Climate Risk Management 29 (2020) 100239

Contents lists available at ScienceDirect

Climate Risk Management

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

Climate risk narratives: An iterative reflective process for co-producing and integrating climate knowledge

Christopher David Jack[a,*], Richard Jones[b,c], Laura Burgin[b], Joseph Daron[b]

[a] Climate System Analysis Group, University of Cape Town, Cape Town, South Africa
[b] Applied Science, Met Office Hadley Centre, Exeter, UK
[c] School of Geography and the Environment, University of Oxford, Oxford, UK

ARTICLE INFO

Keywords:
Co-production
Climate information
Decision-making
Narratives
Urban planning
Adaptation

ABSTRACT

We introduce the concept of Climate Risk Narratives (CRNs), their origin, and their evolution through a *trans*-disciplinary engaged research activity around urban climate resilience. While the use of narratives as a communication and engagement device is well established and similar concepts such as scenarios and storylines exist, we describe the learning and value that this specific formulation of narratives has brought to an in-depth engagement process. In particular, we describe and explore how different types of uncertainty can be represented, how narratives can be co-produced, the value they bring to integration and interrogation of relevant knowledge, and the emerging role of narratives as *trans*-disciplinary engagement devices or boundary objects. The value of CRNs in producing climate knowledge and integrating it into decision-making is demonstrated through case study examples. Principles for developing CRNs and good practice in their use are proposed before mapping out future directions for research and practice.

1. Introduction

The challenges associated with integrating climate information into real-world decision-making are both significant and well documented. Specific challenges include identifying decision maker information needs and aligning these with climate science outputs (McNie 2007, Dilling and Lemos 2011, Kirchhoff et al, 2013); tailoring these outputs to ensure relevance to the decision context (Tang and Dessai 2012, Jones et al., 2015); and quantifying and communicating confidence and uncertainty (Stainforth et al, 2007, Daron et al, 2015). There is strong evidence to support co-production as an effective and important overarching principle in addressing these challenges, from the perspectives of producing information that is salient as well as building trust, confidence, and ownership of information with decision makers (Lemos and Morehouse 2005; Pohl et al, 2010; Polk 2015; Robinson and Tansey 2006; Swilling 2014; Harris and Lyon 2014).Fig. 1.

However, the real-world implementation of co-production still raises significant challenges for climate scientists and decision makers (Hegger and Dieperink 2014, Vincent et al, 2018, Briley et al, 2015). This is particularly true in complex decision contexts such as urban climate resilience planning where problems have many components and decisions are seldom well defined but involve ongoing multi-faceted negotiations and deliberations around policy direction, strategic planning, and resource prioritization. It is often not clear how to determine climate information needs, or even where climate information can most effectively be introduced into such decision contexts. Different information may also be needed at different stages of a decision process (Bloemen et al., 2019)

* Corresponding author.
E-mail addresses: cjack@csag.uct.ac.za (C.D. Jack), richard.jones@metoffice.gov.uk (R. Jones), laura.burgin@metoffice.gov.uk (L. Burgin), joseph.daron@metoffice.gov.uk (J. Daron).

https://doi.org/10.1016/j.crm.2020.100239
Received 20 December 2019; Received in revised form 10 May 2020; Accepted 3 June 2020
Available online 10 June 2020
2212-0963/

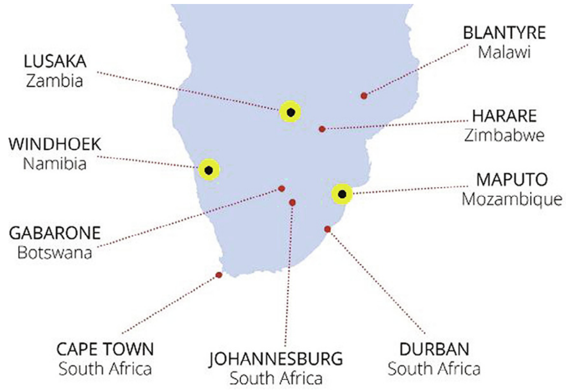

Fig. 1. Map of FRACTAL partner cities with Tier 1 cities highlighted.

and persistent challenges include communication and representation of uncertainty and confidence, and mismatches between the information needed and what climate science can provide (Singh et al 2018). Co-production modes of engagement facilitate navigating these challenges but do not directly provide solutions to them.

The Future Resilience for African CiTies And their Lands (FRACTAL) project, funded by the Future Climate For Africa programme of the UK government Department For International Development / Natural Environment Research Council, has the overarching objective of improving urban climate resilience in southern Africa through the effective integration of climate science information into urban decision-making. FRACTAL is structured around four key elements:

1. Climate science research focused on distilling decision-relevant climate information from available observations, model simulations and expert knowledge.
2. Social science research to improve understanding of the decision-making context in the case study cities.
3. Embedded researchers, local academics employed through the project, positioned within local city government to provide a strong link between the decision context, the local partner university and other project parters.
4. Learning Labs (McClure 2020), *trans*-disciplinary research engagements comprising short dialogues, longer multi-day workshops and virtual engagements in between. These are explicitly designed using principles of *trans*-disciplinarity (Nicolescu, 2014; Klein 2013) by engaging both disciplinary and non-disciplinary expertise through participatory processes to integrate knowledge relevant to distilling "burning issues" in the cities and plans or actions to address them.

The Learning Lab face-to-face series of workshops provided the core engagement activity between a wide diversity of relevant stakeholders and researchers. They were designed to be open ended, with no predetermined objective, and reflexive, whereby participants continually re-evaluated and redirected the content and structure. While the overarching objective of the project involved providing climate science information and integrating it into decision-making, the information needs and research methods were not known at the outset and it was intended they would emerge, potentially uniquely, within each city process. The Learning Labs were also designed to generate research findings on effective co-production and *trans*-disciplinary methodologies.

A particularly useful element that has emerged from many FRACTAL city engagements is the Climate Risk Narrative (CRN). These are narrative descriptions of a context under different plausible climate futures. They qualitatively integrate climate science evidence with local socio-economic, environmental, and built environment contextual knowledge and information. They are intended to describe climate related risks which are meaningful for communities and decision makers in a specific context (a city-region issue in FRACTAL's case). Uncertainty is captured through developing multiple CRNs, each written in the form of an observed certain reality, across a range of plausible futures rather than using uncertainty language, such as "rainfall might decrease or increase" within a single narrative. CRNs typically use a written format, though they have also been represented visually using infographics (e.g. Fig. 4). An example set of narratives can be found in the supplementary information.

Given the aims of the Learning Labs, CRNs have emerged as "boundary objects" (Star 2010; Van Pelt et al., 2015), collaborative learning tools that facilitate engagement across disciplinary or practice boundaries and allow for diverse perspectives and interpretation of information, including lack of consensus. Importantly, CRNs were not originally envisaged or understood as boundary objects. Rather they were originally introduced to initiate conversations between climate scientists and decision makers, and as a means of communicating uncertain climate projections in ways that make the information contextually relevant and meaningful to encourage engagement and uptake.

Understanding their role as boundary objects has enabled further conceptualization around how CRNs are produced and used in co-production and *trans*-disciplinary engagements. This paper then examines the initial and developing hypotheses that CRNs are useful in communicating and integrating knowledge on climate risk, what we have learned within the FRACTAL project about their application as boundary objects, their limitations and caveats, and recommendations on their application more generally in climate services co-production processes.

2. The FRACTAL project and Learning Labs

To advance FRACTAL's overarching aim it undertook deep engagement with at-risk city communities in case-study cities, relevant decision makers and other actors to identify burning issues and formulate solutions through integrating both natural and social science research, and local expertise. Cities are widely accepted to be complex problem spaces, integrating socio-economic, political, and physical systems that are hard to observe and understand, let alone predict their evolution. In developing countries, and particularly in Africa, rapid urbanisation and the dominance of informality strongly magnifies that complexity (Pieterse 2010, Pieterse 2011, Parnell and Pieterse 2016, Bettencourt 2015). Furthermore, the increasing connectivity of trade, economics, politics, and information, means that cities need to be understood, planned, and managed in a regional (or even global) context. The primary case study cities of Windhoek, Lusaka, and Maputo, and the secondary case study cities of Harare, Gaborone, and Blantyre, all exhibit characteristics and challenges associated with rapidly growing cities in developing economies. It was clear from the outset that FRACTAL was engaged in a complex problem space and needed to adopt suitable approaches that added value and avoided harm.

A key principle of engaged research in complex contexts is to ensure wide stakeholder engagement, awareness of the current socio-political dynamic, and sensitivity to complex histories (Parkes & Panelli 2001). Participants within each case-study city included government (e.g. city councilors, town planners, ministry representatives), *para*-state institutions (e.g. water and power utilities, community and resident advocacy groups), local university researchers, and international partners (e.g. researchers, government support institutions, engineers, training institutions). Local partners provided expertise on current sensitivities and their historical contexts through applying another key principle, the use of participatory processes to promote dialogue rather than focusing on information delivery (Harris and Lyon, 2014). In FRACTAL, Learning Labs provided this dialogue space and typically entailed 2 to 3 days of engagement and field visits. Learning Labs were the primary mechanism through which participants were able to steer both the ongoing activities within each city as well as the overarching natural and social science research (McClure, 2020). The content focus, direction, and end points of the Learning Lab approach were determined by the participants.

A key challenge faced at the outset was how to introduce climate information into the Learning Lab process without this information forming an externally imposed framing of the problem space. Cities are faced with many looming challenges, climate change being only one, with climate scientists having neither the expertise or remit to decide how important climate change is within the spectrum of challenges. The hypothesis was that if climate change was a priority issue to be incorporated into decision-making because of potential risks and impacts then this should emerge naturally rather than being directed or assumed. This challenge was approached by focusing initially on a process to enable participant to identify and deliberate over the "burning issues" before climate information (including CRNs) were introduced. Then by framing CRNs as plausible futures incorporating these burning issues and, at least initially, as conversation starters to facilitate collaborative engagement on the actual risks imposed by climate change, CRNs have helped to introduce climate information without dominating the broader urban decision-making process.

3. Background on the CRNs and narratives

The concept and use of CRNs has evolved non-linearly over many years and will be described in the examples provided in this and the following section. These demonstrate key principles and understanding which emerged and are described in section 5.

3.1. The South African 3rd National communication development

CRNs were first developed for the climate projections section of the South African 3rd National Communication (3NC) under the United Nations Framework Convention on Climate Change (UNFCCC, DEA, 2017) reporting mechanism. The previous National Communication used a more conventional approach of presenting quantitative projections of climate variables derived from two different downscalings of global climate model simulations. The associated text described the projections, summarised important messages and highlighted their level of agreement and uncertainty. Conventional descriptions of uncertainty were used such as "Summer rainfall *may* change by between −20% and + 30%" or "Temperatures will increase by between 1.5C and 2.5C by the 2040 s". This language is generally an accurate reflection of the evidence, but difficult to translate into context (Por, et al 2010; Budescu et al 2011; Budescu et al 2014). It is also difficult to capture common links between climate variables. For example, projections may support a scenario of increased rainfall associated with moderate temperature increases and decreased rainfall associated with higher temperature increases. This might result in statements such as: "Rainfall may increase by 10% to 30% in which case temperatures may increase by between 1 and 2C", and "rainfall may decrease by between −10% and −20% in which case temperatures may increase by between 1.5 and 2.5C". Even with just two variables these statements become unwieldy to engage with, and with more variables or indices they rapidly become incomprehensible.

In developing the 3NC, the lead author proposed using multiple narratives as an alternative approach to communicate uncertainty in future climate projections. The intent was to directly provide climate change narratives rather than rely on readers to construct their own based on complicated climate change evidence. The CRNs aimed to be a more effective communication device, transforming available evidence into relatable and comprehensible stories about the future. Multiple narratives allowed for different combinations of change to be isolated. The narrative text didn't include uncertainty language because each was written as one of several plausible futures representative of climate change uncertainty. Inevitably therefore, the CRNs were not attempting to represent every possible future climate state but rather indicative, plausible, and internally consistent stories.

A further aim of the 3NC narratives was to encourage the construction of integrated, multi-sectoral, impact and risk profiles. As is common in such reports, the climate change evidence is provided to various sectoral expert or expert teams who then use this evidence to infer or model impacts in their sector. This introduces two challenges. The first is that each sector team is required to interpret the climate change evidence, typically independently of other sectors. Secondly, this independence makes it difficult to integrate impacts across sectors if each uses different methods, assumptions, interpretations of the climate evidence or knowledge production processes. The hypothesis was that by providing coarse scale initial socio-ecological impact information narratives would spark conversations and deliberations resulting in cross-sectoral integration of knowledge.

Several challenges were encountered in the process of writing CRNs for the 3NC. Firstly, the 3NC was focused on national provinces, some of which are large and climatologically diverse so writing a small set of CRNs is insufficient to cover a representative range of climate futures. For example, some provinces include both summer rainfall and winter rainfall climate regimes with different signals emerging for each due to different processes at play. This results in very many plausible provincial scale narratives. Secondly, developing appropriate and realistic content on the socio-ecological impacts was difficult in the absence of substantive engagement with sectoral experts. The diversity of impacts and the potential interactions across sectors, such as between water, agriculture, economics and health, was overwhelming at such large spatial scales. Thus in the absence of any specific sectoral or other focus, the result was rather generic impact storylines within each narrative that were not sufficiently engaging to sectoral experts.

This first experiment revealed the need to constrain the focus or scope of the context being addressed, but more importantly demonstrated that critical importance of co-producing CRNs with a diversity of expertise and stakeholders.

3.2. City of Cape Town climate risk narratives

The second application of CRNs was for climate change projections for the City of Cape Town, South Africa. Here two changes were made in the process. First, expert elicitation was used to develop the CRN climate storylines. This involved a process similar to the Delphi method (Dalkey and Helmer, 1963) where a number of city-resident climate experts were tasked with constructing brief physical climate change stories for the city and surrounding region, including the key water catchment mountain areas. These were submitted anonymously and blind reviewed by the same group, and then rated in order to identify strongly supported plausible stories and eliminate weakly supported stories. Three plausible futures were identified. The process revealed little real contention and a consistent plausible range of future climates. However, the value of the process was in refining the climatological plausibility of each future. This process is similar to the climate process storylines of Dessai et al. (2018) which used expert elicitation to construct plausible narratives around climate variability and change for a region and set of climate variables.

The second change, implemented in response to the 3NC experience, was to engage more users in the process. This was done through a workshop hosted by the City of Cape Town municipal decision makers and technical experts where the CRN concept was explained, supporting evidence presented and break-out groups focused on participants areas of responsibility (e.g. water, health, transport). Each group was provided one of the three narratives of plausible futures and asked to respond to three questions: (1) how would the climate information feed into their work, (2) what further information is required, and (3) were the impacts described in the narratives realistic? Several responses provided useful insights into the CRNs. These included comments related to the content and form of the narrative messages:

- “We need simple messages, not complex science”
- “Be clear, don’t be scientists”
- “Scenarios = be as clear and specific and confident. Don’t sound ambivalent. Give us the bottom line.”
- “Narratives are good in combination with data”
- “They are a focused way of presenting user information and quite friendly.”
- “Narrative are a powerful device for synthesizing information, good for internalizing information”
- “Narratives should include the bigger global picture”
- “It is better to have narratives”
- “Impacts are negative – can we tie in positive impacts too?”

while other comments spoke to questions about the framing and utility of the CRNs:

- “Can you express information in probabilities?”
- “The local government is crude - they don't need details, they need big messages.”
- “There is a concern that they cannot be applied in terms of getting resources from politicians - politicians need scary numbers”

A further question was asked in discussion: What would you do if presented with all three narratives at the same time. Responses varied with the following two response being indicative of the range of possibilities discussed.

- “We would choose one”
- “We need ranges - We understand it’s not a matter of probabilities - so we must have ranges”

Generally, participants found the content and form of the narratives useful but expressed a desire for even stronger messaging. There was some discussion about the negativity of the impacts and whether more focus could be placed on positive impacts. Questions about the probabilities of each narrative were discussed at length with some participants wanting to be able to select the single most likely future and others more comfortable with a range of possibilities. The workshop discussions also highlighted the complexity of city decision-making. Many participants expressed a need for evidence to motivate for actions or budget allocations. Participants also represented distinct technical areas and so, while a need for integration across sectors was expressed, so was the need for sector specific information and detail.

When considering feedback and discussion on CRNs, it is important to note that their role is to improve integration of climate risk information into decision-making. The primary objective is not necessarily to meet specific desires expressed by decision makers. These are extremely important considerations but require deeper interrogation. For example, many decision makers request one, most probable, narrative. This isn't necessarily difficult. Expert judgment or a consensus process could almost certainly achieve this. Analytical methods exist to reduce uncertainty ranges including simple ensemble averaging. However, this introduces the risk that the single narrative identified is significantly different from the reality that unfolds resulting in adaptation plans which fail or are redundant. So, it may be technically easy to satisfy the needs or desires of information users at a superficial level but then fail them at a deeper level. We'll return later to the nature of the encompassing process that should surround CRN production because this is a critical and essential element, arguably even more important than the CRNs themselves. The next examples describe the application of CRNs within just such an encompassing process.

4. Climate risk narratives in the FRACTAL cities

FRACTAL has applied CRNs within 3 primary focus cities (Windhoek, Lusaka, Maputo) and 3 secondary focus cities (Harare, Gaborone, Blantyre) and their supporting regions using a range of approaches. In the former, initial CRNs were developed by climate scientists in the project because, at the time, CRNs were still understood as climate information communication and conversation starting tools. They investigated the available evidence, typically GCM projections from the Coupled Model Inter-comparison Project phase 5 (CMIP5) (Taylor et al 2012) as well as downscaled projections and historical observations, to construct the different climate storylines. Desktop research on trends in relevant socio-economic components, including population growth and urbanization, determined potential impacts of the different climate futures on key sectors such as water supply, health, agriculture.

CRNs were introduced into city Learning Labs where local city experts from government, NGOs, civil society and academia were able to engage with them through various participatory processes. Discussion on the narratives was used to further develop them, particularly with respect to local contextual information, potential impacts and societal responses, and to evolve thinking on how they were used as an integration tool. Incorporating the CRNs into this learning process has been a significant step forward and it is this step that has allowed their true value to emerge as they are taken up in developing city strategic and implementation plans (see examples below). We now briefly describe the process undertaken in each city, outlining the key learning outcomes.

4.1. Lusaka

The climate evidence the Lusaka CRNs were based on included historical observations and future projections of rainfall and temperature statistics within Lusaka city as well as the much larger Kafue catchment. The Kafue river provides 50% of Lusaka's formal water currently but may provide up to 80% in the future if current infrastructure projects are successfully completed (Lusaka Water Supply Master Plan). The large scale of the Kafue potentially introduced a challenge to the CRNs for the same reasons as large spatial scales were a problem in the UNFCCC 3NC example above. However, we were not interested in impacts or other details within the Kafue catchment, only in potential risks to the Kafue river flows. Socio-economic elements in the CRNs were focused on Lusaka city itself.

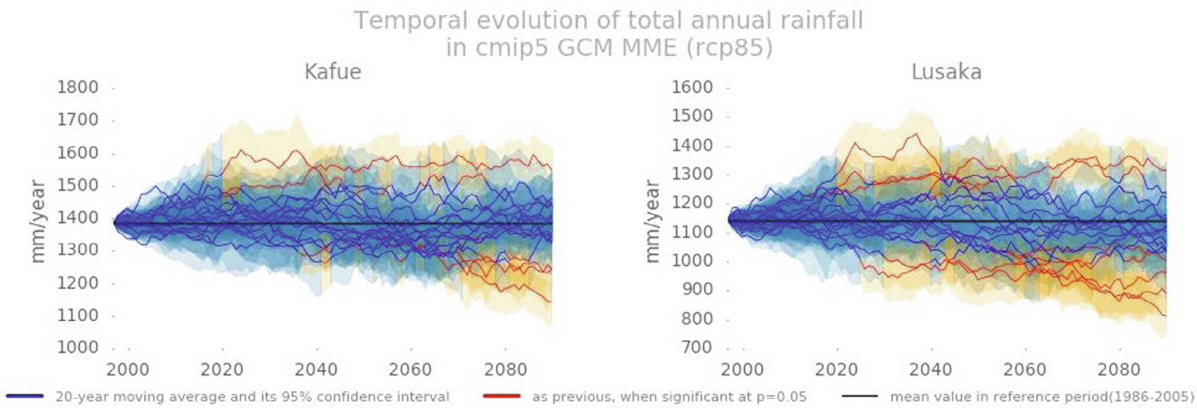

Fig. 2. CMIP5 multi-model ensemble projections of total annual rainfall for the Kafue catchment (left) and Lusaka (right). To aid comparison, rainfall magnitudes have been adjusted so that each model's mean value during the 1986–2005 reference period is the same as the multi-model mean. Thin lines represent each model's 20 year mean anomaly while shaded areas around each line represents the 95% confidence interval around the anomaly (to indicate natural variability uncertainty). Color shift occurs when model 20 year anomaly is significantly different from the reference mean at p = 0.05.

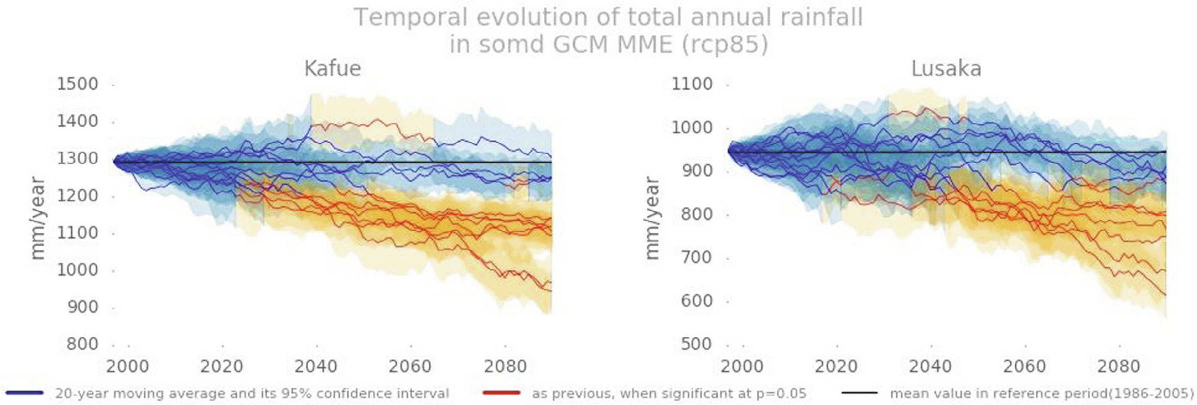

Fig. 3. As for Fig. 2 but using SOMD (Hewitson and Crane, 2006) statistically downscaled CMIP5 projections instead of original CMIP5 model projections.

Both CMIP5 projections as well as statistically downscaled projections developed at the University of Cape Town were analysed (Hewitson and Crane 2006). While CMIP5 projections pointed to high uncertainty in projected rainfall changes (Fig. 2), with many models projecting either increasing or decreasing rainfall across the Kafue catchment and Lusaka, the downscaled projections showed a stronger tendency of drying, particularly post mid-century (Fig. 3). Additionally, CMIP5 projections indicated a possible slight increase in daily rainfall intensity which the statistically downscaled projections did not demonstrate. This disagreement between climate projection models and methods is not uncommon for rainfall and formed a key element of research with FRACTAL (Dosio et al 2019). A risk framing was applied to the problem. The larger Learning Lab process in Lusaka had already identified *peri*-urban water supply and quality and flooding as “burning issues” with reductions in average rainfall a key driver of water supply risk and increasing intensity of heavy rainfall events a key driver of flooding risk. The CRNs thus covered the range of no rainfall change through to reductions in rainfall and included the possibility of increased frequency and intensity of heavy rainfall. All are supported by the evidence, but do not fully span the range of CMIP5 and downscaled projections. While evidence for the possibility of increasing rainfall was always presented alongside the narratives, the risk framing and iterative engagement with decision makers guided the decision to not include an increased rainfall narrative and this was supported by the participants. Other climate evidence including possible shifts in seasonality were included in discussions but as shifts in seasonality largely affect agriculture rather than urban water supply, this evidence did not become part of the CRNs.

During the development of the CRNs FRACTAL partners in Lusaka identified the need for and produced a set of policy briefs on guidance to city decision-makers around the burning issues. The CRNs played a key role in integrating understanding about climate risks within this process. Similarly, the CRNs have played a key role in the development of the Lusaka Water Supply Action and Investment Plan (WSAIP) led by FRACTAL partners in Lusaka.

4.2. Windhoek

The Windhoek CRNs (final version in the Supplementary Information) closely followed the Lusaka approach initially but built on its lessons learned to make some minor alterations to the writing and co-production processes. A more streamlined process was used to distill future versions of the climate for the city-region. An initial attempt to compile a small number of climate futures was carried out by one climate scientist. These were then assessed and iterated in discussions with other climate scientists. The climate evidence indicated a variety of possible hazards including decreasing rainfall and increasing extreme rainfall. Three plausible climate futures were selected to capture a wide spread across the range of uncertainty in the climate information, though not necessarily the most extreme cases. In the socio-economic aspects of the narratives, several provocative but plausible statements were included to trigger debate and engagement during the co-production session in the first Windhoek hosted Learning Lab.

The CRNs, and the reasoning behind them, were presented during the Learning Lab by a climate scientist. Emphasis was placed on them being an initial draft to be deliberated and developed using the range of local and technical knowledge held by the participants of the workshop. Following lively discussions in small groups, oral and written feedback was provided to the project team covering both the content and format. A key piece of constructive feedback received was that a visual format would enhance the CRNs and encourage users to engage with the longer written format. These conversations worked to set the scene for further discussion on “burning issues” within the city in a climate change context.

Discussions within subsequent Labs frequently referred back to the CRNs and they became a point of common understanding, reflecting the participants' shared concerns and ambitions for their city. This shared understanding allowed the FRACTAL team to engage more deeply with the participants, including in the development of the City of Windhoek’s Integrated Climate Change Strategy and Action Plan (ICCSAP), which was being formulated by the city council. For example, a CRN infographic, targeted at the sectors in the ICCSAP, (Fig. 4) was co-developed at the request of a city council partner after reflection on the CRN process and feedback at the Learning Lab. The infographic was subsequently used in a training session of members of the council on

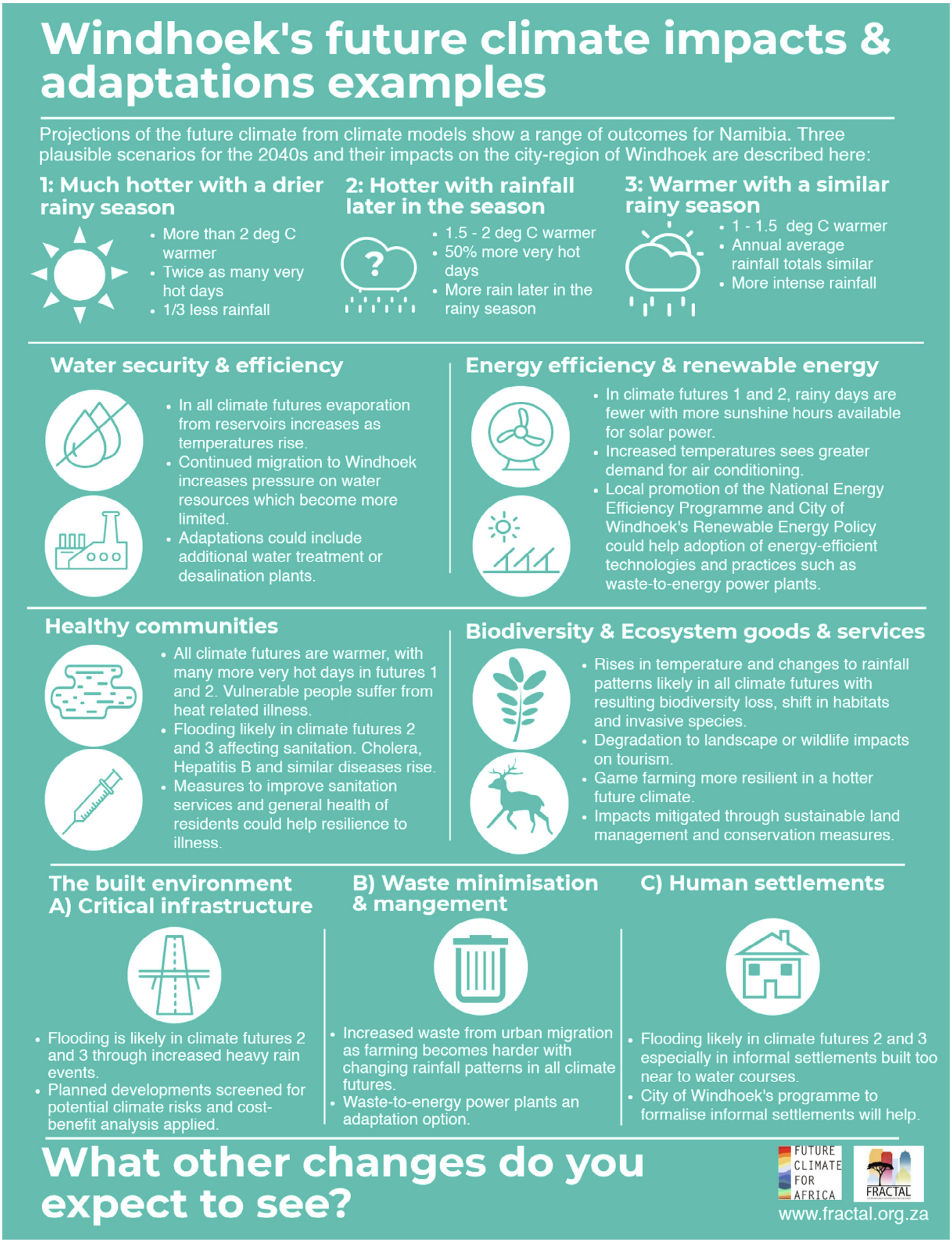

Fig. 4. Climate Risk Narrative infographic developed through the FRACTAL Windhoek Learning Lab process.

"Transformational Leadership in Climate Change" and will be included in the ICCSAP due for imminent publication. Future work on the CRNs in Windhoek will aim to integrate the ICCSAP and other existing development plans. These CRNs will describe different versions of the city with and without specific actions, allowing the City of Windhoek to reflect on and demonstrate the importance of their development plans.

4.3. Maputo

The first set of CRNs for Maputo, developed following the first Learning Lab in the city, similarly adopted an approach of characterizing different but distinct climate futures for the year 2040. Engagement with city stakeholders through the Learning Lab identified three "burning issues" for the city: 1) drainage and sanitation, 2) shortage of potable water, and 3) water governance/ management. These concerns were used to focus the content of the CRNs. Analysis of future climate projections from CMIP5 and a downscaled Met Office ensemble (Buontempo et al., 2014) focused on trends in temperature and rainfall and led to three different narratives characterized as: 1) much warmer, drier in surrounding regions, 2) slightly warmer, no rainfall change, and 3) warmer, increases in extreme rainfall. The CRNs provided quantitative climate change information based on the supporting evidence, with qualitative information on possible impacts determined by the climate scientist writing the narratives. Two formats were used to communicate the CRNs. The first was text narratives, several paragraphs long, and the second was an infographic with three columns for the three narratives, each containing the summary climate information, selected impacts and possible adaptation solutions.

One of the challenges recognized in the process of constructing the new CRNs for Maputo, also experienced in other cities, was the need to provide more salient and precise information about impacts in focus sectors. Thus before the second Maputo Learning Lab it was decided to adopt a different approach. Rather than initially articulating different climate futures, the process involved gathering information on the broader challenges facing the water sector and constructing narratives that sampled different water risk futures. This involved a dialogue with key water sector actors and resulted in a rich set of information about key risks including the poor state of piping in the city, poor institutional coordination, and unequal water tariffs being charged to different communities. They were also asked to imagine different ways in which the city might respond and evolve in the future given different actions, incentives and political will to address water sector risks. This information was then compiled and drafted into two "water risk narratives" for the city of Maputo – described as "business-as-usual" and "transformative decision-making".

For each water risk narrative, the climate model evidence used to construct the previous CRNs was incorporated. For simplicity, only two climate futures were considered: 1) hotter and drier, and 2) warmer with more extreme rainfall, consistent with narratives 1 and 3 used in the first Learning Lab. This produced four CRNs in total – one for each combination of the two water sector futures and two climate futures (e.g. business-as-usual under a hotter and drier scenario). The CRNs were communicated as text-based narratives written in the present tense as well as summarized and communicated in an infographic.

A key challenge in overlaying the climate information was the lack of clear entry points for linking climate hazards to specific water sector risks. This was because much of the content of the water risk narratives focused on non-climatic factors. The result was some minor edits throughout and a short section in the middle specifically describing the climate hazards. This section focused on impacts to municipal water supply and the imagined impact of a drought in the 2030 s, loosely based on the impacts of drought experienced in 2017 and 2018.

As in other contexts, the intention was for the CRNs to prompt discussions on how climate change may impact the water sector in Maputo and which adaptation and policy interventions could be considered robust to the different plausible futures. However, because the information on water sector impacts was much more specific than in previous CRNs and included details of specific organizations involved in water supply and regulation, the discussion largely centered on the accuracy of the description of the city's water sector governance. And despite using information provided by water sector stakeholders in the dialogue, some participants became defensive about how organizations were represented and would respond to future risks.

The lessons from these engagements were that confounding non-climatic factors, including protection rights for water resources and budget constraints, are more difficult to deal with than determining interventions that are robust to an uncertain climate future. However, during feedback at the end of the event, participants did say they had a greater appreciation of the need to consider alternative climate futures in planning and policy decisions.

5. Principles and application

The previous sections have shown that the structure and form of CRNs can be flexible though the following key principles and elements should inform their development:

1. CRNs describe a number of plausible futures as supported by the available science and socio-economic evidence.
2. Each CRN should describe a physically plausible and internally consistent climate storyline in as much as this is supported by the evidence.
3. Language should be written in the present tense set in the future period to avoid cognitive effects such as future discounting.
4. Individual CRNs are written with absolute certainty. That is, they are written from the point of view of someone observing rather than someone predicting so terms such as "very likely" or "30% probability" should not be used.

Point 4 is especially important as it avoids any language of uncertainty which is often an obstacle to engaging with climate information. Despite the rigour often attached to the language of uncertainty used in climate science (e.g. IPCC assessments), it is unavoidable that people will understand words such as *likely* or terms such as *some evidence*, in widely different ways (Budescu et al., 2014).

Multiple CRNs are developed in order to capture climate and potentially other sources of uncertainty (point 1). In almost all contexts uncertainty about future climate changes are large enough that multiple narratives are required. The number of narratives to develop is subjective and requires balancing the desire to span the range of plausible futures whilst ensuring their practical use and engagement. In practice three was often the number settled on, unless circumstances require a variation from this, with more becoming increasingly onerous to engage with particularly in workshop/discussion sessions. Generally, temperature related projections are uni-directional with uncertainty around magnitude rather than sign of change and so temperature uncertainty can often be effectively combined with rainfall uncertainty. This is particularly true for CRNs describing the 2040 s or earlier when the implications of emissions uncertainty is relatively small. In fact, multiple narratives introduce the possibility to describe co-variability of temperature and rainfall in those cases where relationships between them exist, e.g. larger temperature increases associated with rainfall decreases and vice-versa, Berg et al. (2015). Even more specific information can be included such as projected changes in tropical cyclone statistics under different degrees of warming, if the evidence supports such inclusion. This again is a case where more conventional methods, such as maps and accompanying descriptive text, often fail to effectively communicate valuable information embedded in the evidence.

Deciding on how to the CRNs should sample the uncertainty space also depends on the decision or uncertainty framing being used. Within FRACTAL a risk framing has been generally assumed or, in some cases, explicitly decided. This means that the sampling of uncertainty is guided by an emerging understanding of the key risks in a context. For example, in Lusaka, the emerging understanding of the complex role of ground water, flooding, and hydropower, led the participants to focus on CRNs describing reduced rainfall and increases in extreme events. These futures are supported by the science evidence, but evidence also exists for the possibility of increases in rainfall. It must be acknowledged that the plausible futures described will only represent a subset of the full uncertainty space and cannot possibly capture multiple variations in seasonality, spatial distributions, etc. However, CRNs primarily aim to promote engagement between climate science and decision-making. Considering a limited set of plausible futures in depth may be more valuable initially than failing to engage with the complex of the full uncertainty range. Engagement with more comprehensive uncertainty ranges may emerge from the initial engagement with the CRNs, as happened in Lusaka where initial engagement with CRNs contributed to further comprehensive water resource modeling considering a much wider uncertainty space than the original CRNs.

Finally, the CRNs generated in a given context will be dependent on those involved in the co-production process. Whilst this would not be expected of the scientific evidence on climate changes and their immediate impact, aspects such as societal implications and responses would be much more dependent on the different values, priorities and interpretations of risk of those involved in the process which would also be expected to change over time. We therefore do not expect CRNs to be fully reproducible and it does not seem necessary that they should be.

6. Supporting climate science evidence

CRNs are fundamentally developed from a suite of evidence. Different types of evidence are used, climate science data, socio-economic data/information, climate vulnerability and impacts information. We focus here on the climate science evidence base though similar challenges and approaches could be applied to non-climate science evidence.

There are two main types of data used to inform CRN climate elements. The first is historical climate data that is used to characterize natural variability and any observed trends as this is a key aspect that should always be included in any set of climate narratives. Indeed, one useful strategy is to first write a narrative that describes the current climate "story". This could describe the occurrence of wetter and drier periods, extreme events, and seasonality and relevant observed climate changes. One useful device is to include reference to recent significant climate events such as drought or period of flooding as they help reduce the psychological distance (Spence et al., 2012) and so help people connect their personal experience to the narratives. So, for example, in the early Lusaka narratives reference was made to "increasing frequency of droughts similar to the 2015/2016 drought". These references also become useful conversation points around the experienced impacts of a climate extreme that can further inform the narrative construction.

The second type of data is future climate projections. It is assumed that an ensemble of projections is used in order to represent an estimate of uncertainty in different variables and statistics. The CMIP5 (van Vuuren et al. 2011) based experiments form a useful source of projections but others could be used, e.g. from the Coordinated Regional Downscaling Experiment projections (Giorgi et al. 2009). An important principle is that CRNs should represent plausible future climate states without assigning probabilities to different narratives that would add a level of complexity to engaging with them. We want to avoid the temptation to focus on a single narrative because it is estimated to be more likely and avoid the others. Further supporting this approach is the reality that it is highly debatable whether probabilities can be assigned to a particular climate future given ensemble experiments like CMIP5 (Sexton et al., 2012, Sexton and Murphy 2012, Parker 2013). We argue that not only is ascribing different probabilities a problem for engaging with CRNs but that we would not be able to defend any probabilities in the first place. This does not mean that a single narrative may not become the focus in a particular context. Indeed, it is often the case that a single narrative becomes the focal point because it is associated with the greatest risk and a risk framing is being applied, as described above.

Parallel work on narrative and storyline approaches (Dessai 2018, Shepherd et al., (2018), as well as other conceptual approaches such as process chains (Daron et al. 2019), provide a useful complement to CRNs and future work in this area should explore in more depth the alignment of climate physical process narratives and storylines approaches, which are more focused on describing the physical climate system, and CRNs with their strong focus on decision relevant contextual knowledge and engagement.

Finally, we must emphasise the important role of trust, which we discuss in the next section. While co-production approaches promote transparency that is critical to developing trust in information, there remain disciplinary details and technical expertise involved in developing climate evidence (as well as other types) that require some level of implicit trust. The climate science evidence informing CRNs does require comprehensive expertise and understanding of climate science, climate modeling, and defensible interpretation of observed and modeled data.

7. Discussion

It is useful to note that there are several complementary and overlapping concepts and approaches. There is a long history of narrative and discourse analysis (Fløttum, 2010; Fløttum and Gjerstad, 2013; Fløttum and Gjerstad, 2017; Nerlich et al., 2010; Jones, 2014) that focuses on identifying the interrogating narrative within texts, or within broader societal discourse. This understanding of narrative has been further developed to improve science communication (Avraamidou and Osborne, 2009). More recently the use of narratives as means of building collective understanding has emerged (Paschen, 2014, Krauß 2020, Vanderlinden et al. 2020) which, while not informing the initial development of CRNs, demonstrates growing support for the narrative approaches (Shepherd and Sobel, 2020).

There are some important distinctions and overlaps between narratives and scenarios. Scenarios are most commonly used in scenario planning, describing multiple futures for a particular context to develop strategies that can take advantage, or avoid negative consequences, of these (see Dessai et al, 2005 and references therein). One could argue therefore that CRNs were initially formulated as climate scenarios and could contribute to a formal scenario planning processes. However, this is not their primary intent and our experiments with producing CRNs has highlighted their value in knowledge generation and deliberation rather than just collating expert opinion as is typically done in scenario development. CRNs have seldom, if ever thus far, been applied directly in a decision-making process. They start and focus conversations between actors in the decision space then through their development result in sharing and refinement of knowledge. This increased knowledge and understanding across multiple actors is the primary driver of improved decision-making, rather than a formal scenario planning process. In some cases, CRNs are being used to frame further modeling (Ilunga 2018) or analysis to support formal decisions.

The innovation of CRNs lies in their role in a process of transdisciplinary engagement such as the Learning Labs (McClure 2020). Upholding the principles of transdisciplinarity is challenging and arguably many co-production processes fail to do so for reasons outlined in the introduction. CRNs play a number of important roles in this ranging from starting and facilitating conversations across and beyond disciplines and helping to balance epistemic power. We discuss this further below.

7.1. *Starting conversations and integrating knowledge*

Starting conversations between decision makers and climate scientists is often difficult even though they are critical to identifying the information needs of both and beginning the process of climate service co-production (Vincent et al, 2018). Climate scientists may attempt to initiate conversations through presenting potentially relevant climate information, but by covering the range of uncertainty and describing caveats and limitations the information is often difficult to comprehend or considered irrelevant by non-scientists (Lemos et al, 2012). Decision-makers often broadly understand that they need climate information but often find it difficult to articulate these needs. Decision-makers generally do not know what is "possible" to provide and so may either limit their requests to be sure that they can be met, or request information that is impossible to provide with any confidence and so are disappointed or frustrated (e.g. Briley et al, 2015). The result is a form of stalemate that is often difficult to navigate. A common outcome is that climate scientists end up providing information that isn't rejected by decision makers but also is never substantively engaged with or integrated into decisions because it is irrelevant or difficult to apply for a range of reasons (Singh et al, 2018).

We have found that one of the key roles of CRNs is in starting conversations. They enable climate scientists to convey rich climate change and impacts messages, including information about uncertainty, in ways readily understood by non-climate scientists because they avoid uncertainty language and are written in story-based descriptive forms that relate directly to familiar context. They therefore form a useful "meeting ground" for starting conversations and can act as boundary object (Star and Griesemer, 1989, Star 2010) to generate new questions for both decision makers and scientists.

The value of this needs to be strongly emphasized. The communication barrier between scientists and non-scientists is significant (Pidgeon and Fischhoff 2012). With vastly different disciplinary backgrounds, experiential knowledge and usage of common terms and words, much time and energy is required to even start generating appropriate questions of the science and understanding of the decision context as it relates to climate.

CRNs have also proved valuable in facilitating conversations and integrating knowledge amongst climate scientists and between them and other knowledge holders, such as hydrologists, engineers, city planners or politicians. For example, discussions in the Windhoek Learning Labs frequently referred to the CRNs and they became common ground between the participants. This shared understanding of climate risks in Windhoek allowed the FRACTAL team to fully engage with the city on development of their ICCSAP. The CRN approach requires climate scientists to consider and assess deep and wide disciplinary knowledge and translate it into an internally consistent narrative story form. In many senses this process is a good example of climate information distillation. In practice approaches and principles of distillation are not well described and this forms a separate area of research and learning within FRACTAL that is closely aligned to the development of CRNs (Jack 2019).

7.2. Managing power and knowledge

The development of CRNs rapidly revealed critically important epistemic questions. Who holds the power in the knowledge generation process? The idea originated in the climate community with initial examples written by climate scientists about a particular context including its non-climate components. As such they clearly held the power to define the dominant form and storyline of the narratives despite limited knowledge and thus value biases towards the climate science evidence and its implications. Further iteration with other knowledge holders nuanced the narratives by correcting misunderstandings of the context, refining language, etc. but could not fundamentally alter the narratives.

This is best served by an example. In FRACTAL engagements within Windhoek, a strong narrative of decreasing summer rainfall in the past and going into the future rapidly emerged from local officials and practitioners. However, analysis of past rainfall trends produces a high probability (> 95%) of positive rainfall trends over the past century: increasing rainfall, not decreasing as reported by local experience. It would be tempting and easy to allow climate science to dominate the knowledge space in this context and relegate local experience to failing memories or skewed perceptions. However, rather than pitting knowledges against each other, these should be seen as opportunities to start conversations that wouldn't normally happen. However, this requires that the conversation happens where trust and relationships are strong. This is one of the key reasons why CRN development should occur within *trans*-disciplinary processes that explicitly target relationship building, trust, and balancing epistemic power.

Within FRACTAL some work was also supported to explore what happens when narratives are first written by representatives from city contexts (Blantyre, Gaborone and Harare) without considering climate change in order to try to oppose the climate science dominance. Even in these examples, climate change still dominated the narratives. This is likely because the task was still framed within the context or question of a changing climate. The Maputo water risk narratives described above are another example where there was an attempt to break away from the dominant climate storylines framing. However, as already noted, it then becomes challenging to overlay climate change uncertainty. These avenues are important areas of further exploration and are being pursued in further related research on perceptions of climate risk (Steynor et al., 2020).

7.3. Risk or impact?

Some have questioned the naming of the narratives as climate *risk* narratives rather than climate *impact* narratives. Under the IPCC framing (Lavell et al., 2012), risk is the combination of hazard, vulnerability and exposure. CRNs aim not only to describe the climate hazard, but, through the integration of contextual knowledge about vulnerability and exposure, to articulate elements of risk. Whilst acknowledging above that we are not ascribing probabilities to the climate hazard elements, each narrative captures the structure (contributing elements) of risk around a certain set of impacts resulting from a particular suite of climate hazards intersecting with vulnerability and exposure. However, non-climate related risk drivers such as increasing water demand, development pressures on ecosystems, or economic effects can also be integrated and the intersection (amplifying or mitigating) of different climate and non-climate hazards is an important element of many narratives. In the urban narratives developed within the FRACTAL project, the non-climate hazard of urban population growth often intersects with the climate hazard of drought to amplify the risk of failed water supply. The integration of non-climate and climate related hazards to describe risk adds value to the knowledge production and integration process. As the risk component is so central, the name Climate *Risk* Narratives is deemed more appropriate.

8. Conclusions

We conclude by reflecting on the story of the CRN approach and how it evolved from a means to improving climate science communication, through to a core element in deep engagement with decision-making experts. This journey reflects a parallel evolution in thinking around how climate information should be integrated into decision-making. We argue that the experiences of applying CRNs across varying contexts and within various processes has provided strong evidence that the integration of climate information into decision-making should be rooted in deep engagement that respects and values multiple types and elements of knowledge and encourages deliberation around diverse perspectives and agendas. Therefore, while improved approaches to communicating climate science including visualisations and other creative methods are important (Harold 2019), the challenge extends beyond communication and rests in developing new understanding and knowledge amongst climate scientists, other scientists, decision makers and other contextual experts.

Other learning emerging out of FRACTAL provides greater detail on the nature and value of these engagement processes and the various elements that are at play. However, CRNs have proved to be an important "golden thread" through these processes (Harold 2019). At the same time CRNs have their limitations and should be applied thoughtfully and reflexively. How the narratives reflect on different stakeholders should be considered critically. The purpose and limits of CRNs should also be clearly communicated up front. It must be clear to all involved how the narratives are constructed, the nature of the evidence supporting them including uncertainties and assumptions, and their role as conversation starters and knowledge integrators rather than definitive predictions of the future.

Finally, there exists great opportunities to explore other approaches to constructing and applying the CRN approach. While we have attempted to list principles and guidance based on our experience and current understanding of their utility, there is certainly scope to adapt and challenge many of these principles. One particular area of interest is around the relative and absolute probability or confidence in the narratives and how such information could be both constructed statistically as well as integrated into the approach in a way that is defensible and adds value.

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.

Acknowledgements

This work has been funded by the U.K. Department for International Development/Natural Environment Research Council via the Future Climate for Africa (FCFA) funded project FRACTAL (Future Resilience for African CiTies And Lands), NE/M020061/1.

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