwa, J., Owuor, S., Kasaija, P., Sseviiri, H., Nsangi, G., Byarugaba, D., 2020. Pathways for resilience to climate change in African cities. Environ. Res. Lett. 15 (7), 073002 https://doi.org/10.1088/1748-9326/ab7951.

Leach, M., Bloom, G., Ely, A., Nightingale, P., Scoones, I., Shah, E. and Smith, A., 2007. *Understanding governance: pathways to sustainability*. STEPS Centre.

Lemos, M.C., Morehouse, B.J., 2005. The co-production of science and policy in integrated climate assessments. Glob. Environ. Chang. 15 (1), 57–68. https://doi.org/10.1016/j.gloenvcha.2004.09.004.

Mamombe, R., Plaxedes Mubaya, C., Mzime, M., McClure, A., 2019. Building relations and receptivity in Harare. Fractal impact story, Available online at: https://www.fractal.org.za/wp-content/uploads/2020/06/IS10-Building-relations-and-receptivity-in-Harare.pdf.

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.

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.

Singletary, L., Sterle, K., 2020. Supporting local adaptation through the co-production of climate information: an evaluation of collaborative research processes and outcomes. Clim. Serv. 20, 100201 https://doi.org/10.1016/j.cliser.2020.100201.

Steynor, A., Padgham, J., Jack, C., Hewitson, B., Lennard, C., 2016. Co-exploratory climate risk workshops: Experiences from urban Africa. Clim. Risk Manag. 13, 95–102. https://doi.org/10.1016/j.crm.2016.03.001.

Steynor, A., Lee, J., Davison, A., 2020. Transdisciplinary co-production of climate services: a focus on process. Soc. Dyn. 46 (3), 414–433. https://doi.org/10.1080/02533952.2020.1853961.

Taylor, A., Siame, G. and Mwalukanga, B. 2021b. Integrating Climate Risks into Strategic Urban Planning in Lusaka, Zambia. In: Conway, D., Vincent, K. (eds) Climate Risk in Africa. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-61160-6_7.

Taylor, A., Jack, C., McClure, A., Bharwani, S., Ilunga, R., Kavonic, J., 2021a. Understanding and supporting climate-sensitive decision processes in southern African cities. Curr. Opin. Environ. Sustain. 51, 77–84. https://doi.org/10.1016/j.cosust.2021.03.006.

Trisos, C.H., I.O. Adelekan, E. Totin, A. Ayanlade, J. Efitre, A. Gemeda, K. Kalaba, C. Lennard, C. Masao, Y. Mgaya, G. Ngaruiya, D. Olago, N.P. Simpson, and S. Zakieldeen, 2022: Africa. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1285-1455, doi:10.1017/9781009325844.011.

Vincent, K., Daly, M., Scannell, C., Leathes, B., 2018. What can climate services learn from theory and practice of co-production? Clim. Serv. 12, 48–58. https://doi.org/10.1016/j.cliser.2018.11.001.

Vincent, K., Archer, E., Henriksson, R., Pardoe, J., Mittal, N., 2020a. Reflections on a key component of co-producing climate services: defining climate metrics from user needs. Clim. Serv. 20, 100204 https://doi.org/10.1016/j.cliser.2020.100204.

Vincent, K., Carter, S., Steynor, A., Visman, E., Wågsæther, K.L., 2020b. Addressing power imbalances in co-production. Nat. Clim. Chang. 10 (10), 877–878. https://doi.org/10.1038/s41558-020-00910-w.

Vincent, K., Conway, D., Dougill, A.J., Pardoe, J., Archer, E., Bhave, A.G., Henriksson, R., Mittal, N., Mkwambisi, D., Rouhaud, E., Tembo-Nhlema, D., 2020c. Re-balancing climate services to inform climate-resilient planning–A conceptual framework and illustrations from sub-Saharan Africa. Clim. Risk Manag. 29, 100242 https://doi.org/10.1016/j.crm.2020.100242.

Vogel, C., Steynor, A., Manyuchi, A., 2019. Climate services in Africa: Re-imagining an inclusive, robust and sustainable service. Clim. Serv. 15, 100107 https://doi.org/10.1016/j.cliser.2019.100107.

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.

Werners, S.E., Sparkes, E., Totin, E., Abel, N., Bhadwal, S., Butler, J.R., Douxchamps, S., James, H., Methner, N., Siebeneck, J., Stringer, L.C., 2021. Advancing climate resilient development pathways since the IPCC's fifth assessment report. Environ Sci Policy 126, 168–176. https://doi.org/10.1016/j.envsci.2021.09.017.