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

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Photo credit: Bettina Koelle

The authors would also like to sincerely thank the broader FRACTAL team and the participants of engagements in all cities, who were central in learning processes and in co-producing knowledge presented in this paper.

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Summary

This working paper contributes to the body of knowledge on principles for co-producing climate services by reflecting on and sharing experiences from the Future Resilience of African CiTies and Lands (FRACTAL) project. FRACTAL was implemented from 2015-2021 in nine southern African cities as part of the Future Climate For Africa (FCFA) programme, with the main aim of co-producing climate knowledge that could inform climate-resilient urban development. Through transdisciplinary learning processes, which were anchored by "learning labs", societal stakeholders worked with researchers from various disciplines to co-explore decision contexts, identify knowledge and capacity needs, and co-design activities to respond to these.

There is growing emphasis on co-producing climate services, particularly to foster partnerships and mutual learning between stakeholders across the climate services landscape. This paper begins by providing a summary of messages from the literature that relates to principles for co-producing climate services, which are categorised according to: i) capacities of stakeholders involved in the processes; ii) design of co-production processes; and iii) institutional, policy and environmental factors.

The principles that supported co-production of climate services during FRACTAL are then presented, which were identified during a retrospective and reflective study that was implemented near the end of the project. The practical activities and efforts that engendered these principles are discussed, as are challenges that were experienced by the team. Principles that were identified as particularly important include:

- Respect and trust: Listening to one another and supporting emotional connections.
- Bigger picture (systems) thinking: Acknowledging that climate risks result from multiple interconnected drivers, and that different groups of people hold knowledge about these drivers.
- Treating in context: context-driven climate research (i.e. context-led approach to exploring problems and thinking about solutions).
- The social element: including activities and events that support socialising, bonding, connecting as people and having fun.
- Catalysing (African) agency: Africa-owned solutions, based on local research and capacity.
- Neutral space and enabling process: a well-designed programme with objectives, boundaries and a carefully managed process at all scales (project scale, city scale, cluster scale).
- Process-driven iteration: some explicit overarching goals were set, but methods and outcomes were generated through iterative processes.
- Transdisciplinarity and (un)comfortable differences: a transdisciplinary approach that is welcoming of complexity, integrates different types of evidence, encourages open-mindedness and is comfortable with differences in ideas, values, inputs and processes.
- Inclusivity and collaboration: a genuine acknowledgement of the importance of different stakeholders, an appreciation of all input (voice equity).

- Linking the current with the past and the future: constructively reflecting on past experiences and current trends for learning, adapting and future visioning. Ongoing learning and reflection was also important within the FRACTAL team and processes.
- Networks and relationships: building networks and relationships across organisations and knowledge domains.
- Embedding researchers: pronounced role of Embedded Researchers (ERs).

Many of the FRACTAL principles are similar to those that are documented in the literature more generally. However, several conceptual and practical developments associated with principles were gleaned by reflecting on FRACTAL experiences. The following are deemed particularly important:

- engaging emotions of transdisciplinary participants and enabling personal relationships across stakeholders;
- presenting scientific information (e.g. forecasts and/or projections) in a "humble" way (i.e. not centring climate information);
- engaging in context-led (not context-informed) research through immersive transdisciplinary learning processes;
- directing specific effort and resources towards enabling participants to have fun and to socialise;
- facilitating active learning processes that support agentive action amongst participants of transdisciplinary processes;
- facilitating a "third space", in which participants can engage as equals and critically reflect on their practices in "home spaces";
- "trusting the process" (i.e. encouraging iterativity);
- acknowledging that often, there is no single right answer in such complex social and decision contexts;
- using topical, contemporary development issues to help a variety of participants to meaningfully interrogate climate risks in the future;
- introducing a pathways framing to link current decisions with the past and future;
- emphasising the importance of learning networks across regions; and
- embedding researchers in decision-making contexts as pivotal transdisciplinary researchers and knowledge brokers.

The paper ends with a reflection on the application of principles in virtual engagements during the COVID-19 pandemic (2020/2021). During this time, the FRACTAL team built on much of the social capital that was established in face-to-face engagements prior to the pandemic. Several principles were strengthened through virtual methods e.g. such engagements allowed a diversity of stakeholders to take part in transdisciplinary learning processes, which supported 'inclusivity and collaboration' and 'networks and relationships'. These engagements did, however, introduce challenges for engendering some principles, particularly when participants battled to secure connectivity to support effective online engagement. In these instances, FRACTAL attempted to support engagement by purchasing technical equipment and data bundles. Another challenge associated with virtual and/or hybrid engagements related to challenges for facilitators and participants alike to notice body language and subtle facial expressions of other participants, which are important in relational learning processes.

While people across the globe increasingly strive for effective and meaningful co-production of climate services, there is also a growing acknowledgement that there is no single 'recipe for success' to enable this way of working. A set of guiding principles provides a more flexible and adaptable approach for guiding co-production. It is the hope of the FRACTAL team that these principles will be applied and tested in follow on work to better understand their applicability and universality.

Figure 1. FRACTAL participants engage in a learning lab game

1. Introduction

Co-production is increasingly acknowledged as the preferred mode for producing climate services. There is a growing body of knowledge related to 'principles' that enable effective co-production of climate services between different types of stakeholders. We aim to contribute to this body of knowledge with practical insights of co-producing climate services by reflecting on and sharing experiences from the Future Resilience of African CiTies and Lands (FRACTAL) project.

FRACTAL was implemented from 2015-2021 in nine southern African cities as part of the Future Climate For Africa (FCFA) programme, with the main aim of co-producing climate knowledge that could inform climate-resilient urban development. Through transdisciplinary learning processes, which were anchored by "learning labs", societal stakeholders worked with researchers from various disciplines to co-explore decision contexts, identify knowledge and capacity needs, and co-design activities to respond to these (see Koelle et al. forthcoming). Learning labs provided an opportunity for stakeholders to convene and constructively engage with complex issues and their contexts in each city, and to consider appropriate actions or responses. Embedded Researchers were also deployed as transdisciplinary intermediaries throughout the project, contracted by local universities in five of the FRACTAL cities and spanning the science-society space by spending time at the municipality/government department (see Taylor et al., 2021).

Through FRACTAL, more than 80 institutions across nine countries engaged in transdisciplinary learning processes, which resulted in notable contributions to climate services in cities. For example, learning labs culminated in the co-development of policy briefs in Lusaka, and FRACTAL was mentioned as a supporting partner in the updated Strategic Plan for Lusaka (2017-2021), which includes climate considerations. In Windhoek, the learning lab process supported the development of the Windhoek Integrated Climate Change Strategy and Action Plan (ICCSAP). FRACTAL engagements advanced solutions to cholera and malaria outbreaks in Maputo. Transdisciplinary engagements in Blantyre, Harare and Gaborone supported mainstreaming of climate considerations into ongoing planning processes.

Building on the growing body of relevant knowledge related to principles for co-producing climate services, the aim of this paper is to offer practical insights based on FRACTAL experiences. These practical insights were gleaned near the end of the project by collaboratively identifying (with the team) principles 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.

2. Why and in what contexts should we co-produce climate services?

Sustainable, climate-resilient and equitable development must consider climate variability and change (Taylor et al., 2021). Usable climate information is necessary to guide climate resilient development, along with mechanisms and capabilities to integrate this information into planning, investments and decisions (Taylor et al., 2021; Vincent et al., 2018). Climate services includes the multitude of processes (including research and decision processes), information and stakeholders who engage in producing climate information (including scientific, traditional, experiential etc.), and in integrating this information into decision-making. Hewitt and Stone (2021) describe the "complex climate service landscape" (pg. 1), which includes the processes, information and stakeholders contributing towards climate services in various contexts.

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 being considered, as well as the broader social and cultural environment in which the climate services process is situated. Several different 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.

There is growing emphasis on co-producing climate services, particularly to "move from dominant supply-driven modes of science" to approaches that foster partnerships and mutual learning between stakeholders (Vincent et al., 2018, pg. 50). This approach is particularly important when stakeholders have limited understanding of the ways in which climate variability and change might influence lives and livelihoods, and limited capacities to access and use different types of climate information, and when researchers have limited understanding of the complex decisions that are being made (Taylor et al., 2021). For example, co-production processes that involve multiple stakeholders (and different types of evidence) are important to understand how climate risks might manifest across diverse landscapes of rapidly growing African cities, and how to foster resilient development to reduce the likelihood and/or impacts of such risks (Taylor et al., 2021).

FRACTAL aimed to facilitate exchange of existing knowledge and co-produce new knowledge that could contribute to climate services in nine southern African cities through learning processes that were founded on transdisciplinarity. This transdisciplinary framing introduced new emphases in climate services processes including *inter alia* rooting climate research in real-life problems, integrating scientific knowledge alongside other types of knowledge, and supporting decisions associated with "policy-making, administration, business and community life" (Polk 2015, pg. 111).

3. What does the literature say about principles for co-producing climate services?

Several studies have shone light on the principles that contribute to the effective co-production of climate services. A synthesis of these studies is presented below, identifying key processes, mechanisms, approaches and considerations. Studies that focus on strengthening climate services more generally (i.e. not co-produced services) were not included in the review. The synthesis of principles is presented according to three interlinked themes that emerged through the review of literature, namely principles associated with capacities of stakeholders, process design and environmental factors. Annex A includes a table of the full list of principles that were gleaned from the literature.

3.1 Capacities of stakeholders

Wall et al. (2017) review social science literature with a view to highlighting factors that influence the co-production of climate services. Findings from this review point to the importance of material, cognitive, social and normative capacities of scientists and societal stakeholders to engage in co-production processes (Van Kerkhoff and Lebel, 2015; Wyborn, 2015; Schuttenberg and Guth, 2015). Material capacities include the finances and spaces (i.e. physical locations) that are required for supporting co-production processes. Steynor et al. (2020) also note the departure of co-production processes from more traditional modes of science-society engagement for climate services and argue that greater time and resource investments are required to support this type of work.

Relational capacities and efforts also play a key role in effective co-production of climate services. Such capacities and efforts include effective leadership, mutual respect and effective communication that enables two-way communication between participants, building trust and investing in longer-term relationships (Singletary and Sterle, 2020; Brugger et al. 2016; Kirchhoff et al. 2013; Golding et al., 2019; Wall et al., 2017; Carter et al., 2020; Daniels et al., 2020; Steynor et al., 2020). The collaborative nature of co-production processes requires empathy from all participants to understand and respect the perspectives of others (Vincent et al., 2018). Wall et al. (2017) emphasise the importance of accountability on the part of researchers, particularly for scientific outputs that are produced and shared during co-production processes. Vincent et al. (2020b) suggest that developing aptitude of participants for reflexivity is important, so that everyone can interrogate assumptions (including their own) on what constitutes knowledge and knowledge generation processes.

3.2 Process design

Bremer et al. (2019) highlight the increasing emphasis on procedural theories for "better understanding and practicing the complex transformative process to climate services at the science-society interface" (pg. 44). This emphasis views co-production of climate services as an iterative interaction or process that unfolds over time. In line with this, Daniels et al. (2020) advocate for moving towards a "process-centric" approach to transdisciplinary collaboration of climate services to support "complex, real-world

decision-making". Several studies note the importance of conscious facilitation and learning objectives and processes in co-production of climate services (Carter et al., 2020; Daniels et al., 2020)

Linked to environmental principles, some studies emphasise the need for co-production of climate services to be driven by context or decision needs (i.e. defined by user needs), and/or that information should be tailored to decision contexts (Carter et al., 2020; Vincent et al., 2018, Daniels et al., 2020). Several studies highlight the importance of inclusivity of such processes, both in terms of participants and the type of knowledge that are represented (Vincent et al., 2018; Carter et al., 2020). Diversity across participants should therefore be embraced, and differences respected (Carter et al., 2020). Hewitt et al. (2021a) report on a series of creative approaches within the Climateurope network that enabled better equality, diversity and inclusivity when considering climate-related issues and potential responses in Europe, such as art, music and photography. Vincent et al. (2018) and Carter et al. (2020) argue that the value of participating in climate services co-production processes should be clear to stakeholders. In some cases, stakeholders might need to be strategically engaged (e.g. senior decision makers) (Daniels et al., 2020). 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.

Daniels et al. (2020) emphasise the importance of identifying solutions, recommendations and ways forward while co-producing climate services. This might involve identifying and responding to training and capacity needs (Daniels et al., 2020). Climate services outputs that support decision processes should be timely (i.e. available for key decisions) and, where relevant, scientific climate data should be co-explored to distil relevant information for climate services (Vincent et al., 2018; Carter et al., 2020; Jack et al., 2020). Climate scientists should also work towards improving transparency in the communication of forecast accuracy, uncertainty and quality (Carter et al., 2020). While learning objectives should be set near the beginning of co-producing climate services, processes should be iterative and flexible (Carter et al., 2020). The idea of "iterativity" was proposed as early as 2005 by Lemos and Morehouse and is supported by Vincent et al. (2018) and Vincent et al. (2020b).

Vincent et al. (2020b), Golding et al. (2019) and Hewitt and Stone (2021) shine a light on the importance of monitoring and evaluating co-produced climate services. These authors emphasise the importance of inclusive and participatory monitoring and evaluation that considers multiple perspectives when exploring the value added by co-produced climate services. Drawing on the "lenses" of co-production in climate change research presented by Bremer and Meisch (2017), Bremer et al. (2019) present eight criteria for evaluating good or successful co-production of climate services, namely: i) the diagnosis role of rebuilding representations of climate, and the social orders for living within this climate; ii) exposing and critically challenging dominant social forces steering climate services; iii) usability of climate information products; iv) social robustness, accountability, and legitimacy of climate information in the face of

uncertainty; v) supporting efficient and effective provision of public services; vi) building adaptive capacity; vii) creation of setting for learning to learn; and viii) empowerment of marginalised groups.

Vincent et al. (2020c) draw attention to the need to address power imbalances in 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. The authors recommend that all partners involved in co-production of climate services should commit to identifying and addressing potential causes of inequality, and should be aware of ways in which their norms can influence co-production. This requires dedicated time for unpacking expectations, allowing for co-constructed priorities, as well as various incentives and ways of working across participants. The authors suggest identifying indicators or measures of success, capitalising on existing participatory tools and promoting adaptive management.

3.3 Institutional, policy and social environmental factors

Several studies emphasise the environmental influences on co-producing climate services, as well as the integration of services and outputs in decision contexts. Daniels et al. (2020) and Steynor et al. (2016) suggest that an important aspect of co-producing climate services is co-exploring and understanding the environmental, social and decision context in which climate services are co-produced. In their perspective piece, Vincent et al. (2020a) argue that a stronger focus on these environmental factors can support better integration of climate knowledge and information into planning. Enabling environmental factors, which might be influenced during co-production processes, include supportive institutions, appropriate policy frameworks, as well as capacity and agency of individuals to make decisions. Similarly, Singletary and Sterle (2020) emphasise the importance of considering institutional cultures and values, power asymmetries and legal agreements that are involved in co-production processes. These authors suggest that experienced boundary organisations or intermediaries can facilitate successful co-production of climate information. This suggestion is supported by Steynor et al. (2020) who report on lessons learned from implementing an "embedded researcher" approach in Cape Town, South Africa.

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.

4. Study approach

Reflective approaches were employed to identify project-specific principles that supported co-production of climate services during FRACTAL. The vast amount of evidence that was produced during the project was also analysed using qualitative methods to better understand the practical dimensions of engendering these principles, and to position these principles alongside the growing body of relevant knowledge, which is summarised above.

Near the end of the first phase of FRACTAL, a subset of the FRACTAL team formed a learning group with the main aim of reviewing major lessons learned from the project. This learning group facilitated a collaborative reflection with the broader FRACTAL team to identify a set of principles that were considered important for the success of FRACTAL. The reflection was initiated by convening an open webinar (i.e. all FRACTAL participants across cities were invited to attend) to identify principles that underpinned the FRACTAL work. The learning group processed this output to distil 13 principles, which were then shared with the broader FRACTAL team again for a second round of feedback. This feedback was incorporated to define a final set of FRACTAL principles, and a framework for understanding how these principles were engendered (Table 1).

Table 1. Framework for surfacing evidence relevant to FRACTAL principles

#	Node (preliminary)	Principle	How was this engendered?	Examples	Extra notes	Enablers	Barriers
1	EQ	Meeting emotional needs, support and connection (emotional intelligence?) across the team	Emotions and feelings were included in many learning activities...	Lusaka Learning Lab 2: activity focused on understanding how people were in the morning...	This links closely with principle on open-mindedness...		
2	Respect	Having adult, respectful conversations (not overly critical or overly emotional)					

Various documents that were generated during FRACTAL were collated to create a database of content for qualitative analysis. This included the contents of the following documents: briefing notes (n = 5), reports from dialogues (n = 3), a training report (n = 1), a technical brief (n = 1), a think piece (n = 1), FRACTAL impact stories (n = 10), journal articles produced (with a process/learning focus) (n = 2), learning lab reports (n = 10), project meeting reports (n = 3), a concept note (n = 1), an exercise explainer (n = 1), working papers (n = 5) and workshop reports (n = 16). Two team members from the learning group coded and analysed the content using the principles as initial themes, while sub-themes and linkages between themes emerged through iterative engagement with the coded content, raw data and weekly discussions between these two members.

After the initial coding and analysis, three knowledge products were developed to share initial findings. These knowledge products included: i) an excel table with information

about each principle (description, how this was engendered, examples, relations with other principles, challenges); ii) a prezi; and iii) a 6-minute animaker video. The broader team was provided an opportunity to provide feedback after reviewing these knowledge products during an open team webinar. The feedback shared during this webinar prompted further coding and analysis of transcribed interviews with FRACTAL researchers (n = 21) and societal stakeholders involved in learning labs (n = 18) using the same qualitative methods described above.

5. Findings from the study

The findings from the study are presented according to four sections below. The first section (5.1.) provides an overview of the FRACTAL principles, which is followed by a reflection of how these principles relate to the growing body of knowledge on principles for co-producing climate services (5.2). This section also provides suggestions for the conceptual and practical developments proposed by FRACTAL based on results from the qualitative analysis. Section 5.3 provides more insight into the practical dimensions of the principles by reflecting on several core principles that provided a foundation for many others, as well as pinpointing several activities that enabled many of the principles.

5.1 FRACTAL principles

The FRACTAL principles are presented in the table below.

Table 2. FRACTAL principles

Principle	How was this engendered? (practically)	Example/quote	Challenges
Respect and trust: Listening to one another and supporting emotional connections	• FRACTAL was founded on transdisciplinarity, which facilitates an openness to framing issues in various ways that make sense to different people. • The transdisciplinary learning process allowed people to express emotions and feelings. • A focus on "burning issues" helped participants (including researchers) to find common ground. • Activities fostered dialogue between participants, and helped everyone understand different perspectives (e.g. role play). • There was transparency amongst participants, with regards to intentions, what was possible, and what could (or couldn't) be achieved (e.g. exploring the accuracy vs. precision of climate change information) • Activities focused on establishing or strengthening "person-to-person" relationships.	Windhoek participant: " That lady from [research institution], she was always trying to understand what you had to say and giving you opportunities to explain. In fact, the whole family of FRACTAL… they didn't come in as experts even though they are experts. They came in with that; I want to learn from you as well." Lusaka participant: "Standing in a circle and stating what you think but it wasn't from a planning document of what you think and know; more what has been your experience".	• A novel way of working for many people, requiring new relational/people-centred expertise.
Bigger picture (systems) thinking: Acknowledging that climate risks result from multiple interconnected drivers, and that different groups of people hold knowledge about these drivers.	• Humble presentation of climate information connected to a wider picture (e.g. co-developing Climate Risk Narratives) • Exercises were designed to exchange knowledge on the local context, baseline challenges, city goals and decision-making processes. • A variety of stakeholders were included to help build the bigger picture. Co-production processes were designed so that all participants could see their value in building this bigger picture. • Governance research and stakeholder mapping exercises helped to understand and situate stakeholders within the bigger picture, and how they connected to one another. • Meeting face-to-face helped to "join up the dots" across the system (i.e. bring different experiences and perspectives together). • Embedded researchers helped to bridge many divides and paint the bigger picture of cities.	Lusaka participant: "I do see some knowledge being produced, especially in terms of system and how cities work. I am seeing information that was not previously being documented, going beyond the formal structures and systems we know like those represented by organograms etc. And the analysis of this knowledge and information coming out of these engagements is now trying to understand how climate information can be infused into these unknown processes in the city. So, I think new knowledge is being produced, across the cities."	• Requires extra effort from all participants to learn new paradigms, terminology, perspectives etc. In the case of climate scientists, extra effort was required to understand the added value of climate (change) information in this bigger picture. • Simplifying climate information in ways that are meaningful to decision makers and can inform effective decision making, but that also integrate the complexity of the bigger picture, can be challenging.

Principle	How was this engendered? (practically)	Example/quote	Challenges
Treating in context: Context-driven climate research (i.e. context-led approach to exploring problems and thinking about solutions).	• FRACTAL embraced a context-led approach to exploring problems and thinking about solutions. The climate research paradigm shifted from the convention of centring work on scientific data and information to centring on contextual issues and diverse stakeholder needs and concerns. • Immersive, multi-day, multi-stakeholder learning labs to "fast track" an understanding of context. • Participants in different cities engaged on their own "burning issues" and co-production processes. For example, the City of Windhoek explored water security in the city and ultimately produced the Integrated Climate Change Strategy and Action Plan (ICCSAP). In Lusaka, FRACTAL engagements contributed to the development of the Lusaka Water Supply Action and Investment Plan (WSAIP). In Maputo, cross-sectoral dialogue fostered through FRACTAL supported the development of an early warning tool for climate-induced vector- and water-borne diseases. • Field trips helped to build an understanding of various aspects of the city system (e.g. visit to Iolanda treatment plant, Shaft 5 borehole and Kafue Gorge hydro power station in Lusaka, and site visits to Namibia Energy Institute, UJAMS Waste Water Plant and Windhoek Reclamation Plant, and the water supply dam for Maputo) • "Holding back" on the climate science; not leading engagements with presentation of climate science and information but rather introducing later in the process, informed by contextual understanding	FRACTAL climate scientist: "With regards to how we contribute to the debate around climate science in the non-climate science spaces, that's a very strong achievement that we did not superimpose – it was held in the back of our minds."	• The uncertainty of context-led processes was sometimes challenging to manage. The context-led learning process was also "messy" and "getting somewhere" took time. Real-world decisions are not as neat as theorised. • Climate scientists had to wait while city-specific needs were co-discovered, which took a long time (months to years over several engagements). • It was challenging for team members not involved in the learning labs to fully grasp the momentum of the project.
The social element: Including activities and events that support socialising, bonding, connecting as people and having fun.	• Social events were included to encourage bonding between participants (e.g. breakfasts in Maputo, Windhoek and Lusaka, dinner in Lusaka, a social evening in Maputo, and a cheese and wine event in Lusaka). • Participants often stayed in the same place during learning labs (e.g. overnight at a lodge outside the city). • As participants became closer, opportunities were created for learning in less formal ways, which helped	Lusaka researcher: "Those times when we agreed that in the evening, there would be informal chats based on FRACTAL work, like when I went to [climate scientist] to discuss climate and climate research. I asked him many questions and he provided lots of information that complemented what happened in the labs. Because when I'm having a beer and asking him	• The language barrier, particularly in Maputo, sometimes introduced challenges.

Principle	How was this engendered? (practically)	Example/quote	Challenges
	people feel more confident to ask questions and sparked different modes of thinking (e.g. "fireside chats"). • Processes, facilitators and participants welcomed humour and fun during learning processes. Fun activities were facilitated so that they didn't feel undermined (e.g. co-exploring terminologies in Lusaka, talk show simulations across cities, and drama skits of the Climate Risk Narratives). • The project budget enabled social evenings.	to explain his work, it's much easier to learn. I don't have an expectation that I must learn yet I learn quite a lot. I think this is also because we're taking one step closer to one another." Windhoek participant: "It really felt like playing rather than working, but not in an offensive way. I think that contributed to people being open and sharing."	
Catalysing (African) agency: Africa-owned solutions, based on local research and capacity.	• Flexibility, iteration and emergence allowed for contextual needs to emerge (i.e. not imposed from visiting development aid/researchers or funders). • An effort was made to support existing and emerging climate 'champions' (e.g. taking different ideas forward in their own work). • FRACTAL aimed to support institutionalisation of climate considerations into planning processes. • Focal points from the local municipality/government organisation and research institutions were core FRACTAL team members. Ideally, a local research institution would lead a climate research project. • Embedded researchers helped to identify context-specific opportunities. • FRACTAL responded to local capacity development needs (e.g. councillors training in Lusaka, transformational climate leadership training in Windhoek). • Budget was ring-fenced to enable city stakeholders to design and implement city-specific research. • Budget was ring-fenced for city-to-city learning activities, which often showcased local (African) solutions.	Windhoek participant: "It has been institutionalised somehow through the municipality. It should be institutionalised in every municipality where you [FRACTAL] worked so that when we have new political leadership, climate change remains on the agenda."	• Significant decision-making power regarding climate change is mandated at national level in many African countries, making it difficult for local representatives (i.e. city authority) to lead context-specific responses. • Political changes and financial constraints within cities sometimes limited solution options. • Working against the history of development aid projects that drive agendas or aim to 'replicate'. • Frequent staff turnover.
Neutral space and enabling process: A well-designed programme with objectives, boundaries and a carefully managed process at all scales (project scale, city scale, cluster scale).	• Ongoing, adaptive planning and reflexivity at the project level (e.g. reflections after every event, at annual meetings etc.). • Extensive planning to secure an appropriate physical space for learning labs, support participants attendance, set up the daily programmes, integrate past feedback, and collate objectives and expectations amongst	FRACTAL researcher: "I think it's the really safe environment that I enjoy. It's different to being at a big science conference where I feel like I can't speak. Feeling like everyone's knowledge is valued and how everyone is working together. I don't think I knew about the ethic beforehand; it	• Managing power dynamics and maintaining voice equity, receptivity and cohesion can be challenging. • Regulating time for the programme, and for specific activities.

Principle	How was this engendered? (practically)	Example/quote	Challenges
	participants. Embedded researchers played a core role in these efforts in the cities. • Application of the concept of the "third" space (i.e. neutral space outside of participants "home" spaces). These were safe spaces, in which people could challenge ideas/inefficiencies without being reprimanded. Dialogue was key in these spaces and facilitators worked within the bounds of cultural appropriateness. • Flexibility while maintaining a core agenda of producing robust and useful knowledge for informing effective decision making. • Allowing all participants to contribute to what are often exclusionary conversations (e.g. the process of producing climate science). • Conscious and sensitive facilitators, and "mucking in" of the whole team to facilitate various activities. Local participants were also invited to facilitate exercises or dialogues.	was experienced while I was there. You can't really appreciate it until you've been there."	
Process-driven iteration: Some explicit overarching goals were set, but methods and outcomes were generated through iterative processes.	• Transdisciplinary learning processes were able to absorb changes and spontaneity (to respond to contextual needs), recognising the need for ongoing adaptation, and being open to iteration. • Funders supported/allowed an iterative process (i.e. not defining outputs upfront).	FRACTAL researcher: "The mantra that we started early in the process to 'have faith in the process' - that really works. The process of course involves all the people; it involves the thinking we do in advance etc. That's just been quite inspirational." Windhoek participant: "The City of Windhoek was very flexible to the process and the FRACTAL team did not impose anything but allowed the process to shape itself which supported a different approach to policy development"	• "Process memory" is jeopardised by staff turnover. • Process uncertainty can be challenging for participants. • Even though the process was iterative, which allowed for co-developed content, the agenda could have been more thoroughly co-designed with a broader group of stakeholders in cities. • With outputs not defined at the beginning, it's hard for participants to understand the value of taking part in learning processes.
Transdisciplinarity and (un)comfortable differences: A transdisciplinary approach that is welcoming of complexity, integrates different types of evidence, encourages open-mindedness and is comfortable	• The transdisciplinary co-production ethic of FRACTAL was stipulated as early as proposal development, and in agreements between partners. • Many different types of knowledge/evidence were explicitly integrated into the co-production and learning processes, including scientific knowledge (e.g. scientific	Lusaka researcher: "That's extremely important in transdisciplinary research because one is able to move beyond their field and be able to speak the language of the other, which is crucially important if we're really going to say something is really co-explored, co-produced etc. I found that	• Managing different perspectives and values on contentious matters can be challenging. • It takes time to build enough trust and understanding across various knowledge boundaries.

Principle	How was this engendered? (practically)	Example/quote	Challenges
with differences in ideas, values, inputs and processes.	climate information and social science research), local knowledge, experiences and perceptions. • Creative methods were employed to investigate problems and potential solutions from different, sometimes contradictory, perspectives. • Humility of researchers, particularly climate scientists, and acknowledgement that there is no "right answer" in contexts of such complexity. The concept of distillation contributed to this ethic, as did the process of co-developing Climate Risk Narratives. • Explicit working with a post-normal science framing. • Exploring contradictions between evidence-based science and complex social dynamics. • Finding common language and terminology. • Embedded researchers created a bridge between science and society. • Emergent project governance (e.g. transdisciplinary city task teams and working clusters). Most of the task team and working cluster meetings were open for anyone in the team to join, which helped connections across research themes and city learning processes. • Sensitive facilitation to allow for moments of discomfort and tensions.	significantly important as a learning point in the climate work."	• Managing different expectations, particularly theoretical and practical. • Transdisciplinary experiences are often hard to document and explain to others. • It is sometimes challenging to understand how different experiences and knowledge types fit together to understand a problem or work towards a solution. • Requires face-to-face time to understand one another and build connections. • Transdisciplinary work is usually expected to happen "over and above" other work (e.g. mandated government activities and disciplinary research). • Discomfort and exhaustion associated with working in a transdisciplinary way. • Academic and government institutions are not conducive to facilitating transdisciplinary work due to their structure and often discrete mandates.
Inclusivity and collaboration: A genuine acknowledgement of the importance of different stakeholders, an appreciation of all input (voice equity).	• Explicitly valuing a diversity of stakeholders. • Attempting to re-distribute power across various knowledge holders e.g. employing diverse methods for different voices and perspectives to emerge. • Grounding conversations in real world relevance (case studies and burning issues) with which the variety of participants could engage. • Creating various platforms for people to come together, and to engage in different ways.	FRACTAL researcher: "The other one was around the repetitive personal interactions and metaphorically seeing the gears shift in people's minds when they felt they were being heard and their contribution was valued. Barriers and boundaries were broken down quite a bit; people felt like they were in the room because their opinion mattered. I thought that was very valuable."	• It was challenging to facilitate genuine collaboration across languages (particularly experienced in Maputo). • There could have been stronger representation of people from peri-urban areas and informal settlements. • Loud people/voices still dominated some parts of the process.

Principle	How was this engendered? (practically)	Example/quote	Challenges
	• Demonstrating the value of collaboration: people realised the importance of understanding other perspectives, mandates, information etc., for achieving their own mandate.		• The diversity of stakeholders, which changed over time, introduced challenges for maintaining momentum – new people had to be "brought up to speed".
Linking the current with the past and the future: Constructively reflecting on past experiences and current trends for learning, adapting and future visioning. Ongoing learning and reflection was also important within the FRACTAL team and processes.	• Acknowledging the contribution of history to current context (i.e. challenges) and locating the learning processes in current issues while planning for the future. This allowed participants to connect with the climate change challenge in a way that was meaningful to them. • Visioning and backwards mapping exercises. • Connecting to planning processes in cities. • Creating a culture of reflective enquiry with processes of learning was a preceding and important element for inclusive and extensive problem solving.	Lusaka participant: "They were very involving; you would act out things, you would do posters, creating your future of your city."	• It was challenging to adequately embrace future uncertainties. For example, knowing which stakeholder groups might substantially influence future development. • It was also sometimes challenging to understand how the current and future connect, and how to engage effectively with the potential trajectory (negative, positive, minor, major changes?) • It was easier to think about general climate change risks than to investigate the nuanced impacts of climate change for future planning of cities.
Networks and relationships: Building networks and relationships across organisations and knowledge domains.	• Collaborative transdisciplinary learning processes that aimed to co-produce knowledge allowed a variety of participants to work together on a common problem. • City-to-city learning processes contributed to creating a learning community. While FRACTAL was context-driven, there were transferable themes and many learning opportunities across cities. Budget was explicitly allocated for city exchanges. For example, Lusaka and Windhoek delegates visited Maputo, Durban and Gaborone delegates visited Windhoek, and an exchange took place between Harare and Lusaka. These activities manifested in a final event (the Urban Caucus in Lusaka), which brought a variety of stakeholders together across FRACTAL cities.	Lusaka participant "informal interactions have been created [through FRACTAL]; people feel comfortable to now pick up the phone to get information from someone else; the large bureaucratic barriers have been overcome". Windhoek participant: "I worked a lot with [participant X] so for me and her… for sure we all did water and she is an engineer, I am a scientist. I think it was a good environment that was created between me and her. And that's why the last part – the two-pager, we had to come together, we teamed up and she came here, and I was writing while she's talking and we talk, then we send one integrated document."	• It was challenging for team members who did not participate in learning labs (i.e. to meet others face-to-face) to form similar relationships and become part of the networks.

Principle	How was this engendered? (practically)	Example/quote	Challenges
	• Learning processes included shared experiences (e.g. site visits) and activities that helped people to "walk in each other's shoes". • Embedded researchers played a key role in facilitating and sustaining relationships across stakeholder groups.		
Embedding researchers: Pronounced role of Embedded Researchers (ERs)	• Embedded researchers (ERs) played a critical role at the intersection of research, decision making and project management in cities. Six ERs were contracted within FRACTAL, who operated within an important trilateral partnership between the local university, city governments, and the FRACTAL project lead partner. • ERs were strongly supported by a dedicated ER coordinator who created a space for connecting and reflecting. ERs were also supported by PIs in the city and municipal representatives. • The dedicated physical spaces made available for ERs at research institutions and government organisations (e.g. desks) were important for ERs to be embedded within these institutions. • Through their placement in local governments, the ERs developed "capacity to undertake collaborative and impactful research on climate-related issues that is guided by and feeds directly into urban policy and practice".	Embedded researcher: "The ER is right at the centre of enabling. You need to make sure you bring together the right kind of people that are going to efficiently input into whatever product you want to have at the end of the process. So, identifying the right people, organising the learning spaces, making sure you are on the right time track, looking for windows of opportunity to do more co-production."	• The ERs experienced unique challenges being hybrids in the decision making and research spaces. Extra time, flexibility and dedication were therefore required by the ERs to navigate the insider-outsider dynamic and create opportunities. • Frequent restructuring and staff turnover within government institutions sometimes posed challenges for the ERs, in terms of building useful relationships. • It was sometimes challenging for the ERs to manage expectations of government and research organisations. Since they officially worked for both, they were allocated responsibilities and tasks in both environments. • Having "one foot in each institution" sometimes limited their full participation in either (e.g. trouble accessing databases)

5.2 Linking FRACTAL principles to the growing body of literature on co-producing climate services

Many of the principles that emerged from the study are similar to those that have been documented in the literature on principles for co-producing climate services, which is synthesised in Section 3. Reflecting on FRACTAL experiences does, however, offer several important conceptual and practical contributions to this body of knowledge (see Table 3 below).

Table 3. Linking findings from the study with the body of knowledge on principles for co-producing climate services

FRACTAL principle	Link with literature	FRACTAL's conceptual contribution
Respect and trust	• Trust should be built among participants (Wall et al., 2017; Vincent et al., 2018; Hewitt et al., 2020; Lemos and Morehouse, 2005; Steynor et al., 2020) • Respect differences between stakeholders and the knowledge that they bring to the process (Carter et al., 2020)	Engaging emotions of transdisciplinary participants and enabling personal relationships across stakeholders.
Bigger picture (systems) thinking		Presenting scientific information (e.g. forecasts and/or projections) in a "humble" way (i.e. not centring climate information).
Treating in context	• Co-explore the context in which climate services are co-produced through bottom-up processes that are framed by the "daily realities" of participants (Daniels et al., 2020; Vogel et al., 2019; Steynor et al., 2016) • Processes should produce tangible outcomes (i.e. information) that is timely and can inform decisions (Wall et al., 2017; Bremer et al., 2019; Vincent et al., 2018; Carter et al., 2020; Carter et al., 2020)	Context-led (not context-informed) through immersive transdisciplinary learning processes. Avoid centring engagements on climate science and climate change information; rather introduce this information once the context has been deeply explored (when and where relevant).
The social element		Directing specific effort and resources towards enabling participants to have fun, prompt active learning, and support socialising to build relationships.
Catalysing (African) agency	• Processes should help to (re)define local understandings of climate and climate action, and help participants find their place within these understandings (Bremer et al., 2019). • Processes should support renegotiation of social and political processes that shape climate services (how they are produced and used) (Bremer et al., 2019). • Consider (and work with) environmental and institutional factors that influence the use of co-produced climate information (e.g. support	Facilitating active learning processes that support agentive action and decision making.

FRACTAL principle	Link with literature	FRACTAL's conceptual contribution
	strong policy frameworks, build adaptive capacity and agency of individuals, strategically engage those with decision making power) (Vincent et al., 2021; Singletary and Sterle, 2020; Daniels et al., 2020; Bremer et al., 2019; Hewitt et al., 2020)	
Neutral space and enabling process	• Co-production spaces should be explicitly included and carefully designed e.g. including learning objectives, unpacking expectations and incentives, and allowing for co-construction of priorities (Wall et al., 2017; Carter et al., 2020; Daniels et al., 2020); Vincent et al., 2020b) • Support conscious facilitation so to encourage and integrate multiple perspectives and knowledges (Carter et al., 2020) • Promote reflexivity across participants to and interrogate assumptions associated with knowledge types and generation. This means that participants should examine their own "practices and perceptions" so that they might engage more productively with those of others (Vincent et al., 2020b; Daly and Dilling, 2019)	Facilitating a "third space", in which participants can engage as equals and critically reflect on their practices in "home spaces".
Process-driven iteration	• Enable flexibility and iteration of the process based on contextual factors and needs (Vincent et al., 2020b; Vincent et al., 2018; Carter et al., 2020; Vincent et al., 2020a; Lemos and Morehouse, 2005)	"Trust the process" (i.e. encouraging iterativity) assuming that it is well designed according to many other principles.
Transdisciplinarity and (un)comfortable differences	• Defined by transdisciplinary collaboration that purposefully seeks to bring about fundamental, long-term benefits (Daniels et al., 2020) • Respect differences between stakeholders and the knowledge that they bring to the process (Carter et al., 2020)	Acknowledging that often, there is no single right answer in such complex social and decision contexts.
Inclusivity and collaboration	• Processes should include of a diversity of relevant participants and knowledge types (Wall et al., 2017; Daniels et al., 2020; Vincent et al., 2018; Carter et al., 2020; Vogel et al., 2019; Hewitt et al., 2021) • Enable learning to learn (social learning) (Bremer et al., 2019) • Work towards remedying inequalities and power asymmetries in cultural contexts and processes of knowledge co-production. Support marginalised	Using topical, contemporary development issues to help a variety of participants to meaningfully interrogate climate risks in the future.

FRACTAL principle	Link with literature	FRACTAL's conceptual contribution
	groups and voices (Vincent et al., 2020c; Bremer et al., 2019)	
Linking the current with the past and the future		Introducing a pathways framing to link current decisions with the past and future.
Networks and relationships	Investment in long-term relationships to underpin effective co-production of climate services (Wall et al., 2017); Vincent et al. 2018)	Emphasising the importance of learning networks across regions.
Embedded researchers	Include boundary organisations/agents/intermediaries (Singletary and Sterle, 2020); Steynor et al., 2020)	Embedding researchers in decision-making contexts as pivotal transdisciplinary researchers and knowledge brokers.

5.3 The practical dimensions of engendering principles

It is in offering practical insights into engendering principles for co-producing climate services that this study adds real weight to the existing body of knowledge. Three principles, and the activities that were implemented to engender these, seem to underpin (or be strongly connected to) many other principles, namely: i) neutral space and enabling process, ii) transdisciplinarity and (un)comfortable differences; and iii) embedded researchers. These connections are explored below.

Neutral space and enabling process: explicit consideration of the learning space, and design of an enabling process for all involved, supported inclusivity and collaboration in FRACTAL. Participants gathered, learned and co-produced knowledge in a "third space", which was more neutral than "home spaces" i.e. spaces in which participants hold some sort of power (i.e. government building, academic institution). The activities that were included in the learning processes enabled participation from different types of stakeholders and encouraged active participation by collectively grappling with issues and brainstorming solutions, thereby supportive agentive action. Many contemporary learning theories acknowledge the importance of facilitating social learning and supporting volitional action to solve complex problems, which are qualitatively different from simpler, more straightforward problems (Illeris, 2018). The learning spaces that were convened during FRACTAL also allowed people to socialise and connect with one another to begin forming the networks and relationships that are important for collective climate action (Ndebele-Murisa et al., 2021). The trajectory of learning processes in FRACTAL cities unfolded as various participants shared their perspectives and contributed evidence, enabling flexibility and iteration with an emphasis on the learning process as equally important as the knowledge outcome (if not more important) (Daniels et al., 2020, Norström et al., 2020).

Transdisciplinarity, (un)comfortable differences: The transdisciplinary framing and welcoming of differences (including uncomfortable differences) provided a foundation for several other principles in FRACTAL. This framing is the reason that spaces were designed to be neutral and enabling, so that processes might be inclusive and collaborative, which helped to develop respectful and trusting learning communities. Transdisciplinarity advocates for building an understanding of the socio-ecological

'system' in which a problem or issue is embedded before considering potential actions or responses to address this problem (Hirsch Hadorn, 2008). Transdisciplinarity in FRACTAL therefore enabled context-driven learning processes, which introduced climate (change) concerns into the 'bigger picture' of city-regions across southern Africa, with deep consideration of place-based dynamics, issues and opportunities. It was this context-driven farming that supported process-driven iteration.

Embedded researchers were key transdisciplinary intermediaries who were specifically engaged to bring research processes closer to the day-to-day realities of city-regions, thereby supporting many of the FRACTAL principles. In particular, by playing a pivotal role in organising and implementing learning processes (including identifying and inviting different participants), these intermediaries supported networks and relationships in cities, and contributed to inclusivity and collaboration. As a result of spending time in context and with relevant actors, they helped to grow a bigger (systems) picture and were also able to both identify and create opportunities to respond to contextual needs, thereby contributing to building agency and ownership of the outcomes.

Based on the table in Section 3.1, several core practical actions contribute to engendering many of the FRACTAL principles, thereby demonstrating good "value for money". These are listed below.

- Adopting a meaningful transdisciplinary approach from the beginning to co-produce climate services and truly value different types of perspectives, norms and knowledge (including academic and non-academic). This included the development of 'task teams' in each city.
- Presenting scientific knowledge in "humble" and accessible ways.
- Carefully selecting and designing dedicated spaces and processes for learning and co-producing knowledge and climate services (e.g. the concept of the "third space" in FRACTAL). Sensitive and experienced facilitators played a key role in these spaces, often engendering many of the principles.
- Including many activities that allow for different types of stakeholders to engage meaningfully and actively in learning processes.
- Focusing conversations/learning processes on issues that matter to participants.
- Designing activities for reflection and adaptive management (including project management). The FRACTAL Monitoring, Evaluation, Reflection and Learning (MERL) framework allowed for ongoing reflection and reflexivity across the team.

6. Application of principles in virtual and/or hybrid engagements

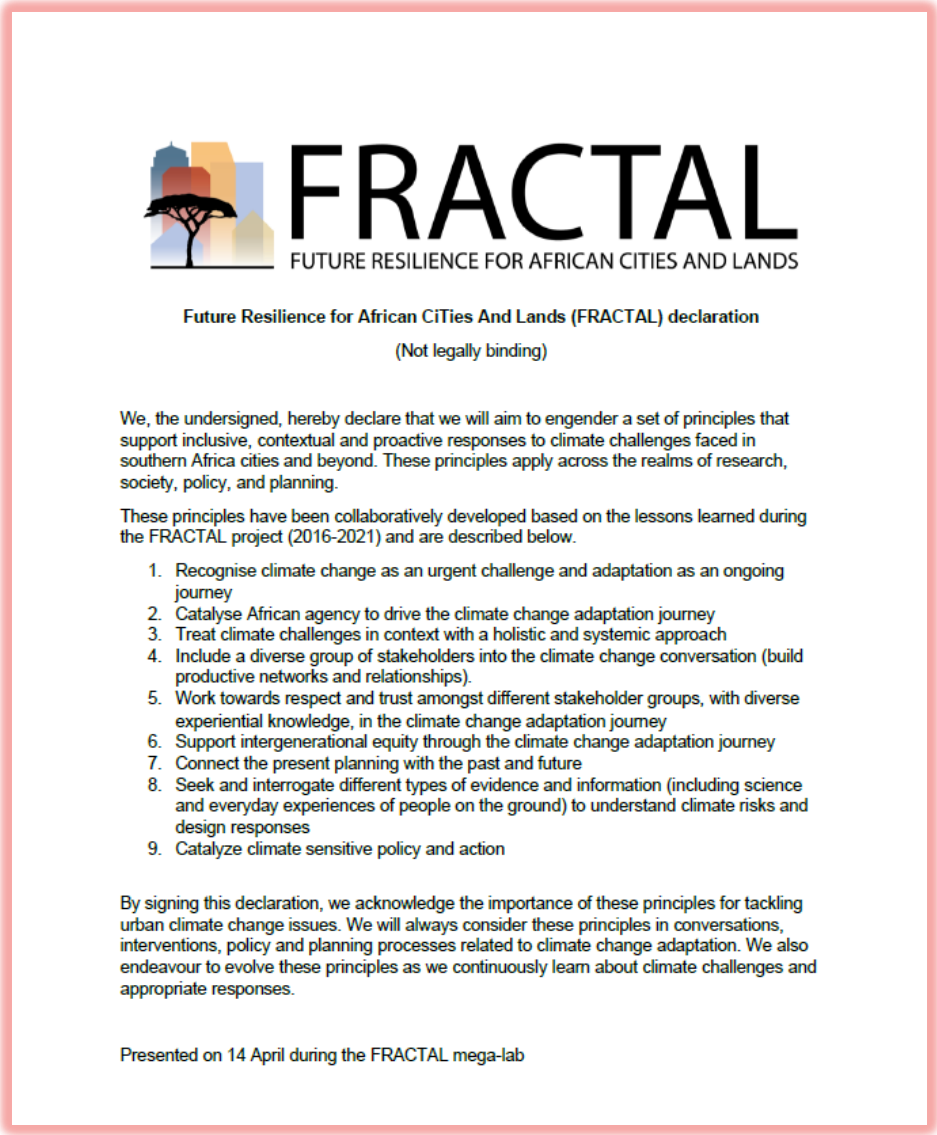
In 2020, the FRACTAL team was forced to explore virtual means of engagement as a result of the COVID-19 pandemic, and international limitations associated with traveling for face-to-face meetings. This last section provides some initial reflections on the importance and relevance of the principles in virtual and hybrid engagements.

The principles continued to be central to FRACTAL engagements in virtual and hybrid engagements, particularly when co-designing these events. The hybrid and online

engagements that were implemented by the FRACTAL team built upon much of the social capital that was established in face-to-face engagements in the first few years of the project, particularly through the 'social element'. Learning networks had been supported in FRACTAL cities, who continued to take part in virtual and hybrid engagements. The engagements were designed to be as 'inclusive and collaborative' as possible, and 'process-driven iteration' (i.e. flexibility of the programme) was supported by adopting additional means of communication (e.g. a WhatsApp group for all facilitators). Virtual engagements allowed for a diversity of stakeholders from various cities to take part in other cities' learning processes, which emphasised principles associated with 'inclusivity and collaboration' and 'networks and relationships. For example, stakeholders from Blantyre, Gaborone and Windhoek participated in a virtual Lusaka learning event.

The final FRACTAL "mega-lab" (April 2021) was implemented as a hybrid event with city-based round table physical meetings of 10-15 stakeholders and virtual engagements using Zoom. While the city-based round tables enabled participants to explore relevant questions in their local context, the virtual sessions allowed the city round tables to connect across regions and share lessons. This large-scale hybrid event culminated in the validation of the "FRACTAL declaration" across city stakeholders. This declaration was based on the FRACTAL principles, which were tweaked to fit the needs of the societal stakeholders across cities who participated in the mega-lab. A copy of this declaration is shown in Figure 2 below . It is difficult to know if the successful dimensions of the online and hybrid engagements were a result of previous face-to-face engagements and the particular skills or characteristics of the project team, but this will be tested in further work.

The virtual and hybrid engagements did, however, introduce challenges for engendering several of the principles. Some team members and stakeholders battled to secure infrastructure and connectivity to support effective online engagement. For example, stakeholders in Zimbabwe often experienced power cuts, which would impact their ability to connect to wifi and often meant that they needed to buy data to participate fully in engagements, some of which were spread over two or three days. The FRACTAL team attempted to support stakeholders by purchasing equipment and data bundles. Another challenge associated with virtual or hybrid engagements related to challenges for facilitators and participants alike to notice body language and subtle facial expressions of other participants, particularly when video was unavailable (this can also link to data or connectivity aspects). Many of the FRACTAL principles seek to strengthen relationships and relational skills across stakeholders, which was more challenging in this type of environment.



FRACTAL

FUTURE RESILIENCE FOR AFRICAN CITIES AND LANDS

Future Resilience for African CiTies And Lands (FRACTAL) declaration

(Not legally binding)

We, the undersigned, hereby declare that we will aim to engender a set of principles that support inclusive, contextual and proactive responses to climate challenges faced in southern Africa cities and beyond. These principles apply across the realms of research, society, policy, and planning.

These principles have been collaboratively developed based on the lessons learned during the FRACTAL project (2016-2021) and are described below.

1. Recognise climate change as an urgent challenge and adaptation as an ongoing journey
2. Catalyse African agency to drive the climate change adaptation journey
3. Treat climate challenges in context with a holistic and systemic approach
4. Include a diverse group of stakeholders into the climate change conversation (build productive networks and relationships).
5. Work towards respect and trust amongst different stakeholder groups, with diverse experiential knowledge, in the climate change adaptation journey
6. Support intergenerational equity through the climate change adaptation journey
7. Connect the present planning with the past and future
8. Seek and interrogate different types of evidence and information (including science and everyday experiences of people on the ground) to understand climate risks and design responses
9. Catalyze climate sensitive policy and action

By signing this declaration, we acknowledge the importance of these principles for tackling urban climate change issues. We will always consider these principles in conversations, interventions, policy and planning processes related to climate change adaptation. We also endeavour to evolve these principles as we continuously learn about climate challenges and appropriate responses.

Presented on 14 April during the FRACTAL mega-lab

Figure 2. Screenshot of FRACTAL declaration

7. Conclusion

While people across the globe increasingly strive for effective and meaningful co-production of climate services, there is also a growing acknowledgement that there is no single 'recipe for success' to enable this way of working. A set of guiding principles provides a more flexible and adaptable approach for guiding co-production. This paper provides insights into principles for co-producing climate services based on FRACTAL evidence and experiences.

The Adaptation Research Alliance (ARA) was established at the end of 2021 as a "global, collaborative effort to increase investment and opportunities for action research to develop/inform effective adaptation solutions"[1]. The ARA has also put forward a set of six principles that align well with those that were important during FRACTAL, through

[1] https://southsouthnorth.org/portfolio_page/adaptation-research-alliance/

which they aim to "instigate a systemic change in the landscape of action research" (ARA principles document). The ARA principles include:

1. Research is needs-driven, solutions-oriented and leads to a positive impact on the lives of those at risk from climate change.
2. Research is transdisciplinary and co-produced with users
3. Research emphasises societal impact.
4. Research builds capacity and empowers actors for the long-term.
5. Research processes address structural inequities that lead to increased vulnerability and reduced adaptive capacity of those at risk.
6. Learning-while-doing enables adaptation action to be evidence-based and increasingly effective

Engendering FRACTAL, ARA or other similar principles requires extra effort and, in many cases, extra resources. However, the value of following this type of guidance has been clearly demonstrated. For example, several notable impacts were associated with FRACTAL transdisciplinary learning processes (see https://www.fractal.org.za/ for more information). In circumstances where it is not possible to implement all of the principles because of resource constraints, consideration and implementation of several principles will likely contribute to more effective co-production of climate services.

It is the hope of the FRACTAL team that these principles will be applied and tested in follow on work to better understand their applicability and universality. Questions stemming from this study include *inter alia*: are these principles universal? Do these principles support co-production of climate services in all contexts and/or cultures? Might some principles be more important for particular stages of the climate service process (e.g. scoping, design, evaluation)?

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Annex A: Summary of principles for co-producing climate services

#	Principle	References
Capacities principles		
1	Promote **reflexivity** across participants to interrogate assumptions associated with knowledge types and generation (including their own).	Vincent et al. (2020b); Daly and Dilling (2019
2	Be sure to invest in/secure **adequate material and time resources**	Wall et al. (2017); Steynor et al. (2020)
3	Be sure there is availability of **adequate cognitive capacities**	Wall et al. (2017)
4	Support/encourage **normative capacities** to work towards a common goal	Wall et al. (2017)
5	Grow/support **relational capacities** that: i) allow for effective two-way communication; ii) support (long-term) relationships, trust and respect; and iii) encourage empathy,	Wall et al. (2017); Vincent et al. (2018); Carter et al. (2020); Lemos and Morehouse (2005); Steynor et al. (2020); Hewitt et al. (2021a)
6	Be sure there are adequate **leadership and management capacities**, including capacity to enable process equity amongst participants (design, governance, finance)	Singletary and Sterle, 2020; Vincent et al. (2020c)
7	Encourage **accountability** of researchers for the outputs/co-produced knowledge.	Wall et al. (2017); Bremer et al. (2019)
Process principles		
1	Enable **flexibility and iteration** of the process based on contextual factors and needs	Vincent et al. (2020b); Vincent et al. (2018); Carter et al. (2020); Vincent et al. (2020c); Lemos and Morehouse (2005)
2	Ensure **process equity** amongst participants (design, governance, finance).	Wall et al. (2017); Vincent et al. (2020c)
3	Explicitly include and **carefully design co-production spaces** e.g. including learning objectives, unpacking expectations and incentives, and allowing for co-construction of priorities	Wall et al. (2017); Carter et al. (2020); Daniels et al. (2020); Vincent et al. (2020c)
4	Support **conscious facilitation** so to encourage and integrate multiple perspectives and knowledges	Carter et al. (2020)
5	**Include diversity** of relevant participants and knowledge types	Wall et al. (2017); Daniels et al. (2020); Vincent et al. (2018); Carter et al. (2020); Vogel et al. (2019); Hewitt et al. (2021)
6	Co-create **local understandings of climate and climate action** to which participants connect	Bremer et al. (2019)
7	**Respect differences** between stakeholders and the knowledge that they bring to the process	Carter et al. (2020)
8	Ensure **value-add for all** involved	Carter et al. (2020)
9	Work towards **tangible and timely outcomes**	Wall et al. (2017); Bremer et al. (2019); Vincent et al.

#	Principle	References
		(2018); Carter et al. (2020); Carter et al. (2020)
10	**Support renegotiation of social and political processes that shape climate services** (how they are produced and used).	Bremer et al. (2019)
11	Co-produce **socially robust and legitimate** knowledge in the face of uncertainty	Bremer et al. (2019); Hewitt et al. (2020); Morehouse and Lemos (2005)
12	Support **efficient and effective provision of public services**	Bremer et al. (2019)
13	Enable **learning to learn** (adaptive and social learning)	Bremer et al. (2019)
14	**Co-explore the environmental and decision context**	Daniels et al. (2020); Steynor et al. (2016)
15	Support **bottom-up processes** that are framed by the "daily realities" of participants	Vogel et al. (2019)
16	Identify **solutions, recommendations and ways forward**	Daniels et al. (2020)
17	**Co-explore and distil relevant information** from data	Daniels et al. (2020)
18	Encourage **long-term sustainability**	Daniels et al. (2020); Carter et al. (2020); Steynor et al. (2020)
19	Work towards **transparency of information** accuracy and certainty	Carter et al. (2020)
20	Include (participatory) **monitoring and evaluation** of process and product impacts	Vincent et al. (2020c); Golding (2019)
21	**Work towards remedying inequalities and power asymmetries** in cultural contexts and processes of knowledge co-production. Support marginalised groups and voices.	Vincent et al. (2020c); Bremer et al. (2019)
22	Include **boundary organisations/intermediaries**	Singletary and Sterle (2020); Steynor et al. (2020)
Environmental principles		
1	**Consider (and work with) environmental and institutional factors** including policy frameworks, adaptive capacities and agency	Vincent et al. (2020a); Singletary and Sterle (2020); Daniels et al. (2020); Bremer et al. (2019); Hewitt et al. (2020)
2	**Strategically engage** those with decision-making power	Daniels et al. (2020)
3	**Consider existing power structures**, as well as social, historical, institutional, and cultural contexts	Daly and Dilling (2019)