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Refocusing the climate services lens: Introducing a framework for co-designing "transdisciplinary knowledge integration processes" to build climate resilience

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ABSTRACT

This paper seeks to reconceptualize climate services in light of the prevailing inability of existing climate information to spur needed policy and action. We propose refocusing the climate services lens by moving away from a narrow, supply-driven emphasis on products. Instead, we advocate moving towards a *process-centric* approach defined by transdisciplinary collaboration that purposefully seeks to bring about fundamental, long-term benefits. Such benefits include increased human and institutional capacity, and the creation of relationships that are essential components of science-informed decision-making for climate adaptation and beyond. Work underpinning this paper consists of a review of existing climate services guidance, and analyses of a survey of climate services stakeholders, and a climate information co-production process case study in Lusaka, Zambia. We identify elements needed to support complex, real-world decision-making that many existing climate services fail to sufficiently consider. We respond by introducing a framework (Tandem), which consists of structured elements and practical, guiding questions informed by empirical analysis. To lay the foundation for both science-informed policy and policy-informed science, the Tandem framework puts forward guidance to achieve three goals: 1) to improve the ways in which all participants *work together* to purposefully design *transdisciplinary knowledge integration processes* (co-exploration and co-production processes that bring together different knowledge types across the science-society interface); 2) to co-explore decision-relevant needs for the co-production of *integrated climate information* (i.e., decision-relevant climate and non-climate information); and, 3) to increase individual and institutional capacities, collaboration, communication and networks that can translate this information into climate-resilient decision-making and action.

Practical implications

Introduction

The prevailing inability of existing climate information to spur needed policy and action warrants a re-examination of climate services provision. A supply-driven, one-directional delivery of climate information from providers (e.g. climatologists, meteorologists) to users (e.g. decision-makers, city planners and extension officers) remains commonplace, with the very terminology of "providers" and "users" underscoring the one-directional information flow. Given the urgency of action needed to adapt to growing climate variability and extremes, facilitating the increased use of *integrated climate information* (decision-relevant climate and non-climate information) is critical for decision-making. Our insights refocus the climate services lens to increase uptake. The approach moves away from a focus on products, outputs and services (e.g. time series plots, risk maps, impact models) crafted by "providers" and presented to "users". It instead emphasizes a transdisciplinary, *process-centric* approach that incorporates knowledge from across science and society. It purposefully seeks to bring about fundamental, long-term benefits (e.g. shared understanding, expanded networks, and new points

Abbreviations: NHMS, National Hydrological and Meteorological Services; LuWSI, Lusaka Water Security Initiative; MEL, Monitoring, Evaluation and Learning; WEAP, Water Evaluation and Planning model; WSAIP, Water Security Action and Investment Plan

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of view) that set the stage for science-informed decision-making.

Tandem: a framework and guiding questions

We introduce a framework, Tandem, [1]which purposefully structures transdisciplinary engagement and collaboration processes, and provides practical guiding questions to inform actors about how to best work together. This framework emerges from analyses of: 1) survey responses from climate services stakeholders, and 2) a three-year climate information co-production process in Lusaka, Zambia. The framework recognizes that the key to collaborative processes is bringing together a wide range of people (e.g., engineers, impact modelers, planners, community representatives, climate scientists and social scientists) who bring together different knowledge from multiple disciplines, decision-making levels and practice. The framework offers practical guidance for these actors to identify integrated climate information needs and to encourage them to *work together* to purposefully design *transdisciplinary knowledge integration processes* (co-exploration and co-production processes using a wide array of knowledge). This collaborative learning approach provides a structure for:

- understanding decision needs;
- guiding actors in designing and delivering an effective transdisciplinary knowledge integration process; and,
- enhancing capacities (both individual and institutional), working relationships and networks necessary for longer-term change and action.

Lusaka case study

To illustrate the elements of the Tandem framework, we summarize them in relation to the process undertaken in Lusaka. This urban case study informed the development of the framework, and spurred further testing and refinement (e.g. Butterfield and Osano, 2020; André et al., 2020), which we hope will continue through additional such efforts in other settings. In Lusaka, we sought to boost the use of climate information in medium- and long-term urban planning[2] by using transdisciplinary co-production and co-exploration processes. Key aspects of the work involved conducting a series of "Learning Labs"[3] with a wide variety of stakeholders, and employing researchers "embedded"[4] in the local policy and planning context. The intentions were fivefold:

- to foster dialogue and collaboration between climate scientists, researchers, urban policymakers and practitioners;
- create an enabling environment for transdisciplinary discussion, research and collaborative learning;
- strengthen working relationships between these different actors;
- develop capacity to incorporate relevant climate information into decision-making processes; and,
- support policy and governance processes based on an increased understanding of the city system and possible future scenarios.

The elements:

Identify and engage stakeholders. Early one-on-one meetings with a range of city stakeholders sought to identify potential partners and "champions" to work closely with and individuals who could bring diverse representation of voices to the process. These actors included the public- and private-sector multi-stakeholder platform, the Lusaka Water Security Initiative (LuWSI), as a champion, and the Zambia Homeless and Poor People's Process Federation as representative of the peri-urban community. Early engagements sought to build relationships, and create safe, innovative learning spaces for open sharing through games, humour, active participation and opportunities for informal networking.

Co-explore issues and context. A discussion of issues participants considered to be most important led them to give highest priority to water insecurity in peri-urban areas, with interconnected sub-themes of 1) declining groundwater levels, 2) groundwater pollution, 3) water supply and sanitation, and 4) increased incidence of flooding. Four transdisciplinary working groups (made up of climate scientists, social science researchers, engineers, city officials and community representatives) identified and mapped each theme's issues and (climate and non-climate) drivers, and explored related governance, decision-making and policies. These groups co-produced policy briefs, which created shared ownership of outputs.

The process included site visits (e.g. to water trusts in peri-urban areas), accounts from other cities (e.g. the water crisis in Cape Town), and interactive games (to co-explore issues, and related language and terminology). To wrestle with complexities and uncertainties of climate projections and societal impacts, participants co-explored different climate and city scenarios. Resulting climate risk narratives[5] emerged as a way to communicate different city futures, and to spur dialogue. A Lusaka-specific Water Evaluation and Planning (WEAP)[6] model used a bottom-up approach to engage participants in co-exploring the current water system, its vulnerabilities and thresholds.

Set focus and learning objectives (to contribute to the monitoring, evaluation and learning process). A culture of learning and reflection was established and carried forward by all participants. As the process developed, ownership shifted from the project team to a shared ownership across participants. This is critical for longer term sustainability. The development of policy briefs, climate risk narratives and the WEAP model served as grounding outputs to focus discussions and provide continuity through the process.

Identify and respond to training or capacity needs. Particular engagements and trainings were requested by participants as needs emerged and as capacities developed. These included a side event for councillors and senior decision-makers and more in-depth climate science training.

Identify solutions and recommendations. Policy brief subgroups mapped potential solutions for each theme, identified interactions and connections, and responsible actors for each action. Cross-city exchanges and inspiring cases from other cities seeded ideas for local solutions. Participants identified: key institutions with relevant mandates and activities, and "windows of opportunity" to build on emerging plans, and existing and prospective tools, including a new Water Security Action and Investment Plan (WSAIP) and a climate-risk screening tool under development.

Co-explore information needs and distil relevant information. Facilitators integrated sessions co-exploring climate messages that had been distilled from data, together with other (non-climate) information, and variables and thresholds in the WEAP water demand model. Participants examined how changes

[1] Online, interactive guidance (www.weadapt.org/tandem) provides instruction intended to foster easy application of Tandem in a wide variety of contexts. The online guidance aims to spur further testing and refinement, and to provide those who apply the methods an opportunity to share lessons learned.

[2] Part of the Future Resilience for African CiTies And Lands (FRACTAL) project.

[3] Learning Labs are safe spaces (Arrighi et al., 2016), that bring together many different types of actors and knowledge. The labs use experimentation, and experiential and social learning processes (Koelle et al., 2019). The format gives participants the freedom to challenge dominant or business-as-usual approaches, and to innovate new pathways for societal transformation.

[4] "Embedded" researchers work in both the local university and the municipal policy and planning context in the city, to gain better access to, and understanding of, urban actors, networks, decision-making processes, and climate information entry points.

[5] These are plausible, relevant stories that aim to envision a future climate scenario and likely associated impacts.

[6] WEAP (www.weap21.org) is a software tool for *integrated* water resources planning that provides a comprehensive, flexible and user-friendly framework for planning and policy analysis.

potentially impacted vulnerabilities and model outcomes. Sessions enabled discussions around trade-offs and assumptions in the model, and how to refine or adapt such assumptions. Ongoing feedback spurred iterative development of the WEAP model, which in turn increased the transparency of the model's assumptions, and enabled participants to reflect on its accuracy. Findings from the model's scenarios showed that the predominant stressor on the system is not climate *per se;* instead, climate has important indirect impacts (e.g. reduced rainfall affects hydropower generation which, in turn, reduces the energy supply needed to pump water to residents). Such insights can inform the WSAIP and other urban planning decisions.

Strategically engage senior decision-makers. A series of high-level breakfasts was held throughout the process to engage and provide strategic messages to senior decision-makers. This engagement and relationship building with policymakers and councillors is key to moving from improved knowledge about the situation (e.g. recommendations in the policy briefs) to action on the ground.

Encourage long-term sustainability. Throughout the process, efforts were made to consider the long-term sustainability of outcomes, for example, in the building of strong local partnerships and networks, and in encouraging ownership of the process to be shared and passed on to initiatives that remain beyond the project's lifetime (e.g. LuWSI).

The elements of the process were not linear. New stakeholders joined throughout the process, and emerging outputs (e.g. climate risk narratives, WEAP water model scenarios) served as vehicles or "conversation starters". These sought to build understanding and capacities through iterative development, input and feedback from participants. The process resulted in diverse outcomes, namely: participants' enhanced understanding of climate change and local impacts; increased awareness of the urgency of climate action and the need for collaborative relationships between partners and networks; increased confidence to ask more informed questions and explore assumptions in producing climate information; shifts in personal behaviour choices; and the integration of climate information into ongoing plans and projects.

Conclusion

We advocate for processes that build confidence and capacity of all participants and relevant institutions, and that establish trusting relationships needed to effectively co-produce relevant, usable information for decision-making. Tandem and its guiding questions are designed to steer and support groups in creating these processes to 1) improve the ways in which all participants *work together* to purposefully design *transdisciplinary knowledge integration processes*; 2) co-explore decision-relevant needs for the co-production of *integrated climate information*; and, 3) increase individual and institutional capacities, collaboration, communication and networks, to translate this information into climate-resilient decision-making and action. We aim to promote science-informed policy and policy-informed science, and to contribute to increased climate coordination, collaboration, learning and action globally.

1. Introduction

1.1. Increasing climate resilience using integrated climate information

Climate change adaptation research has been slow to impact policy and practice (Klein and Juhola, 2014; Lemos et al., 2012). Meeting the global challenge of our key international agendas – the Paris Agreement, the Sendai Framework for Disaster Risk Reduction, and the United Nations Sustainable Development Goals – requires decisions and actions underpinned by climate (and other) sciences. Facilitating the increased integration and use of decision-relevant climate and non-climate information (hereafter *integrated climate information*) for decision-making is critical, particularly given the level and urgency of action needed to effectively limit and adapt to climate variability and extremes. Despite the tremendous potential to integrate climate and other types of information into decision-making, few products and services are well designed and/or well used (Porter and Dessai, 2017). The primarily adaptation-focused climate services literature (Larosa and Mysiak, 2019), offers only selected examples of climate projections translated into direct adaptation action (e.g. Goosen et al., 2013). Moreover, the extent to which knowledge constrains or enables adaptation critically depends on how that knowledge is developed, shared and used to achieve the desired adaptation objectives (Klein et al., 2014). This situation suggests that a reconceptualization is in order. It is increasingly recognized that the supply-driven, one-directional delivery of climate information from providers or experts (e.g. climatologists, meteorologists) to users (e.g. decision-makers, city planners and extension officers) has limitations (Brasseur and Gallardo, 2016). Yet, in some cases the practice persists, with the very terminology of "providers" and "users" underscoring the one-directional information flow (Bremer et al., 2019). People who bring diverse types of knowledge to the task are important and valuable beyond those traditionally defined as climate information providers. In a truly collaborative endeavour of this kind, roles are not static; indeed, they must be fluid because all participants need to both provide and gain information on climate or context. The process means that providers sometimes become users, and the other way around.[7] Thus, hereafter we deliberately use the term "actors" or other status-neutral language to refer to individuals who, by definition, will provide and use information throughout the process.

1.2. Reconceptualizing climate services

Calls for alternative, more collaborative and iterative approaches for climate knowledge generation (Dilling and Lemos, 2011) recognize that to address the "usability gap" (Lemos et al., 2012), climate information must be salient, legitimate and credible (Cash et al., 2003). This aim requires tailoring of climate information with other types of information to address the complexity of needs, capacities, and the socio-political and institutional contexts of decision-makers. Increasingly, research shows that, with some caveats, co-exploration[8] and transdisciplinary co-production[9] create more situation-relevant knowledge (Bremer and Meisch, 2017; Meadow et al., 2015; Steynor et al. 2016; Taylor et al., 2017, Vaughan and Dessai, 2014, Rodela and Gerger Swartling, 2019). Whether intended or not, other benefits – such as "learning, empowerment, institutional capacity or new representations of nature and society" – flow from many co-production processes (Bremer et al., 2019: 43). These may, in fact, be more important outcomes than the generation of knowledge products (Norström et al., 2020). Yet, the planning and design of co-production processes are not as purposeful or as collaborative as they could be, largely because they frame the generation of outputs as the end product, and as an incentive for participation (Harvey et al., 2019) or ignore political differences between participants, and their values, norms, interests and beliefs (Turnhout et al. 2020). This paper responds to this situation by arguing for a reconceptualization of climate services. We propose deliberately moving away from a narrow focus on delivery of tailored products and

[7] A decision-maker can be described as a "provider" or "expert" through his or her provision of contextual information on, for example, local decision-making processes, to a climate scientist. This situation, in turn, renders the scientist as the "user" of such contextual information.

[8] Co-exploration is a process that examines different knowledge, skills and practices to reach a *common understanding* of what decision-makers potentially need from climate (and other) science (and vice-versa), and what is scientifically feasible and defensible in terms of meeting that need (Taylor et al., 2017).

[9] Transdisciplinary co-production is a process in which stakeholders from science and society *work together* to combine different knowledge, skills and practices to create new, relevant knowledge that addresses a shared concern or need (Taylor et al., 2017).

specific outputs, and instead, moving towards a transdisciplinary, process-centric approach in which collaboration purposefully seeks to bring about wider, long-term benefits: namely, foundational human and institutional capacity development and relationship building that set the stage for viable climate change adaptation action and, indeed, for any other science-informed decision-making in the public arena.

1.3. Transdisciplinary knowledge integration processes

We propose a move towards the purposeful design, following Harvey et al., (2019), of transdisciplinary co-exploration *and* co-production processes (hereafter *transdisciplinary knowledge integration processes*) that bring together different knowledge types and disciplines, including climate science, and different actor types, across the science-society interface. Purposefully designing such processes could improve the ways in which actors *work together* to: co-explore decision contexts, uncover decision-relevant climate (and other) information needs, co-produce integrated climate information, and enhance capacity. Transdisciplinary knowledge integration processes can increase the shared understanding of a problem, build trust and confidence to engage in unfamiliar knowledge spaces, and, in turn, strengthen capacity, relationships and networks over a longer timeframe.

1.4. Existing climate services guidance

The effort to improve the use of climate information has produced several structured frameworks and models (e.g., the Global Framework for Climate Services, Enhancing National Climate Services, World Meteorological Organization Guidance on Good Practices, European Roadmap for Climate Services[10]). The majority provide broad principles or recommendations about what climate information products and services should deliver, or how that information can be tailored (Dinku et al., 2014; Lemos et al., 2012). Historically the focus has been on improving the availability, access, and quality of climate information, and, more recently, on co-production and understanding of decision contexts in which information will be used. However, in theory and in practice, a supply-driven approach remains commonplace. Information and products are generally presumed or incentivized to be a singular end product (Harvey et al., 2019), an outcome often delivered and tailored by scientists who do not always fully appreciate the potential needs, context, goals or capacities of the people they seek to help. As a result, examples of structured guidance to support complex, real-world decision-making are few. Those that exist are predominantly sector-, location- or context-specific (e.g., Participatory Integrated Climate Services for Agriculture [Dorward et al., 2015] and Participatory Scenario Planning [CARE International, 2018] for smallholders and community-based decision-making, predominantly in Africa; and EUPORIAS [Christel et al., 2018] for the energy sector in Europe).

There are some notable exceptions. WISER's[11] guidance on Equitable and Inclusive Co-production for Weather and Climate Services (Carter et al., 2019) provides a systematic yet context-specific process for the co-design of climate services using building blocks and principles; it recognizes a co-production spectrum ranging from consultative to immersive. Another exception is the set of principles derived from lessons learned about the theory and practice of co-production (Vincent et al., 2018). The authors advocate for the *product* to be decision-driven, process-based and time-managed, and for the *process* to be inclusive, collaborative and flexible. We acknowledge that both the WISER guidance[12] and Vincent et al. (2018) are "process-based" approaches that explore some of the more intangible results of co-production needed for long-term change. At the same time, they focus on supporting the production of tangible co-production outputs (e.g., seasonal forecasts, climate risk narratives, maprooms[13]).

Norström et al., (2020) define co-production as a process that develops capacity, builds networks, fosters social capital, and implements actions that contribute to sustainability, rather than simply producing knowledge. Such high-quality co-production for sustainability requires that processes should be: 1) context-based; 2) pluralistic; 3) goal-oriented; and 4) interactive. Building on this, we draw a clear distinction between the work of preceding efforts, which, while similar in spirit, are different in focus. We propose a paradigm shift for climate services in two ways:

- by making the collaboration *process* itself a focal point from which everything else flows; and,
- by expanding the intended outcome, from a singular, climate-specific output to the cultivation of foundational characteristics that are versatile enough to help people make science- and evidence-informed climate adaptation decisions.

The approach is thus "process centric", a term we use to underscore the focus on the process itself. That is, the nature of the interaction expands institutional and individual capacities and confidence, relationships, collaborations, communication and networks, across the socio-political and governance landscape. Such interaction *may* increase the likelihood of a climate services output or product, but this is not necessary or guaranteed. Indeed, the generation of an output or product may not be as important as the process itself (*ibid.*).

It has been argued that co-production processes can reproduce, rather than mitigate, existing unequal power relations, and that they often do not contribute to societal transformation (Turnhout et al., 2020). We envision a process intent on increasing the *learning* of all participants (Reed and Abernethy, 2018) to co-create a shared understanding among 1) decision-makers about climate (and other) sciences and their possibilities and limits; and 2) climate professionals about the needs and real-world political, social and economic constraints facing decision-makers. This builds a foundation in which decision-making underpinned by science and evidence can gain traction – in climate-specific arenas and beyond.

1.5. Objectives

The objectives of this paper are to 1) assess how co-exploration and co-production processes to develop integrated climate information can address barriers and leverage opportunities to increase the use of climate information in decision-making, and 2) develop a *process-centric* framework that offers structured, practical guidance for actors to *work together* to purposefully design and deliver such processes. To achieve this, we analyse 1) survey responses from climate services stakeholders to unpack perceived barriers and potential responses for the effective use of climate information; and 2) an urban climate information co-production process in Lusaka, Zambia, to identify *outcomes* from, and *elements* and *characteristics* that support, a transdisciplinary knowledge integration process. Given our findings, and to encourage their further application and testing, we propose a framework (Tandem) with

[10] The Global Framework for Climate Services (GFCS Framework) (WMO, 2016), Enhancing National Climate Services (ENACTS) (Dinku et al., 2014), WMO Guidance on Good Practices (WMO, 2018), and the European Research and Innovation Roadmap for Climate Services (European Commission et al., 2015).

[11] The Weather and Climate Services for Africa (WISER).

[12] We note that the Learning Lab co-production process undertaken in Lusaka, Zambia, and elsewhere in southern Africa was part of the Future Resilience for African CiTies And Lands (FRACTAL) project, which informs our paper and the WISER guidance.

[13] A collection of maps and other figures that monitor climate and societal conditions at present and in the recent past (https://iridl.ldeo.columbia.edu/maproom/).

guiding questions (Table 3) to inform actors in structuring their transdisciplinary engagement, interaction, collaboration and learning processes. While we acknowledge that Tandem derives from one specific case, namely that of a funded co-production process focused on urban planning and decision-making, we encourage testing by other researchers and practitioners in other contexts (e.g. Butterfield and Osano, 2020; André et al., 2020). To support refinement of the framework, and in response to needs identified in the survey, the Tandem guiding questions can be accessed in online interactive guidance,[14] which offers good practice examples, methodological resources, and learning shared by the wider climate services community.

Section 2 outlines the empirical evidence and methods of analysis. Section 3 presents the results of the analysis of perceived barriers to and potential responses for increased climate information uptake, and the outcomes, elements, and characteristics of a transdisciplinary knowledge integration process; the section concludes by introducing the Tandem framework. Section 4 examines the Tandem philosophy, its added value in relation to existing guidance, its applicability and limitations and Section 5 concludes.

2. Methodology

2.1. A survey of climate services stakeholders

To explore the challenges and opportunities for improving the use of climate services, we distributed a survey[15] to recipients of the newsletters of the Climate Services Partnership (CSP) and the online climate adaptation platform, weADAPT[16] in April 2017. The 42 responses came from a mix of self-identified climate service actors from NGOs, media, consultancies, the private sector, online platforms and networks, and research, civil society, and science-policy organizations. A review of responses according to completeness and depth of qualitative responses narrowed the field to 30 responses for inclusion in analysis.[17] Of these 30 responses, 19 respondents (63%) self-identified across more than one “type” – provider, intermediary or user - recognizing the limiting nature of categorizing traditional roles. Out of the 30 respondents, 17 (57%) identified as providers, 23 (77%) as intermediaries and 17 (57%) as users, representing a range of sectors.[18] Among all respondents, 40% had more than five years’ experience in the field of climate services, and two-thirds had more than three years’ experience.[19]

To identify the most prevalent perceived barriers and responses, we posed the following research questions: “What barriers exist to the effective use of climate information?” and “What potential responses exist to increase the use of climate information?” We used qualitative content analysis (in an inductive approach) to systematically describe the meaning of the qualitative data (Mayring, 2000; Schreier, 2012) to produce a set of priority categories of barriers and responses.[20] Answers classified as “barriers” referred to: gaps in existing climate service provision; obstacles to accessing climate data and information and their use by decision-makers; challenges in the development, delivery and use of climate services; and, perceptions as to why climate services were ineffective. Answers classified as “responses” referred to: how climate scientists could meet the needs of decision-makers; how users could be supported to identify their climate data and/or information needs; potential entry points for climate services; overcoming challenges in the development, delivery and use of climate services; reasons services or information were perceived to be effective; how decision-makers and climate scientists could effectively engage with each other; and any new opportunities the respondent saw for climate services going forwards.[21]

2.2. A climate information co-production process in Lusaka, Zambia

In Lusaka, Zambia, a series of Learning Labs sought to enhance the use of climate information in medium- and long-term urban planning[22] using transdisciplinary co-production and co-exploration processes, supported by researchers “embedded”[23] (Pretorius et al., 2019) in municipal policy and planning departments within the city. Learning labs are safe spaces (Arrighi et al., 2016) that bring together many different types of actors and knowledge. The labs use experimentation, and experiential and social learning processes (Koelle et al., 2019). Key to their success are how the labs are facilitated (*ibid.*, Reed and Abernethy, 2018) and how different voices can be heard. The format gives participants the freedom to challenge dominant or business-as-usual approaches, and to innovate new pathways for societal transformation. In Lusaka, the intention was fivefold:

- to foster dialogue and collaboration between climate scientists, researchers, urban policymakers and practitioners;
- create an enabling environment for transdisciplinary discussion, research and collaborative learning;
- strengthen working relationships between city leaders, technical staff, researchers, non-governmental stakeholders and community representatives;
- develop capacity to incorporate relevant climate information into decision-making processes; and,
- support policy or governance processes based on an increased understanding of the city system and possible future scenarios (Arrighi et al., 2016).

To identify a set of outcomes and priority elements and characteristics from documentation of the Learning Lab process, we formulated the following research questions: “What *outcomes* did the process achieve?”, “What *elements* were present in this climate information co-production process?” and “What *characteristics* did the process have?” We selected 19 documents[24] from the Lusaka process (March 2016 - November 2018) as material for analysis. This subset, while not exhaustive, offered broad coverage of the co-production process from start to finish. It included documentation of all major transdisciplinary engagements and concepts developed, as well as reflections from a range of actors throughout the process and at the end of the final engagement. Following review of all documents for text relevant to the process (*Outcomes*, *Elements* and *Characteristics*), we inductively developed nodes under these categories[25] that shaped the design of the Tandem framework (Table 3). Nodes for *elements* and *characteristics*,

[14] www.weadapt.org/tandem

[15] Survey questions are included in Supplementary Material (A).

[16] www.weadapt.org

[17] The remaining 12 responses were incomplete and included no or minimal responses to long answer questions. These were not included in the analysis.

[18] Water, agriculture and food security, biodiversity, coastal and marine management, disaster risk reduction, energy, finance, forestry, health, urban planning, infrastructure and transport.

[19] See Supplementary Material (A) for all survey questions.

[20] The small sample size precluded statistical analysis. Analysis by respondent type was not undertaken due to a number of respondents self-identifying across more than one type. Due to the balanced spread of type and depth of experience of the respondents we feel that this does not limit the analysis.

[21] See Supplementary Material (B) for further detail on the methodology and the full node structure developed using an inductive category development approach (open coding).

[22] Part of the Future Resilience for African CiTies And Lands (FRACTAL) project.

[23] “Embedded researchers” work in both the local university and the municipal policy and planning context in the city, to gain better access to, and understanding of, urban actors, networks, decision-making processes, and climate information entry points.

[24] See Supplementary Material (C) for information on documentation used for analysis.

[25] See Supplementary Material (D) for node structure for analysis of the Lusaka climate information co-production process.

Table 1
Barriers to the use of climate information.

Barrier	Explanatory detail
Disconnect between actors	Lack of direct engagement and interaction between climate scientists and decision-makers. Lack of personal relationships or connections. Physical distance between specialist scientists and decision-makers (i.e. based in different countries).
Information is not **decision-relevant**	Information is irrelevant for decision-making (i.e. inappropriate data variables, spatial or temporal scales, or lack of integration with other non-climate information).
Poor **data quality and coverage**	Real and perceived data gaps in observational records, limited local coverage, and differences in data standards and procedures leads to concerns about data quality and scientific credibility.
Insufficient **sectoral and impact studies**	Insufficient or inaccessible information available on how climate may impact different sectors (e.g., impact models on agricultural and crop productivity).
Weak or limited **data translation** and **risk communication**	Assumption that those who receive the data have the same level of understanding as those who generate it. Limited or unclear guidance accompanies technical data regarding: 1) how to interpret data; 2) complex concepts such as uncertainty and the scalability of climate information; and 3) when and how information can and cannot be used. Formats and dissemination modes are not user friendly.
Lack of **funding**	Inadequate financing or suitable business models for the affordable provision of climate information.
Lack of **political commitment**	Insufficient commitment or buy-in from institutions (e.g. national governments) and individuals (e.g. senior decision-makers) to develop supportive institutional policy and legal environments for climate information provision and use.
Inadequate **capacity among those producing climate information**	Lack of institutional incentives and, thus, ability and willingness of those generating information (e.g. NHMSs, universities, private sector) to collaborate and share data, standards, practices, capabilities and experiences with each other. Technical experts can struggle to effectively engage with non-technical audiences; this communication requires a different skillset to that of research.
Insufficient **capacity among those seeking climate-relevant information**	Decision-makers may not fully recognize or articulate their climate information needs. Limited awareness of climate services, and little available information on 1) how and where to access such services; and 2) how to interpret and use climate information that emerges. Lack of institutional and operational processes for climate information inclusion.

(Source: summarized results from the authors' survey)

necessary for specific *outcomes* inform the practical guiding questions of Tandem. The process undertaken in Lusaka and the particular nodes produced through the analysis address the barriers and implement a number of the proposed responses from the survey.

3. Results

3.1. Barriers

A wide range of perceived barriers to the effective use of climate information emerge, as expected, from survey responses. We recognize that while barriers fall into most commonly cited and distinct categories (Table 1), many are interrelated, and can reinforce and perpetuate one another. For example, the lack of interaction between what have traditionally been termed "providers" and "users" perpetuates the simultaneous challenges on both sides. Decision-makers struggle to interpret available climate information, and fail to recognize or identify their information needs. Climate scientists fail to fully recognize decision contexts, and overestimate decision-makers' abilities and capacities to interpret and use climate information. Without a fundamental shift in the nature of the interaction between these two camps, communication is likely to remain inadequate. Moreover, any information produced is unlikely to be relevant and perceived as legitimate, key qualities that make climate information actionable.

The barriers identified from survey responses mirror many findings in the climate services literature. Frequently cited examples include the following:

- weak or ad hoc relationships and interaction between traditional "provider" and "user" groups (Brasseur and Gallardo, 2016; Lemos and Morehouse, 2005);
- incomplete understanding on the part of scientists regarding broader decision contexts beyond climate (McNie, 2007);
- a mismatch in spatial, institutional and temporal scales of research and those of decision-making and policy (Bruno Soares and Dessai, 2016; Vincent et al., 2017);
- underestimation of the value of integrating different knowledge types (scientific, practical, local) (Lemos et al., 2012);
- narrow perceptions of types of decision-makers and stakeholders (Porter and Dessai, 2017); and,
- confusion among decision-makers from fragmented information, inconsistencies in results and varying formats from multiple sources of information, and the use of technical language and terminology (Adams et al., 2015).

As such, discerning credible information can present a challenge for decision-makers. Indeed, many would-be beneficiaries of climate information remain largely unaware of the importance and potential value of such information for decision-making (Cortekar et al., 2017; Bruno Soares and Dessai, 2016).

3.2. Potential responses

Table 2 illustrates the most commonly cited potential responses to increase the use of climate information from the survey. Many responses are interrelated and supportive of each other. For example, through trusted relationships and engagement between scientists and decision-makers, scientists are more likely to understand decision-makers' contexts and capacities to interpret information. They are thus better able to work towards generating more usable material that brings climate considerations together with other information. Likewise, by engaging with and asking questions of climate scientists, decision-makers and other stakeholders will likely enhance their capacity to recognize both the potential and the limits of climate information, better interpret it, and thus better articulate their information needs.

The challenges cited in the survey reinforce the need to take two key steps:

- recognize that the development of climate information *with* (rather than simply *for*) decision-makers and other stakeholders is essential if the information is to be beneficial and used appropriately (Funtowicz and Ravetz, 1993); and,
- integrate climate information with other types of information (e.g. social, economic, environmental).

Deeper and sustained engagement can build awareness and capacity

Table 2
Potential responses to improve the use of climate information.

Response	Explanatory detail
Create **decision-relevant** information	Relate climate information to decision-makers' needs. Recognize the complexity of decision contexts and constraints facing decision-makers. Seek to integrate relevant climate and non-climate information e.g. through impact models or studies.
Integrate **different knowledge types**	Enhance relevance of information, combine knowledge from different scientific disciplines and from society. Involve and seek input from stakeholders with varying expertise and experiences.
Build **relationships and engagement** between actors	Seek ongoing, long-term engagement. Build personal, sustained relationships through direct engagement. Seek to establish trust and common ground and language as a foundation for collaborative working and co-ownership.
Strengthen the **capacity of climate scientists** to **work with decision-makers**	Enable scientists to build trusted relationships and work with decision-makers; support upskilling in clarity of communication and collaboration.
Improve **data translation** and **risk communication**	Use accessible and understandable information formats (e.g. visualizations, maps), non-technical language and supporting explanatory material (e.g. on the potential application of the information). Disseminate information in an accessible mode for stakeholders.
Strengthen the **capacity of decision-makers** to interpret and use data	Support upskilling of decision-makers on the potential uses, and the limits to the use, of information, where and how information can be accessed and how it can be (reliably) interpreted for application.
Employ approaches to **improve data accessibility**	Foster closer relationships and increase the distribution of climate information, use networks and intermediaries (e.g. extension officers, NGOs) or set up agreements or MOUs. Encourage more collaboration between expert climate groups for data sharing strategies.
Build and maintain **credibility**	Advance the further development of quality standards, processes and principles for the creation of climate information.
Share **good practices**	Share exemplars of climate information and practices to demonstrate their value, benefits and applicability to decision-makers and other stakeholders. Provide learning for others through platforms for knowledge exchange.

(Source: summarized results from the authors' survey)

for people confronting the unfamiliar: new and complex concepts such as climate uncertainty on the one hand, and the socio-political and economic realities of decision-making on the other. Sustained, iterative engagement, thus, enhances the prospects of generating both "useful" and "usable" climate information (Lemos et al., 2012; Lemos and Morehouse, 2005; Tall et al., 2014).

As a snapshot of perceptions from climate services community members, the survey responses point to the importance of and need to improve the connection and building of trusted relationships between actors of different types. It is clear that ongoing, iterative relationships critically shape the usability of science (Dilling and Lemos, 2011). Increasing capacities of various actors is key: to generate better understanding of decision contexts, but also to interpret the value and limits of climate information. The survey responses also underscore the importance of creating decision-relevant information that integrates different knowledge types. *Transdisciplinary knowledge integration processes* can increase the capacities of all actors involved, enabling deeper and possibly tacit knowledge to be uncovered and co-explored, and more informed questions to emerge.

3.3. Climate information co-production process in Lusaka, Zambia

From our documentation analysis of the climate information co-production process in Lusaka (carried out in Learning Labs), framed by our research questions, we found short-term "outcomes" and positive markers of *early* change that suggest potentially wide-reaching benefits. We identify process "elements" (describing what was done; Fig. 1) and "characteristics" (how this was done) that led to these outcomes.[26] These elements and characteristics provide the basis for practical guiding questions (Table 3) of the Tandem framework (Fig. 2). (The node structure for *elements*, *characteristics*, *activities* and resulting *outcomes* is available in Supplementary Material (D)).

In terms of outcomes, wide-reaching benefits of the co-production process include:

- a deeper understanding of climate change and local impacts;
- increased awareness of the urgency of action required to adapt to these impacts;
- increased ability and confidence among participants to ask deeper, more informed questions of each other, and to co-explore assumptions in producing climate information;
- increased awareness of other stakeholders and the need for, and development of, collaborative relationships between partners and networks;
- shifts in personal behaviour choices; and,
- the integration of climate information into ongoing plans and projects.

The transdisciplinary process aimed to create shared understanding, expanded networks, and shifts in perspectives, worldviews, mindsets, and ways of working (Taylor et al., 2017; Scott and Taylor, 2019). In addition to our documentary evidence, at the end of nearly three years of Learning Labs, one *climate scientist* commented:

> *"…the questions that people were asking felt more informed. When thinking back [to the beginning], people didn't really understand how to frame their questions and we didn't know how to frame our answers. People were less afraid to ask questions [at the end of the process]".*

These benefits provided by this type of deep, transdisciplinary engagement can potentially facilitate longer-term change and underpin climate-resilient decisions. An *engineer* from the Lusaka process reflected:

> *"I've had a personal shift in the way I think, and I don't see myself going back but at the same time, the question is whether the environment in which I'm working is conducive to this way of thinking".*

This points to the need for behavioural shifts *and* institutional capacity development for sustained change. That is, national, regional and local institutions must develop the capacity to adapt decision-making processes and procedures to promote and encourage champions, and to incentivize collaboration. Likewise, individuals need to develop a desire for collaborative learning, in addition to developing specific skills and expertise.

The urban case study in Lusaka informed the development of Tandem (see the Practical Implications chapter for a fuller description of the case). Our documentation analysis led us to distil a node structure

[26] See Supplementary Material (D) for node structure of analysis of the Lusaka climate information co-production process.

Table 3
Tandem framework and a sample of guiding questions, supported by evidence from the Lusaka case (underlined = iterative elements). A full list of questions is available in Supplementary Material (E) and in the online version of Tandem (www.weadapt.org/tandem).

Element	Examples of questions to guide the design of the transdisciplinary knowledge integration process	What happened in the Lusaka context?
Identify and engage relevant stakeholders	● What organizations are working on climate resilience-related issues with **relevant sectoral expertise and experience**? ● Can **champions or change agents** be identified in these organizations? ● Which **groups are impacted on the ground** and can provide representative voice(s)? ● How can early engagements be designed to **build trust and a safe learning space** between a **diverse mix of participants**? ● Can a **local organizing team** be established to support the logistics and facilitation, and maintain relationships in between face-to-face engagements? ● *What engagements might work best to* ***bring other stakeholders into the process*** *as needed?* ● *How can* ***information developed in the process be shared on a regular basis*** *with participants?*	● Engaged participants and developed partnerships. ● Created a safe learning space. ● Established a local "Task Team" to: ensure the smooth organization of engagements; strengthen local partnerships; identify new stakeholders to invite to the process; identify or create "windows of opportunity"; and coordinate a quarterly "Digest" updates for all participants.
Co-explore and understand the context	● What **adaptation issue(s)** are being experienced? ● How can engagements be designed to **co-explore:** the **drivers** of these issues (**climate and non-climate**); the **complexity of multi-sector system-wide issues; and different perspectives and priorities?** ● Can **site visits**, first-hand accounts and **examples from other contexts** help to spur discussion, learning and unpacking of adaptation issues and solutions? ● How can activities (e.g. the use of graphics, maps, narratives, models) be designed to communicate to and engage participants on various **approaches to climate risk assessment, global climate modelling and projections and downscaling of data**? ● How can discussions be designed to co-explore the agreement or uncertainties around **institutional mandates** and **responsibilities**, and **institutional capacity strengths and weaknesses**? ● In the **policy, planning and implementation** landscape, what plans, projects and policies are in place or in the pipeline?	● Co-explored "burning issues" with a diverse range of science and society stakeholders. ● Working groups identified and mapped issues and drivers, explored governance, decision-making and policies, and co-produced policy briefs. Shared ownership of the policy briefs was a common thread grounding the co-exploration process. ● Participants attended site visits and heard first-hand accounts from other cities. ● Actors participated in interactive games, co-produced climate risk narratives, and co-explored scenarios from a water system model of Lusaka, to create a shared foundation for further work.
Set focus and **learning objectives** (to contribute to Monitoring, Evaluation and Learning process)	● *Can* ***learning objective(s)*** *be agreed for the process or for specific engagements?* ● *Can qualitative* ***indicators*** *be developed to measure* ***impact particularly where outcomes are intangible?*** ● *How can* ***reviews and reflections provide feedback and learning*** *for the process?* ● *How can a* ***culture of learning and reflection*** *be encouraged between all participants?* ● *Can the process be anchored through developing* ***tangible outputs or projects?***	● Learning and reflection was core to both the project team and across all participants. Ownership shifted to participants. ● The development of policy briefs, climate risk narratives and the WEAP model grounded activities and provided continuity.
Identify and respond to **training or capacity needs**	● *Have* ***specific capacity needs*** *emerged from the co-exploration 'phase'?* ● *How can these be addressed to achieve most impact?* e.g. *training of trainers, senior decision-makers, politicians, technical planners etc.*	● Capacity development and trainings. e.g. a side event for councillors and senior decision-makers and more in-depth climate science training.
Identify solutions, recommendations and ways forward	● What **scale-appropriate solutions and recommendations** (temporal, spatial) can be identified? ● Can **examples from other contexts** help to identify possible adaptation measures? ● How can solutions **build on** "**windows of opportunity" e.g. existing efforts and initiatives or leveraging existing partnerships**? ● Which **structures or actors are needed to deliver and to contribute or support the delivery** of these solutions? ● *Which* ***decisions are critical to unpack further? Which need further support*** *with climate – and other – information?*	● Identified emerging plans and tools to link to and build on, including the WSAIP, climate risk screening tool and a new statutory instrument on monitoring groundwater abstraction. ● Inspiring cases from other cities as well as learning from cross-city exchanges seeded ideas for local solutions in Lusaka.

(*continued on next page*)

Table 3 (*continued*)

Element	Examples of questions to guide the design of the transdisciplinary knowledge integration process	What happened in the Lusaka context?
Co-explore and "**distil**" **relevant information** from data	• Can **specific information needs at relevant time and spatial scales now be articulated for particular decision-making processes or development of plans, processes or tools**? • How can activities and engagements be designed to **co-explore these information needs and the process, assumptions and trade-offs of distilling key messages from data**? • How can sessions be designed to be **accessible to the varying levels of technical capacity and knowledge of participants**? • How are **data and information being communicated, shared and disseminated?**	• Co-explored the key messages distilled from climate data, the assumptions used in developing the WEAP water model, and how the model's findings could inform decision-making. • Participants co-explored how changes in variables and thresholds impacted the vulnerability space and model outcomes.
Strategically engage senior decision-makers	• What **key messages and new information** emerging from the process need to be **communicated to key influencers and senior decision-makers**?	• High-level engagements with senior decision-makers, e.g. policymakers and councillors.
Encourage **long-term sustainability**	• What is needed to **maintain networks, partnerships and action** after the process? How can these be put in place as the process is ongoing? • Can a strategy or ideas for **continued conversations** and **longer-term research and engagement** be developed?	• Long-term sustainability and ownership of outcomes through strong local partnerships and networks.

of elements (describing what was done; Fig. 1) that led to outcomes and positive markers of early change. We summarize each element here in relation to the Lusaka process for clarity.

Identify and engage stakeholders. Early engagements built safe, innovative learning spaces and relationships identifying a key "champion", Lusaka Water Security Initiative (LuWSI, a public- and private-sector multi-stakeholder platform), and key partners, for example, the Zambia Homeless and Poor People's Process Federation giving voice to the *peri*-urban community.

Co-explore issues and context. Early and continued co-exploration, in particular, provided a foundation for further work. By co-exploration, we refer to the process of *examining* different knowledge, skills and practices to reach a common understanding, in contrast to the *combining* of these in co-production (see [8,9]). Learning Lab participants prioritized *peri*-urban water insecurity, declining groundwater levels, groundwater pollution, water supply, sanitation, and flooding as key challenges. Groups co-explored climate and non-climate drivers to co-produce recommendations (policy briefs), learning from: local site visits; other cities; interactive games; climate risk narratives; [27]and, water system vulnerabilities.[28]

Set focus and learning objectives (to contribute to monitoring, evaluation and learning process). A culture of learning and reflection was established, and, over time, ownership shifted from the project team to a shared ownership across participants. Critical for longer-term sustainability, this ownership, and the development of policy briefs, climate risk narratives and the water demand model served as grounding outputs to focus discussions and provide continuity through the process.

Identify and respond to training or capacity needs. Particular engagements and trainings were requested by participants as needs emerged and as capacities developed. These included a side event for councillors and senior decision-makers and more in-depth climate science training.

Identify solutions and recommendations. The groups co-producing policy briefs mapped solutions, interactions, connections, and responsible actors to tap into the policy planning and implementation landscape, institutional capacities and current adaptation responses. A new Water Security Action and Investment Plan (WSAIP) and a climate-risk screening tool emerged as possible "windows of opportunity" to build on. Cross-city exchanges and inspiring cases from across southern Africa seeded ideas for local solutions.

Co-explore information needs and distil relevant information. Facilitators integrated sessions co-exploring distilled climate messages from data, together with other (non-climate) information, and variables and thresholds in the WEAP model, to examine model vulnerabilities and outcomes. Results showed important indirect climate impacts on the system, which can inform the WSAIP and urban planning.

Strategically engage senior decision-makers. High-level breakfasts were held throughout the process to engage and provide strategic messages to senior decision-makers. This engagement and relationship building with policymakers and councillors is key to moving from improved knowledge about the situation (e.g. recommendations in the policy briefs) to action on the ground.

Encourage long-term sustainability. Throughout the process, efforts were made to consider the long-term sustainability of outcomes. This is evidenced through the building of strong local partnerships and networks and in encouraging ownership of the process to be shared and passed on to initiatives that remain beyond the project's lifetime (e.g. the multi-stakeholder platform, LuWSI).

[27] These are plausible, relevant stories that aim to envision a future climate scenario and likely associated impacts (Jack et al., 2020).

[28] WEAP (www.weap21.org/) is a software tool for integrated water resources planning that provides a comprehensive, flexible and user-friendly framework for planning and policy analysis.

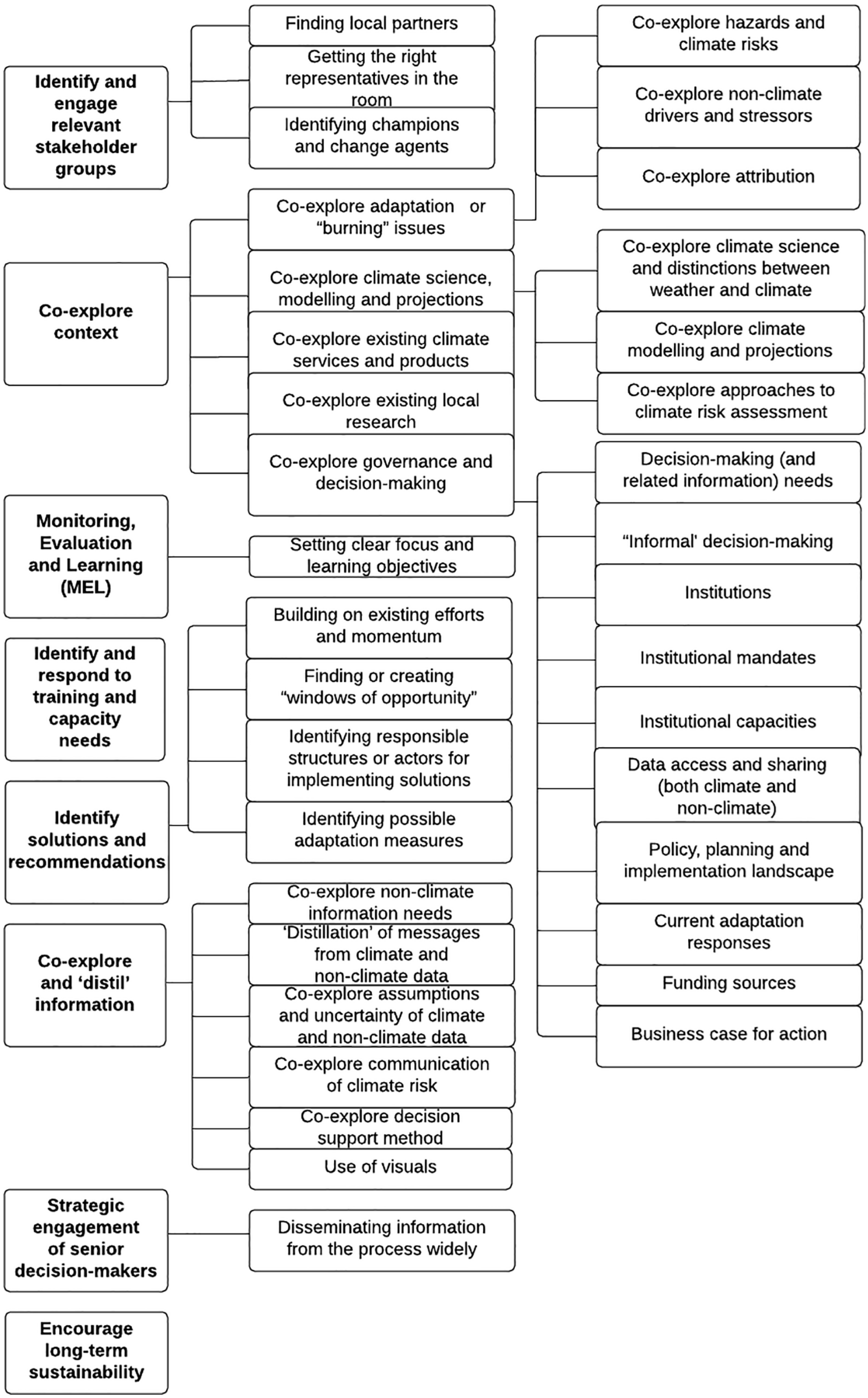

Fig. 1. Node structure resulting from Lusaka document analysis. Cross-cutting and ongoing elements are available in Supplementary Material (D).

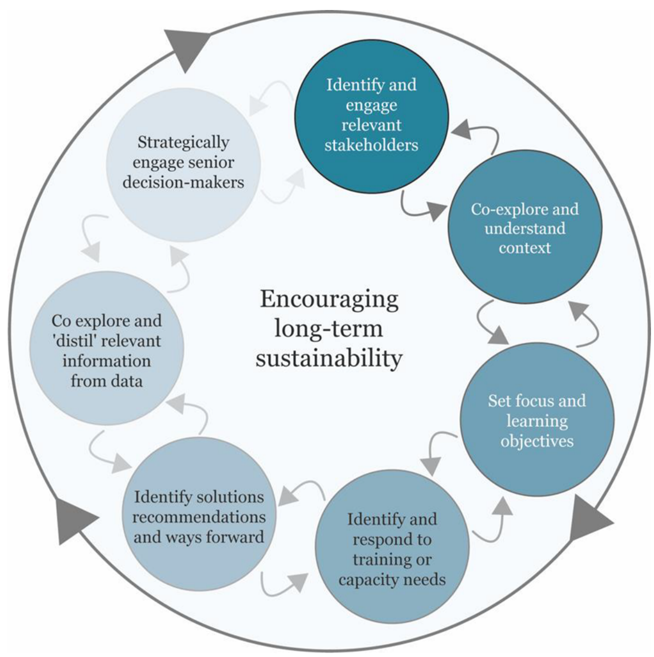

Fig. 2. Constituent elements of the Tandem framework.

Cross-cutting and ongoing elements include: co-exploring scales (temporal and spatial); co-exploring interactions and connections; and, learning and knowledge sharing from other cities.

We use the term characteristics to define how things were done in the process. The characteristics of the process proved to be as important as the key elements and, as such, also inform the guiding questions within the Tandem framework (Table 3). Movement from a superficial understanding of a problem to a deeper understanding of potential solutions required challenging commonly held views and values about complex issues. In Lusaka, this transition occurred through experimentation in the design of interaction and participation in engagements (e.g. using role plays, games and skits, planning site visits, creating spaces for informal conversations and networking). Such engagement can help participants to deal with the social and cognitive challenges of accommodating contrasting worldviews, and potentially conceding aspects of their own (Harvey et al., 2019). One *city stakeholder* noted:

> *"I was compelled to learn because I needed to put things in a box. But some things created dilemmas as their meanings fell between two boxes. As you are deliberating, you are clarifying… You need to justify your actions."*

Our analysis reveals the importance of creating a "safe learning space" (Arrighi et al., 2016) for participants to openly share questions and ideas, challenge assumptions, and learn from and with other participants. Agreeing ground rules for engagement, including roles and responsibilities (*ibid.*) can help by setting the tone for open, receptive engagement and effective collaboration between different actors from different disciplines and backgrounds. Frequently cited processual characteristics describing how elements were delivered and outcomes achieved involved: participant ownership and commitment; trust-building and openness; a diversity of participants; a level of informality, with space created for informal conversations; an interactive and participatory way of learning; multi-day engagements; sharing of information before and between engagements; and continuity, flexibility and adaptability (of the process and participants).[29]

[29] See Supplementary Material (D) for full node structure, including characteristics, and (E) for how this informs the framework.

3.4. A proposed framework: tandem

Based on our analyses, we introduce a framework (Tandem) and practical guiding questions to inform actors working together to purposefully structure their transdisciplinary engagement, interaction, and collaborative learning. The framework consists of a structured set of elements (see Fig. 1) and practical guiding questions (see Table 3 for example questions[30]). These are informed by the elements and characteristics (in bold below) identified from the Lusaka case study, and address the barriers, and implement a number of the proposed responses from the survey.

The Tandem elements are not linear. Indeed, elements are iterative and interrelated, and, in practice, they require revisiting, as actors deepen their awareness, understanding and capacity. While a ***continuity of process is important***, so, too, are ***flexibility and adaptability*** in designing engagements (e.g. revisiting stakeholder identification and bringing in new partners as connected issues are identified).

The guiding questions of the Tandem framework emphasize ***iterative stakeholder identification and engagement***, and the ***co-exploration of issues and context*** to better understand not only climate and non-climate drivers but also local governance and decision-making landscapes. Tandem emphasizes the participation of a ***diversity of stakeholders*** from across disciplines, science and society, socio-economic strata, and the policy and practice interface. The aim is to engage in co-exploring locally relevant issues to deepen levels of understanding of what are often complex and interconnected challenges, driven by underlying vulnerabilities. At an early stage, potential partners and champions already working in this space, both individual and institutional, may align with one another, and bring others into the process. Over time, the same actors need not carry out all elements; in fact, it is more likely that a number of collaborators may be involved at various stages throughout the process as actors change and the process evolves.

In early co-exploration, those actors seeking to provide climate information can work to enhance their understanding of underlying adaptation issues and drivers; decision domains and decision-making processes; socio-political, governance, policy and institutional contexts; existing climate services; and previous adaptation research and responses. Likewise, other actors can seek to better understand the language of climate science; the difference between historical and projected climate trends; and approaches to climate risk assessment, climate modelling, and downscaling of data. This collaborative learning can provide a foundation for a deeper understanding of the system in question, and how climate fits within that. This foundation may raise many questions and identify many capacity needs. As such, ***setting a focus and learning objectives*** can help identify and prioritize learning and action as a group, and ***identifying and responding to training or capacity needs*** may be a prerequisite for further work exploring climate and other data. A tendency to focus on individual capacity needs, should not eclipse institutional capacity needs: critical for the ***longer-term sustainability*** of change and action. Considering how partnerships, networks and potential solutions can go beyond the lifetime of a process requires early and ongoing consideration, from initially identifying potential partners and champions who can take work forward through to enhancing relevant individual and institutional capacities needed for such action.

Early co-exploration and deepening of understanding are key to identifying or creating institutional, policy or project "windows of opportunity" (e.g. building on existing work or momentum where possible; developing and working with champions) for ***solutions and recommendations*** to move forward. With particular solutions in mind, drilling down into decision-making processes and the information needs for such processes requires deeper ***co-exploration of information needs*** (both climate and non-climate) and "***distillation" of relevant***

[30] The full list of Tandem questions is in Supplementary Material (E).

information from data (Jack, 2019) that can support such solutions and recommendations. This continued co-exploration allows actors to:

- strengthen identification of decision-relevant integrated climate information, and,
- better understand the process, assumptions and trade-offs of distilling key messages from (climate and other) data, and the related applications and limits of applications of such information.

Strategically engaging senior decision-makers with focused key messages emerging from the learning process is a critical factor in maintaining political buy-in (and thus, possibly financial support) for the **longer-term sustainability** of change and action.

Each of the elements in Tandem contain guiding questions (Table 3 provides selected examples of questions[31], supported by evidence from the Lusaka case). These are designed to prompt actors to consider potential ways to design engagements to create a safe, experiential learning space for varied actors to interact with each other in an open way. The nature of engagement is important for the collaborative learning process itself to increase the capacity and confidence of actors (e.g. to work together, ask and frame more informed questions of each other, understand and interpret information). The ***broad diversity of participants*** is important, yet such diversity may result in ineffective engagement and collaboration if varying levels of experience or knowledge are not acknowledged and addressed in an ***open and trusting environment***. Using innovative games and exercises to spark ***interaction and broad participation*** can engender trust between actors. Likewise, the space for ***informal conversations*** and the ***continuity of relationships*** over a series of ***multi-day engagements*** can give the time to more deeply unpack and co-explore complex issues, and to pursue collaborative ***learning*** as a group. For such engagement, working relationships and solutions need to be sustainable in the longer-term. Creating a sense of ***ownership of and commitment to the process*** among all participants is important, and itself enhances the capacities of actors involved. A common thread between multiple engagements over time can contribute to a sense of continuity and belonging to a process.

4. Discussion

4.1. The underpinning philosophy of the Tandem framework

Consider a tandem bicycle. Two (or more) people with differing skills, styles and fitness levels need to overcome these differences to pedal in harmony to move forward. To achieve this, riders need to communicate with one another, and to adapt their individual approaches, learning as they go, perhaps somewhat tentatively at first, until a rhythm is set. The alternative - for each rider to embark on a solo journey at her own pace and style - may seem easier. But independent riders on such journeys face risks. Riders who find themselves adrift from a fellow rider may lose their way, or they may choose different endpoints as events unfold along the journey. Indeed, without close and trusted communication en route about complications (traffic, road closures, for example), independent riders may never reach the same destination. In fact, reaching a particular destination may not be as important as the journey itself which offers continual learning, reflection and adaptation as confidence, strength, flexibility and skills improve.

This is the philosophy that underpins the Tandem concept. The people who have traditionally been considered "providers" driving a climate information co-production process may steer in one direction (e.g., they focus largely on climate drivers), but their purposes may not suit the purposes of decision-makers who need to incorporate information into complex decision-making contexts (e.g., they find the information irrelevant or unusable). Working *in tandem*, while more challenging, ultimately reduces this risk. Going on the journey together (following a transdisciplinary knowledge integration process) promotes a shared understanding of obstacles, and fosters greater coordination, collaboration, more effective communication and learning along the way.

4.2. Building on existing guidance: the added value of tandem

In line with other guidance described in Section 1.4 (namely, Carter et al., 2019; Vincent et al., 2018; and Norström et al., 2020), Tandem is a continued attempt to refocus the climate services lens. We argue that the goal of integrating climate science into more policy and action requires a rethink of the climate services field. It needs to move away from a process in which "experts" or "providers" produce information for decision-making "users", who help to tailor the end-product. Rather, it should move towards a process in which collaborative learning is the defining characteristic, and the outputs, though sometimes intangible, provide foundational benefits. Among such benefits are increased confidence, better human and institutional capacity on all sides, and networks that break down barriers to science-informed decisions.

We, and others such as Norström et al., (2020), argue that such outcomes are critical entry points for larger-scale and longer-term transformational change because they tap into values, politics and power. The fundamental concept of Tandem is to attempt to improve the likelihood that such intangible benefits – in the form of human and institutional capacities – will emerge when collaborative learning is the purpose of undertaking the process. Tandem does not assume that a product will be the outcome. Hence, it is *process centric*. The nature of the interaction may increase the likelihood of the production of a climate services output or product, as was the case in Lusaka, but this is not guaranteed. Nor is this required for the process to be considered successful. This distinguishes Tandem from both WISER's guidance on Equitable and Inclusive Co-production for Weather and Climate Services (Carter et al., 2019) and the set of principles derived from lessons learned about the theory and practice of co-production (Vincent et al., 2018). Though both of these have similar ambitions, and recognize intangible outcomes, they are nevertheless process-based, with a focus on collaboration as a needed process to co-produce weather and climate service products.

Tandem challenges the notion that climate information in itself is usable by decision-makers. In many cases, climate variability and change are multipliers of – and thus interconnected with – existing stressors and development issues that are often the root causes of vulnerability (Schipper et al., 2016). Thus, opening up multiple and often competing worldviews and perspectives allows participants to collaboratively explore their own assumptions, and tap into the tacit knowledge that often drives decision-making. Connecting climate scientists with a multiplicity of diverse actors, across the science-society interface addresses the wider, complex factors necessary for long-term change and action. This can result in stronger relationships, collaborations, communication, and networks across the socio-political and governance landscape. Such a process is more likely to lead to climate-resilient decisions borne of increased awareness, confidence, and capacity to interact with new types of knowledge and actors.

4.3. Applicability and potential use of Tandem

Applying Tandem could underpin adaptation-specific and other science-informed planning and action at a range of scales and in different contexts. This could include supporting climate-resilient cities, climate proofing infrastructure, increasing the use of seasonal forecasts in farmers' planning, and enhancing the robustness of national or sector development plans. Its applicability may be more immediately apparent for Global South contexts in which challenges are complex and urgent,

[31] A full list of questions is available in Supplementary Material (E) and in the online version of Tandem (www.weadapt.org/tandem).

and the use of integrated climate information is limited (Butterfield and Osano, 2020). This does not preclude its relevance in other contexts. In fact, Tandem has much to offer processes in the Global North (e.g. André et al., 2020), where there may be a tendency to rush towards data solutions before fully co-exploring contexts and needs.

We argue that Tandem offers a powerful vehicle for decision-makers and other stakeholders to assess whether a transdisciplinary knowledge integration process includes them as full partners, and to advocate for changes where they see the need. The structured nature of the framework offers a way to capture learning about these processes in a standardized way. This supports a community of theory and reflexive practice (Bremer et al., 2019), to share knowledge more effectively, learn from good practice and potentially evaluate impact.

4.4. Limitations and areas for further work

While Tandem and its constituent elements and guiding questions draw largely on empirical evidence from one context-specific case and a survey, its application and testing in other contexts continue.[32] We recognize that the Lusaka case, while exploring many differentiated vulnerabilities and solutions, does not address all situations. Tandem's application in other contexts will likely spur the development of further questions to strengthen and refine the framework. We advocate further research into the design and implementation of effective and accountable monitoring, evaluation and learning (MEL) of long-term outcomes and intangible benefits of such processes.[33] Further work is required to understand what is needed within processes to support sustainable, long-term use of integrated climate information in decision-making and related partnerships.

The time and resource intensiveness of co-exploration and co-production processes can be a barrier (Turnhout et al., 2020).The lack of institutional, financial, technical and career incentives to dedicate time and resources to translate climate science work into "usable science" (Dilling and Lemos, 2011) with societal impact can inhibit climate science experts from sharing data, standards, practices, capabilities and experiences, and collaborating with other actors, as identified from the survey responses. While Tandem does not address this directly, its approach to identifying, engaging and collaborating with a wide range of stakeholders could go some way towards bringing different groups together to share good practices and procedures to enhance data quality and credibility.

5. Conclusions

To achieve traction, global climate, disaster risk reduction and sustainable development agendas require policy action informed by science. The science itself must be perceived as legitimate and credible. It must reflect the complexity of real-life needs and situations faced by people in the position to make policy decisions and take action. People are an important part of this equation. Information that is trusted is most likely to emerge from people who are trusted, and relationships built on trust. As a result of our work, analyses and experiences, we argue that the focus of climate services must shift. To create impact, collaborative learning processes are needed between many different kinds of relevant people who all have roles to play. Climate scientists (traditionally called "providers") and decision-makers and stakeholders (traditionally called "users") must both "provide" and "use" information. In short, they must learn from one another to advance, and to bring about results that fully reflect the integration of knowledge that spans many disciplines and many sorts of expertise. Thus, one insight of this paper is that the pursuit should be to build human and institutional capacities, and to establish critical networks and relationships that set the stage for both science-informed policy and for policy-informed science (Pelling et al., 2008).

This paper introduces a transdisciplinary framework, Tandem, that shifts the existing paradigm in two ways. First, it makes the collaboration *process* itself a focal point. Second, it expands the aims beyond climate per se, to purposefully seek broader benefits (e.g. increased capacity and new relationships) that provide the foundation for science-informed policies and decisions of any nature to gain traction in a complex world. Using the tandem bike analogy, the transdisciplinary knowledge integration "journey", when taken in partnership, itself builds skill, strength, flexibility, coordination and clearer communication. Such benefits render the climate service product "destination" potentially less important than the process or journey itself. Such shifts resonate with related literature that underscores the idea of climate *adaptation* services supporting broader adaptation planning processes (Goosen et al., 2013).

Tandem draws on analyses of empirical evidence from 1) survey responses from climate services stakeholders; and 2) a climate information co-production process in Lusaka, Zambia, where early signs of broad, inclusive and positive benefits subsequently surfaced. All participants – both traditional users *and* providers – emerged with a deeper understanding of climate change and local impacts, increased awareness of the urgency of climate action, an appreciation of the need for collaborative relationships between partners and networks, and increased confidence to ask more informed questions of each other. Behaviours shifted. Ongoing plans, policies and projects in Lusaka began to integrate climate information. Similar in spirit to the observation that "the medium is the message",[34] our key contribution here is that the process is the product.

The insights from this analysis, the literature, and the current lack of traction in policy settings lead us to argue that there is an urgency to transform approaches. The change needed applies to climate services that remain supply-driven, and use stakeholder engagement or even co-production as an afterthought or as a means to an end. Rather, we advocate for an evolution. We urge processes that use the power of genuine collaborative learning. Our work suggests that this can shift perspectives, worldviews and mindsets; build confidence and capacity on all sides; and create the trusted relationships needed to effectively engage. Deep transdisciplinary co-exploration and co-production processes can generate information to spur science-informed decision-making for climate adaptation and beyond. This is an approach that takes time and resources. Tandem requires that we no longer group people into "providers" and "users". Everyone in the process must fluidly shift from providing information (science or context) and using it (context or science). Under such a tenet, "engagement" is neither an optional extra, nor necessarily a means to an end. Instead, collaboration purposefully seeks to build shared understanding among all participants. Such science-stakeholder dialogues have the potential to support more robust, longer-term, climate-resilient decision-making. They can also innovate new pathways for societal transformation.

6. Data statement

The 1) anonymized dataset of survey responses; and 2) reviewed Lusaka Learning Lab documents, are available upon request from the authors.

[32] Case studies (André et al. (2020) (Sweden, flooding and heat risk, urban planning); Butterfield and Osano (2020) (Kenya, Nigeria, rural agriculture); Biskupska and Salamanca (forthcoming), Indonesia, use of traditional knowledge; Santos and Gerger Swartling (forthcoming), Colombia, gender-differentiated decision-making) examine the viability of an earlier version of Tandem (Daniels et al., 2019)).

[33] See Salamanca and Biskupska (forthcomig).

[34] The phrase comes from "Understanding Media: The Extensions of Man," a 1964 book by Marshall McLuhan, who argued that the media, not the content that they carry should be the focus of study.

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CRediT authorship contribution statement

Elizabeth Daniels: Conceptualization, Methodology, Formal analysis, Writing - original draft. **Sukaina Bharwani:** Conceptualization, Methodology, Writing - original draft, Project administration, Funding acquisition. **Åsa Gerger Swartling:** Conceptualization, Methodology, Writing - original draft. **Gregor Vulturius:** Conceptualization, Methodology, Writing - original draft. **Karen Brandon:** Conceptualization, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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