Climate Policy

ISSN: 1469-3062 (Print) 1752-7457 (Online) Journal homepage: www.tandfonline.com/journals/tcpo20

How is climate science used to inform national-level adaptation planning in southern Africa?

Ailish Craig, Rachel A. James, Emma Archer, Joseph Daron, Christopher D. Jack, Richard G. Jones, Alan T. Kennedy-Asser, Jessica Lee, Alice McClure, Christopher Shaw, Anna Steynor, Andrea Taylor & Katharine Vincent

To cite this article: Ailish Craig, Rachel A. James, Emma Archer, Joseph Daron, Christopher D. Jack, Richard G. Jones, Alan T. Kennedy-Asser, Jessica Lee, Alice McClure, Christopher Shaw, Anna Steynor, Andrea Taylor & Katharine Vincent (15 Apr 2025): How is climate science used to inform national-level adaptation planning in southern Africa?, Climate Policy, DOI: 10.1080/14693062.2025.2488988

To link to this article: https://doi.org/10.1080/14693062.2025.2488988

CLIMATE POLICY
https://doi.org/10.1080/14693062.2025.2488988

Taylor & Francis
Taylor & Francis Group

OPEN ACCESS Check for updates

How is climate science used to inform national-level adaptation planning in southern Africa?

Ailish Craig [a], Rachel A. James [a], Emma Archer [b], Joseph Daron [a,c], Christopher D. Jack[d], Richard G. Jones[c], Alan T. Kennedy-Asser [a], Jessica Lee[d], Alice McClure[d], Christopher Shaw [e], Anna Steynor[c], Andrea Taylor[f,g] and Katharine Vincent [h,i]

[a]School of Geographical Sciences, University of Bristol, Bristol, UK; [b]Department of Geography, Geoinformatics and Meteorology, University of Pretoria, Pretoria, South Africa; [c]Met Office Hadley Centre, Exeter, UK; [d]Climate System Analysis Group, Environmental and Geographical Sciences Department, University of Cape Town, Cape Town, South Africa; [e]Climate Outreach, Oxford, UK; [f]Centre for Decision Research, Leeds University Business School, Leeds, UK; [g]Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds, UK; [h]Kulima Integrated Development Solutions, Pietermaritzburg, South Africa; [i]Global Change Institute, University of the Witwatersrand, Johannesburg, South Africa

ABSTRACT

Climate model projections are increasingly being included within adaptation planning across sectors but there is limited understanding of how they are being used, and to what extent they improve adaptation planning. This article investigates how climate projections inform adaptation planning processes in the National Communications (NCs) to the United Nations Framework Convention on Climate Change (UNFCCC) in 16 southern African countries through a document analysis together with 18 key informant interviews. The study found that all the NCs include future climate model projections for the mid and/or late twenty-first century and focus on average changes in temperature and precipitation; meanwhile, the models, scenarios and time periods used vary between countries. The climate analysis is often detached from the adaptation planning section of the NC. The impacts and adaptation sections focus on key risks, such as flooding and drought and have limited recognition of uncertainties, suggesting plans are made without considering the full range of plausible futures. The role of climate science in the adaptation planning process varies, with some evidence of highly collaborative processes, resulting in evidence-based adaptation options across sectors and scales. In many cases, boundary agents play a key role in interpreting and communicating climate projections. We suggest that providing additional climate projections is unlikely to improve national adaptation planning, despite their scientific benefits. Instead, the focus should be on developing approaches and collaborative processes to distil and interpret climate information in different contexts, to enable decision-makers to understand the range of plausible futures, including changes in climate alongside growing populations, urbanization and changing economies.

Key policy insights

- Climate data analysis in policy documents is often limited to average temperature and rainfall, and the average of many models, which may underestimate emerging risks, for example, from heat and sea level rise.
- Climate data analysis is sometimes detached from impact assessment and adaptation options; a potential barrier to rigorous decision-making.

ARTICLE HISTORY
Received 31 July 2024
Accepted 31 March 2025

KEYWORDS
Climate projections; climate adaptation; climate services; southern Africa; decision-making

CONTACT Ailish Craig ailish.craig@bristol.ac.uk School of Geographical Sciences, University of Bristol, Bristol, BS8 1SS, UK
Supplemental data for this article can be accessed online at https://doi.org/10.1080/14693062.2025.2488988.

- Collaborative processes can integrate climate science into risk assessment and adaptation planning, with a key role for boundary agents.
- Improving evidence-informed adaptation planning requires the interpretation of information through a collaborative process.

1. Introduction

Countries are increasingly focused on developing national climate change adaptation options and plans to promote a climate-resilient future. Additionally, countries are also developing and submitting documents, such as National Communications (NCs) and National Adaptation Plans (NAPs), in alignment with their commitments as Parties to the United Nations Framework Convention on Climate Change (UNFCCC). Mid- and end-of-century climate projections can provide a range of plausible futures which may help to support the national planning processes, including economic or sectoral planning and climate policies (Jones et al., 2015). The inclusion of climate projections has become common; however, there is still a somewhat limited body of research evidence showing specifically how climate projections are currently being used in this context in southern Africa.

As such, this study aims to identify what climate projections are included and how they are used in national climate adaptation planning processes. As all countries in southern Africa have submitted a similarly structured National Communication to the UNFCCC, we conduct a document analysis of NCs, allowing for between-country comparison. To complement the document analysis and provide a broader understanding, 18 interviews were conducted with experts who were involved in the formulation of NCs and/or other climate adaptation planning.

Effective climate service processes provide climate information in a usable way. Although initiatives have focused on improving climate services, there remains a persistently limited use of climate projections in decision-making (Jones et al., 2015; Weaver et al., 2013). One reason for this limited use is the 'usability gap' between the climate information that is produced by climate scientists and what is actually useful or usable to those in the policy arena (Lemos et al., 2012). In the context of national climate adaptation planning there have been initiatives aimed at improving climate projections for decision-making by providing ready-to-use resources, portals and technical guidance to generate climate projections (Jones et al., 2015; LDC, 2012; Lu, 2015; McSweeney et al., 2010).

Yet using climate projections to inform national adaptation planning in southern Africa, remains a complicated process (Jack et al., 2020; Singh et al., 2018; Tall et al., 2018) and the uncertainties and complexities of climate science contribute to the usability gap (Bornemann et al., 2019; Lemos et al., 2012; Vincent et al., 2020b). Whilst many scientists agree that a high-quality set of climate projections would use multiple scenarios and a large ensemble (Jack et al., 2021), there are no agreed-upon criteria for what results in a good set of climate projections. As such, there is no quality control or set methodologies for the climate projections used in the NCs or NAPs. Climate projections have multiple sources of uncertainty: model uncertainty, natural variability, emissions and socioeconomic factors (Jack et al., 2021) and although downscaled climate projections are often desired by decision-makers, this can result in additional uncertainties. Although uncertainties are a global issue, they are particularly problematic in southern Africa where many of the climate models have large biases (Munday & Washington, 2018) and models disagree on the direction of future precipitation change (Bhave et al., 2022; Lazenby et al., 2018). Other challenges to climate change adaptation planning include short political cycles (Steynor & Pasquini, 2022), limited government ownership due to the involvement of external technical consultants and lack of financial capital (Theokritoff & Lise D'haen, 2022).

There is a robust body of research on the use of shorter timescale weather information in decision-making (Rigby et al., 2022; Singh et al., 2018; Vaughan et al., 2018) and end-user decision-making (Born et al., 2021; Clarkson et al., 2022; Vaughan et al., 2019). However, more examples of how long-term climate information informs adaptation and investment are required (Vaughan & Dessai, 2014), particularly at national and sub-national levels in Africa. Climate projections are already being used for decision-making processes, but research on how they are used in practice in sub-Saharan Africa is limited. In a study that explored the use of weather forecasts and climate projections in national documents in Malawi, researchers found long-term climate projections were rarely used, and there was more focus on shorter timescales (Vincent et al., 2017). There has been limited previous research focusing on the use of climate science in NCs, with the exception of the global review of how science is customized in NCs by Skelton et al. (2019). They found variations in the complexity of the climate modelling methods used globally, including in southern Africa.

This study will be the first to use National Communications to investigate the way climate projections are used for national-level adaptation planning, focusing on southern Africa. We address the following research questions: (a) What climate projections are included in National Communications and other national adaptation planning processes in southern Africa? (b) How is uncertainty represented, interpreted and communicated? and (c) How do climate projections inform national adaptation planning processes and are there barriers? This paper includes an overview of National Communications and the methodological approach in Section 2 and a combined results and discussion section in Section 3. The paper concludes with a broader discussion which considers how science-informed adaptation planning can be improved (Section 4) and a conclusion in Section 5.

2. Research methodology

A qualitative approach was taken and included a document analysis of National Communications and key informant interviews (KII). A flow chart of the methodology is available in Figure 1 and further details are in the Supplementary Materials.

2.1. Document analysis

A document analysis of the National Communications to the UNFCCC was undertaken for the 16 countries in the Southern African Development Community (SADC); Angola, Botswana, Comoros, Democratic Republic of

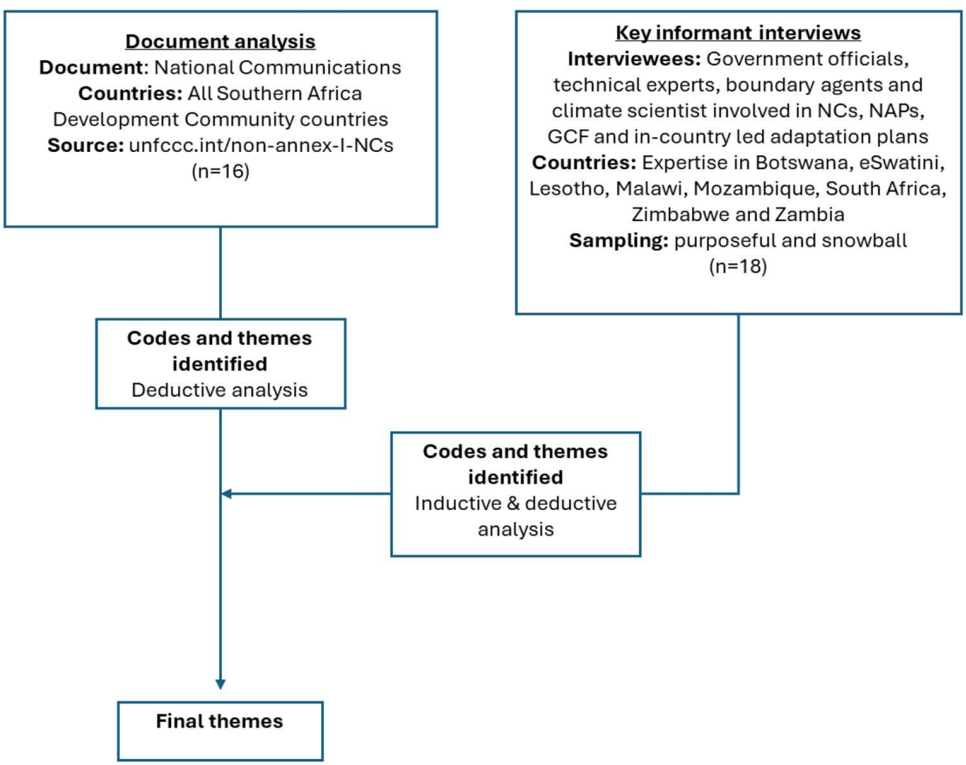

Figure 1. Methodology flowchart.

Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe. It is a requirement for Annex 1 and Non-Annex I Parties to the Convention to submit NCs every four years. The NCs report the country's progress towards climate adaptation and mitigation targets and are an opportunity to highlight any gaps and constraints they are facing in meeting their targets. The UNFCCC provides technical support, whilst financial support is available through associated agencies (Sova & Schipper, 2019).

The NCs include 6 key sections: national circumstances; greenhouse gas inventory; vulnerability and adaptation; technology; research and observations and education, information and capacity building. We focus on the vulnerability and adaptation chapters, within which countries usually provide climate projections and key summaries. The document analysis used deductive thematic analysis, whereby codes were developed *a priori* and are based on literature and theory.

2.2. Key informant interviews

Alongside the document analysis, 18 key informant interviews (KII) were conducted to provide a deeper understanding of how climate projections feed into adaptation decision-making processes. Experts were chosen using purposeful and then snowball sampling (Creswell, 2014) to ensure all participants had been involved in national adaptation planning and/or the development of NCs, NAPs and/or produced climate information within the SADC region. Although the document analysis only included NCs, a wider criterion than solely NCs' involvement was decided for the KII for two reasons: (1) to recognize that NCs are only one part of a country's adaptation activities and (2) to ensure a large enough sample size.

The group of experts included climate scientists, government decision-makers, technical experts and people in boundary organizations (see Supplementary Material Table 1). Boundary agents foster the exchange between the production of knowledge and its use to support evidence-informed decision-making and in this context include impact modellers, consultants and applied researchers (Bednarek et al., 2018). Meanwhile, technical experts provided external technical assistance to countries developing adaptation plans. After 18 KII, common themes were starting to emerge, and saturation had been reached. Thematic analysis of the KII was undertaken in NVivo using both an inductive and deductive approach (Terry et al., 2017). The final themes are combined themes from the KII and the document analysis (Figure 1). Quotes were taken from the transcripts as a narrative support to the key findings.

3. Results and discussion

The following section combines both the document analysis and KII to answer key questions. The participant group is indicated in each quote which are climate scientists (CS), boundary agents (BA), government officials (GO) and technical experts (TE). KII discussed a wide range of contexts including NCs, NAPs, internally driven national adaptation planning, private company adaptation planning, GCF project proposals, city-level planning and community-level planning.

3.1. What climate projections are being presented for adaptation planning?

Climate projections of temperature and rainfall were included in all of the NCs. The scenarios, models and timeframes used for the climate projections vary and this is illustrated in Table 1. The types of model results presented include analysis of output from future experiments with global General Circulation Models (GCMs) and analysis of output from statistical or dynamical downscaling of GCMs (dynamical downscaling is done with Regional Climate Model (RCMs)). Some of the reports make use of products designed to make it easier for users to generate projections for their own applications. Skelton et al. (2019) refer to these as 'look-up' studies, such as the UNDP Climate Change Country Profiles (CCCP) (McSweeney et al., 2010) which have figures for each country that can be inserted into a policy document, and 'plug-n-play' software packages where users can generate customised projections, including MAGICC/SCENGEN (Wigley, 2008). In a few cases, it is unclear which approach has been used to generate the projections. The most commonly used

Table 1. Overview of the climate projections used in the most recent National Communications of the 16 countries in the SADC region. Model names are written as stated in the documents themselves (and may not correspond to official model short names.)

Country	Year & Iteration	Type of climate projections	Extra information	Timeframe	Scenario	Models used	Number of models
Angola	2021 (2nd)	GCMs – dynamically downscaled & look-up study	CORDEX – Africa & UNDP CCCP	2021–2050, 2051–2080	RCP 8.5	GCMs (MPI-ESM-MR, HadGEM2-ES, NCC-NorESM1-M), RCMs (CCLM5-0-15, REMO2015)	3 GCMs, 2 RCMs
Botswana	2019 (3rd)	GCMs – downscaled	Specific downscaling method unclear	2050	RCP 4.5 & 8.5	Not stated	Not stated
Comoros	2013 (2nd)	Plug'n'play & look-up study	MAGICC-SCENGEN & UNDP CCCP	2025, 2050, 2100	SRES A2, A1B & B1	Not stated	Not stated
DRC	2015 (3rd)	GCMs – statistically downscaled & plug'n'play	Specific downscaling method unclear & MAGICC-SCENGEN	2046–2055, 2056–2065, 2081–2090, 2091–2100. 2050, 2100	SRES B1, RCP 2.6, RCP 4.5	GCMs (CCCMA, MPI-ECHAM CNRM and IPSL)	4 GCMs
Eswatini	2016 (3rd)	GCMs – statistically downscaled	CMIP5 GCMs, specific downscaling method unclear	Not stated	RCP 4.5 & 8.5	Not stated	10 GCMs
Lesotho	2021 (3rd)	GCMs – dynamically downscaled	CORDEX – Africa	2011–2040, 2041–2070, 2071–2100	RCP 4.5 & 8.5	GCMs (CCCma-CanESM2m CNRM-CERFACS, CNRM-CM5, ICHES-EC-EARTH, MIRCO-MIROC5, MOHC-HadGEM2-ES, MPI-M- MPIESM-LR, NCCC-NorESM1-M and NOAA-GFDL-GFDL-ESM2M)	8 GCMs
Madagascar	2017 (3rd)	Plug'n'play	MAGICC-SCENGEN	2025, 2050, 2075, 2100	Not stated	GCMs (HadCM3, CSIRO MK.0, ECHAM5/MPI-O)	3 GCMs
Malawi	2021 (3rd)	GCMs – statistically downscaled	Specific downscaling method unclear	2011–2040, 2041–2070, 2071–2100	RCP 4.5 & 8.5	Not stated	Not stated
Mauritius	2017 (3rd)	GCM- dynamically downscaled	Single RCM	2051–2070, 2061–2070	RCP 4.5 & 8.5	RCM (COSMO-CLM)	1 RCM
Mozambique	2022 (2nd)	GCMs – statistically downscaled & look-up study	Downscaled CMIP3 projections from the 2009 National Disaster Management Report & UNDP CCCP	2046–2065, 2080–2100, 2030, 2060, 2090	SRES A2, A1b & B1	GCMs (ECHAM, GFDL, IPSL, CCCMA, CNRM, CSIRO and GISS).	7 GCMs
Namibia	2020 (4th)	GCMs – statistically downscaled	Specific downscaling method unclear	2040–2069, 2070–2099	SRES A2	Not stated	8–35 GCMs
Seychelles	2013 (2nd)	Plug'n'play	MAGICC SCENGEN	2070–2100, 2025, 2050, 2100	SRES A1, B2	GCMs (CMS, ECHS, ECH4, GFD, HAD2, HAD3, MODBAR)	7 GCMs
South Africa	2018 (3rd)	GCMs dynamically & statistically downscaled,	Dynamical: CCAM Statistical: self-organizing maps.	1960–2099, 2040–2060, 2080–2099	RCP 4.5 & 8.5	GCMs (ACCESS I-0, GFDL-CM3, CNRM-CM5, MPI-ESM-LR, NorESM I- M and CCSM4), RCM (CCAM),	Dynamical (6) & statistical (11) downscaling + 14 additional
Tanzania	2015 (2nd)	Plug'n'play	MAGICC/SCENGEN	2050, 2100	Not stated	Not stated	Not stated

(*Continued*)

Table 1. Continued.

Country	Year & Iteration	Type of climate projections	Extra information	Timeframe	Scenario	Models used	Number of models
Zambia	2020 (3rd)	GCMs – statistically and dynamically	CMIP5 GCMs for statistical downscaling, CORDEX Africa	2020–2049	RCP 4.5 & 8.5	GCMs (CanESM2, CNRM-CM5 and MPI-ESM-MR)	3 GCMs
Zimbabwe	2022 (4th)	GCMs – dynamically downscaled	CORDEX – Africa	2020–2040, 2041–2060, 2061–2080, 2080–2099, 2070–2099, 2071–2100	RCP 4.5 & 8.5	Not stated	10 GCMs, 7 RCMs

emissions scenarios were Representative Concentration Pathways (RCP) 4.5 and 8.5; however, it is important to note that not all countries state the scenario(s) adopted or used a single scenario. Similarly, the timeframes chosen varied with some countries using projections up to 2100, and other countries focusing more on projections for the mid-twenty-first century. It is unclear why different climate projection approaches were adopted. However, older NCs used MAGICC SCENGEN, whilst newer NCs were more likely to use CORDEX, which is likely driven by advances in modelling and software.

Although the projections in the NCs were for the mid or late twenty-first century, participants explained that nearer-term information for 5–10 years in the future was favoured for adaptation planning. National strategies, agendas and planning occur on shorter time scales (Vincent et al., 2017) and climate information should align with that temporal scale. In some cases in East Africa, seasonal forecasts were viewed as climate change planning (Steynor & Pasquini, 2022). However, predicting the climate on a 5–10-year timescale is challenging (Goddard et al., 2013; Nyamwanza et al., 2017), thus projections for the mid or late twenty-first century may not give a good indication of how the climate will evolve over the next 5–10 years. Longer timescales were mentioned by the interviewees but information beyond 2050 was not generally perceived as useful, including for accessing funding. One participant highlighted the value of using longer-term climate information because '*if you take this [decision making] route, yes it may work in three years, but in the next 15, 20 years plus, it may not work* – BA'. Meanwhile, a government official believed that '*a prediction up to 2050 can be useful, and it can inform some decision-making processes*-GO'. However, the participant was not using climate projections currently.

The annual averages or totals of temperature and precipitation are the most commonly used indices (Figure 2) with fewer NCs included projections for sea level rise ($n = 4$), tropical storms ($n = 1$), sea temperature ($n = 1$) and flooding ($n = 1$). In the content analysis of the 16 NCs, 'flood' and 'drought' were a top 5 mentioned hazard in 16 and 13 NCs, respectively and are mentioned in other sections of the NCs. This emphasis on extreme events is to be expected, yet, the climate projection section of the report rarely includes analysis beyond average temperature and precipitation.

The use of annual averages or totals could mask such extremes, and the limitations of relying solely on annual means were highlighted by some interviewees who '*didn't find the trends in terms of total annual rainfall. But the trends that we did find [were] in what we call extreme rainfall indices – CS.*' The particular focus on mean temperature and precipitation is not clear. It is common for climate projections to include these variables in summaries and this style may have been adopted in the NCs.

Many of the older NCs are based on projections from MAGIC-SCENGEN and UNDP CCCP, which are relatively coarse in resolution. The more recent reports tend to use statistical or dynamical downscaling, suggesting an improvement in climate projection capacity. Downscaled climate projections were preferred by governmental participants, a finding that aligns with Steynor et al. (2016). Yet downscaled climate projections have many uncertainties, especially for precipitation (James et al., 2017; Lennard et al., 2018), and thus do not necessarily lead to greater confidence (Wilby & Dessai, 2010). Of the interviewed climate scientists and boundary agents, 4 discussed the challenges of downscaling. There was an awareness that downscaling to a district or city level was '*very difficult from a scientific rigour perspective-CS*' and were wary of

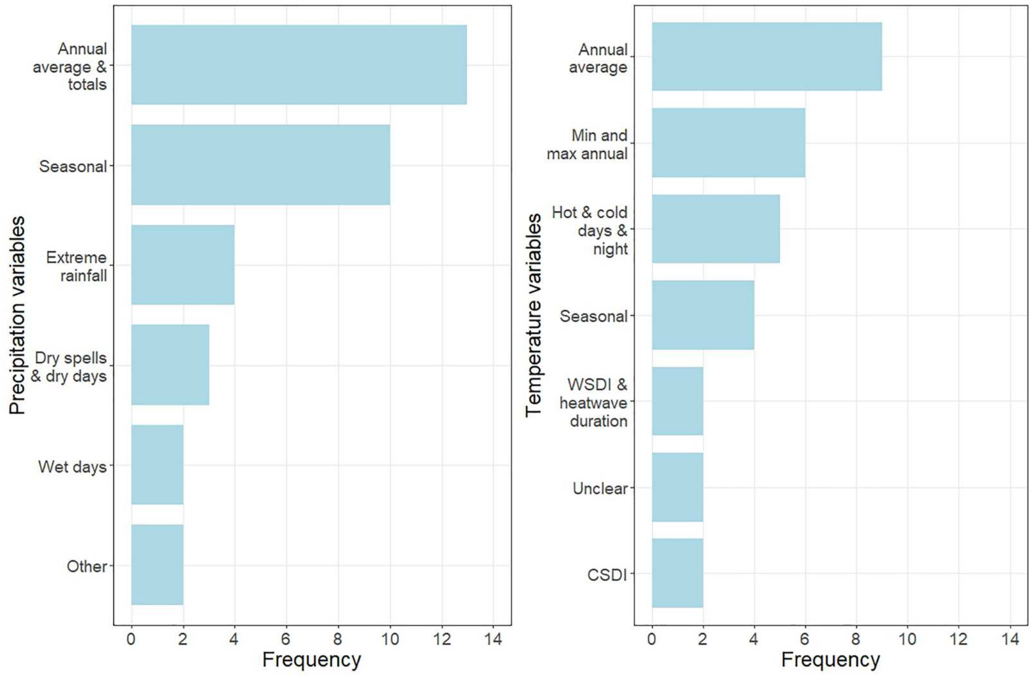

Figure 2. Temperature and precipitation variables used in the climate projections of National Communications. The frequency indicates the number of NCs in which each variable is analysed. WSDI-warm spell duration index, CSDI – cold spell duration index.

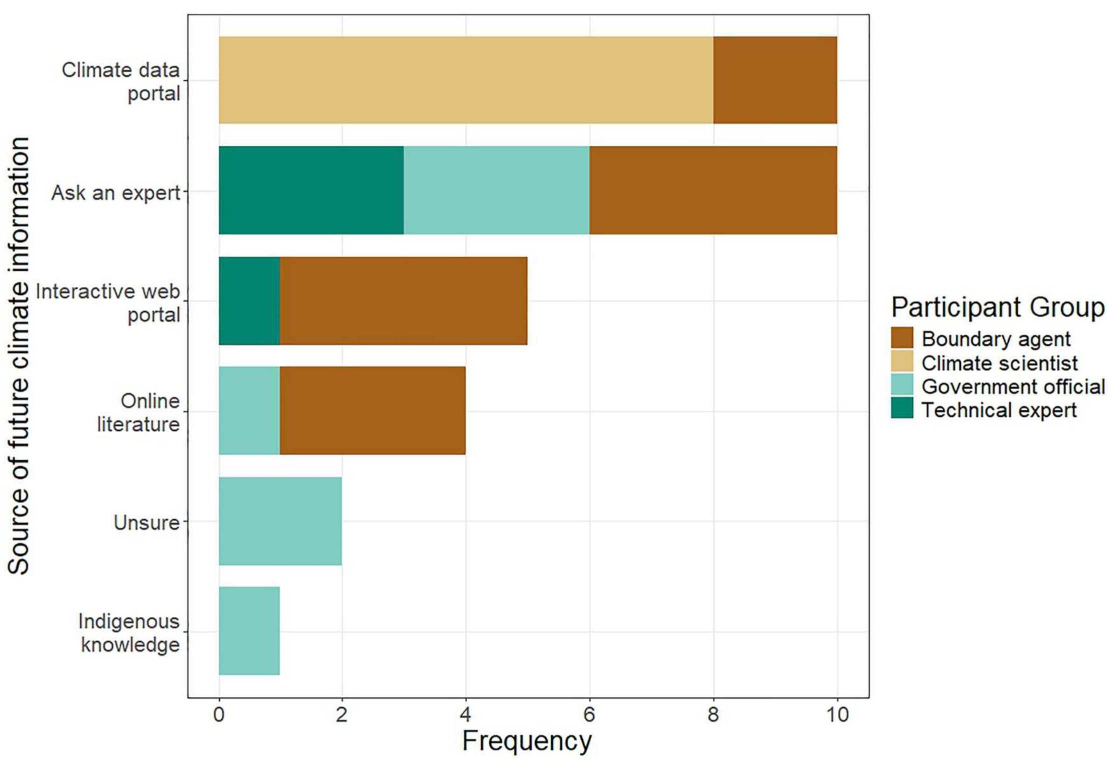

Figure 3. Source of climate information or data used by interviewees, based on the participant group.

providing high-resolution projections because '*in terms of accuracy, I wouldn't trust anything that would go down below 10 kilometres to be honest. Just microclimates will have a much bigger impact at that point – BA.*'

The interviewees sourced their information from a range of locations and formats (Figure 3). Unsurprisingly, climate scientists accessed data so they could conduct their own analysis. Portals such as the World Bank Climate Change Knowledge Portal (CCKP) were not used by government officials, despite the portal being specifically for development practitioners and policymakers. The CCKP was described as '*good if you understand the terminology. They do talk about percentiles* – BA' which could be a barrier to entry for non-climate experts. A review of 42 climate information websites found that they overestimate the ease of use and require a significant level of technical capability (Hewitson et al., 2017). Although it may not be usable by decision-makers, boundary agents had positive feedback for the CCKP which '*allows you, despite not being a modeller, to also just play with it and create different scenarios, which is user friendly-BA.*'

Concerns about the quality of the data and information were highlighted now that people have '*more and more access to the Internet. They will find data, they can use it. But again garbage in, garbage out-CS.*' Climate projections are sometimes available without supplementary metadata, robustness or validity information and users are not able to judge this for themselves (Hewitson et al., 2017; Steynor et al., 2016). A technical expert suggested the production of a '*traffic light system … .[where for] some type of decisions, you would say, we have reasonably good information … which you should definitely aim to apply those in a decision. And then [for other types of decisions], the science is just not there yet-TE.*'

3.2. How is uncertainty acknowledged?

The representation and acknowledgement of uncertainty of climate projections in the NCs were generally accounted for by adopting multiple emission scenarios, and multiple models and providing a range of values when stating projections (Supplementary Figure 1). Uncertainty was accounted for by using multiple models by 11 NCs; meanwhile, 5 NCs did not state the number of models used and 1 NC used a single RCM. The number of models used ranged from 1 to 35 (Table 1). An analysis of a subset of 5 CMIP5 GCMs found that at least 13 GCMs would be needed to adequately capture the range of projected mean changes in temperature and precipitation (McSweeney & Jones, 2016). As such, the number of models for many of the NCs may be too low, which could result in maladaptation.

The NCs vary in terms of their treatment of different climate model futures. Some NCs explicitly acknowledge that different GCMs have different future projections, leading to uncertainty in how the future will unfold. Yet in many of the NCs, there is limited or no recognition of inter-model uncertainty. Where inter-model uncertainty is acknowledged in the climate projections chapter, it often doesn't appear in other sections. Similarly, many of the models in the NCs use central estimates from the ensemble (including both mean and median) which is not always communicated transparently, and it is not clear to the reader that this conceals uncertainty from different GCMs. The multi-model average will not correspond with any of the individual models' responses and so may fail to capture important future changes (Shepherd et al., 2018). In contrast, the South African NC includes alternative narratives for how the climate of each province could unfold e.g. 'hot and dry' or 'warmer, wetter', a relatively novel approach for representing uncertainty which has shown promise in work with decision-makers (Jack et al., 2020). Whilst many NCs used both lower and higher emissions scenarios and NAP guidance recommends RCP 4.5 and RCP 8.5, interview participants focused more on higher emissions.

The way in which climate scientists and boundary agents account for, and represent uncertainty varies too. One climate scientist explained that '*after validating [climate models], then you choose the ones which are able to simulate your climatology. And those are the ones you use in the analysis. To reduce the uncertainties, you use what they call a multi-model ensemble. So a multi-model ensemble reduces the uncertainties inherent in each climate model – CS.*' In contrast, another climate scientist explained that '*you have to compare [the models] with the observation to try to validate. But you don't know how it will predict the future – CS.*'

There is no agreed-upon method for constructing robust and reliable climate projections or for dealing with the uncertainty of climate projections (Jack et al., 2021), so varying opinions on validation and uncertainty are to be expected. However, uncertainty can be confusing as '*sometimes people use different models and the results*

Table 2. Examples of climate projections informing adaptation planning and projects, based on KII.

Decision making	Decision context	Evidence
To understand future context and impacts	City-level contribution to national environmental report	*'they [the climate projections] were really as guard rails to give us a sense of how things might change … to give us a sense of the various options that might lie in our future … Then we bounced off the impact section rather than the projection section. They certainly informed us at the beginning when we produced our first review of climate change impacts in the city" – GO*
Starting point for designing adaptation options	NAPs	*'The way it's designed, you do the projections, based on the projections, you do the adaptation options. And of course we consider what exists, but it's built on the latest assessment … it's more a new set of adaptation options." – TE*
To prioritize feasible adaptation options	NAPs	*'this is what it says in terms of the rainfall requirements, in terms of projection, in terms of the floods, the droughts, what are your priorities? So each province had to give us its own priorities." – GO*
Continued justification and improvement of existing adaptation options	NCs and NAPs	*'basically, try not to create divergency but uplift what is there and if there are gaps, try to bridge those gaps … . They have already done a lot of work at developing adaptation planning or policies. Then if you analyze the climate information, and then you open up a new set of possibilities before the existing possibilities are realised, then you face a lot of feedback and iterations in terms of what they would like to do." – CS*
To access funding for projects	Proposals for large funding organizations	*'Some of the projects that we have designed are based on climate information. The climatic variations we've been observing … have given us the opportunity to develop concepts and develop proposals and provide credible background information and justification to have such projects funded. That's the only way you can actually convince a donor.' – BA*
To justify already planned projects	GCF funding proposal	*'But what I'm trying to say is very often the climate rationale is very divorced from the larger part of the project. Either because people don't understand it or because they see the climate rationale as literally the tick box that gets you GCF money.' – BA*

are not agreeing. So then the question is, which results do you adopt at national level? – BA.' Where climate projections are used for adaptation or vulnerability assessments the uncertainty cascades and increases through the stages of analysis (Wilby & Dessai, 2010). Accounting for, representing and communicating uncertainty is a challenge; however, it is essential it is conveyed in some (rigorous) manner (Fischhoff & Davis, 2014), and will be discussed in later sections.

3.3. How do climate projections link with the adaptation planning process?

The climate projections are included in the vulnerability and adaptation section of the NCs, in which countries are encouraged to assess their vulnerability to climate change impacts (Vincent et al., 2017). The NC adaptation options make reference to previous policy documents, recent events and impact studies (with and without climate projections) as well as the climate projections in the NC themselves. In most cases, there is a stronger link between the adaptation options and the vulnerability or impact analysis than the climate projections. Often, the climate projections section seems quite disconnected from the rest of the chapter, both in terms of the focus (climate projections focusing more on temperature and rainfall, whereas impacts and adaptation focus on hazards and risks, such as flooding or drought) and in terms of timescale.

In addition, interviewees highlighted that climate projections feed into adaptation planning and funding in a multitude of ways with examples from various planning contexts and not exclusively from the NCs (Table 2). There have been previous concerns that climate information is not being included in national and development planning in sub-Saharan Africa (Jones et al., 2015). According to the KII, climate projections are being used to inform adaptation planning and projects at different stages of the process and carry different amounts of weight in informing decisions.

3.4. How does science interact with adaptation planning and policymaking in practice?

Understanding the decision-making context and how climate information could best inform planning depends, in part, on how science and policy interact. There is a need for iterative interactions between the 'user' and 'producer' which has been researched and documented previously (Dilling & Lemos, 2011; Dinku et al., 2018; Vincent et al., 2017; Vogel et al., 2019). A typology of interactions between climate information users and providers were constructed by Wilby and Lu (2022) which included off-the-peg (limited interaction that is one-off or use of ready-to-use information and portals), outsourced (providers give expert services to meet user-defined objectives) and bespoke (co-production and mutual learning for specific purpose). There was evidence of all three types of interactions in the interviews. Some interactions and collaboration were highly iterative and could be described as bespoke and may '*involve the policymakers … from national level up to grassroots … We want to work with them from the start of the project until we start implementing, monitoring and evaluation. We do everything together until the very end* – BA.' Meanwhile, others were more demand-driven or off-the-peg and '*very quickly get a consultant on board within a week to produce a report but they will have very little influence over how the project actually got designed-TE.*' However, this off-the-peg approach does not work when users cannot articulate or do not know, their needs (Grossi & Dinku, 2022; Vincent et al., 2020a; Vincent et al., 2020b) or when there is a gap between what is needed and what is, or can be, provided (Hewitt, 2020). During adaptation planning '*that was the challenge where you would be able to use that information, make projections, downscale it. They're not so much available, particularly in certain parameters [such as] floods* – GO.'

Based on the KII, there were many examples of collaboration between climate scientists and government officials with various levels of interaction. These examples include a climate advisory group that involves '*people from university, from the other sectors, from the private sector, from the NGO's … That group helps us to develop many of the plans and the reports – GO.*' Whilst some decision-makers may be open to discussion about new ideas, the issue of time and funding may restrict this from occurring. The participants shared their views of other players within climate adaptation planning. One climate scientist shared that '*people don't talk to the science; they don't want to use science information for the national development. We will do a lot of studies from a scientific perspective, but whether these are inputting into the policy formulation, that's another ball game altogether, but also don't forget the politics involved – CS*'. On the other hand, a government official explained that '*in the research community and the science community, there's still quite naive notion that facts will speak for themselves – GO.*' Finally, certain sectors may require '*building capacity of other stakeholders to understand where they would [be] able to link climate change and their sector. … For instance, building capacity of maybe health personnel where they will be able to see climate change and health – GO.*'

Developing this deep collaboration and understanding is particularly challenging in contexts where consultants are recruited to contribute climate projections to feed into adaptation processes. One interviewee highlighted that in the context of NAPs specifically, '*in some cases it's just international consultants doing the whole [climate projections] work … our preferred approach is, of course, to work with the national office because there's a huge issue of then ownership and how will that asset be used in the future if the government officials are not even aware of it – TE*'. Another interviewee explained that no longer using consultants improved the adaptation planning process: '*it was done by country experts, not a consultant. If these two documents were done by a consultant, I know that would have found it very difficult to link it to the NAP – BA*'.

3.5. How are climate projections communicated and interpreted?

The challenge of interpreting and communicating climate projections was highlighted by 13 interviewees across all 4 types of participants. However, 2 interviewees did not perceive interpreting or communicating climate projections as a problem and it was not discussed by 3 participants. Climate scientists, boundary agents and government officials had examples of lessons learnt in practice when trying to communicate climate projections to non-climate experts and aid their understanding (Table 3).

Table 3. Examples of approaches to improve communication of climate projections based on experiences of climate scientists, government officials and boundary agents.

Learnings	Evidence
Learning from a social scientist	*'We've done … policy briefs as outputs of projects and convened policymakers and presented to them. But I have [to] learn because sometimes it's hard for us natural scientists to communicate to policymakers. By working with the social scientists we sometimes learned how to communicate – CS.'*
Developing own communication skills	*'I wasn't even told I'd talk to people when I trained as a natural scientists, like now I spend my life engaging with people. No one ever gave me those tools. I had to develop them myself – GO.'*
Presenting in a different style	*'I went in all bright eyed and with all the IPCC information and all of that, I presented beautifully and was wonderful. And the maps were pretty and the graphs are amazing. Everyone in the room just looked at me completely blank and they were so disappointed. And then I think two weeks later, I went back and had to present roughly the same stuff to the same stakeholders, but in a way that it made sense – BA.'*
Learning each other's terminology	*'We need to sit down, I mean, rehearse even. Okay, I'm going to talk to someone who doesn't understand. I have to have a sort of a catalogue of captions or with legends of what these words mean, because some are too technical. Now it's about time for you natural scientists to start learning from [policymakers]. Yeah, because they've got their own expectations. They've got their own words – CS.'*
Involving local expertise	*'What I've learned is that for you to produce this [National Communication], you need expertise, local expertise that can guide experts in terms of where is information and so if you have that, you can walk away with a very rich Communication – CS.'*

Two of the interviewees had used climate projections in high-quality impact studies for sector and sub-sector adaptation chapters of the NCs. Interviewees provided examples of how the NCs are compiled, for example '*when we're doing, scenarios and analysing the data, going through the indices. Already we start to integrate the people who are going to take the indices and reflect on what do they need for their respective sectors – CS.'*

The process of building trust and understanding climate projections and their uncertainties occurs over time (Coventry et al., 2019; Grossi & Dinku, 2022). Previous research highlighted climate scientists struggle to work with people who are not highly technical or numerate (Porter & Dessai, 2017) but there were efforts to persevere through the challenge. One climate scientist highlighted that '*we need to humble ourselves. You know, we have this, this technical jargon that is not well understood by everyone* – CS." Meanwhile, a government official with a background in sciences explained 'm*y science is useful, but quite frankly, it doesn't hold any weight against the need to understand the politics*-GO.'

3.5.1. How is uncertainty communicated and interpreted?

The communication and interpretation of uncertainty varied greatly and continued to be a challenge for climate scientists and boundary agents (Pidgeon & Fischhoff, 2011). There was a concern about communicating uncertainty from some boundary agents and climate scientists as '*it's always difficult because if you acknowledge that there's so much uncertainty, [decision makers say] 'we're just not going to trust you', which is the last thing that you want. It's a bit of a fine balance – BA*." Meanwhile, some government officials discussed uncertainty in decision-making more generally, rather than the uncertainty of climate projections. Although decision-makers are aware of the existence of uncertainty, they do not necessarily always understand its implications in climate projections (Bornemann et al., 2019), and even the meaning of the word 'uncertainty' is interpreted differently. One participant provided a nuanced understanding of the flow of uncertainty in practice: '*sometimes you use words like 'this looks like plausible, like this is one of the likely consensus that this signal is going to look like' … But even if you have tried to maintain that these are probabilistic statements, the sector specific experts who is going to take that message, don't be surprised when you go some pages down the line [to read] 'this region is likely to get warmer by five degrees'. Then you get a statement that says, 'according to the climate model, we're going to experience five degree warmer temperature in the future' – CS.'*

Meanwhile, in the NCs there were several examples where the climate projections section included a range of future projections, but the key summaries in the rest of the report were based on the average of many models. There was no real consensus on how climate scientists and boundary agents communicate uncertainty to decision-makers. Different examples are provided of how (not) to communicate uncertainty in Table 4.

Although climate experts can understand stippling and plume plots (examples in Daron et al., 2021; Jack et al., 2020) non-climate experts may struggle to understand (Coventry et al., 2019). As highlighted in Table

Table 4. Examples of communication of climate projection uncertainty raised in the KII.

Communication of uncertainty	Evidence
Stippling or cross-hatching shown on maps	*'there's all that cross hatching. I'd want you to be able to see that there is uncertainty in those models. Hopefully, that should be quite apparent. It's not always apparent. I've had to explain this a few times.' – BA*
Simplifying language	*'For stakeholders, the uncertainties, you don't want to be more technical. We just highlight that every model has its own risks … it's always important to say, to highlight, even in simple term of high, low, medium to say there's always these uncertainties.' – BA*
Past analogues to illustrate potential impacts	*'we develop impact storylines. That's something we are trying to do in all of our countries to indeed communicate the risk better. And really to say, okay, let's look at what happened in the past. This, instead of having every 50 years now, it's going to happen every ten years.' – TE*
Difficulty in communicating technical approaches used by scientists	*'SOMS [Self Organising Maps] analysis, and even the plume plots and stuff which seem to be fairly, relatively simple. There's a lot of complexities, and it's hard to communicate that.' – BA*
Select alternative plausible scenarios	*'You could have a hotter, wetter future or a warmer, drier future. We know there's a hell of a lot of science behind it, and there's some probability of going on with it, and then this would be the impacts … .you start to see … there's commonality between things I can do under a hotter wetter and a warmer, drier scenario'. – BA*
Using multi-model distribution to communicate a range of possibilities	*'Normally what we do you take this model distribution and try to at least communicate the upper bounds, the lower bounds and then the middle range, just to just to give a sense of where the spectrum of possibility lies.' – CS*
Reports with different levels of information	*'Normally we give them the summary and maybe we have among the people working in the ministry, the scientists who want the details. Then we show them even the graphs and how the analysis was done.' – CS*

4, the use of analogues to communicate plausible climate futures can be useful in sectors that are less familiar with probabilities (Dessai & Hulme, 2004); however, in the absence of future climate projections analogues may be less practical as they are based on past events and historical or recent data.

4. How can science-informed adaptation planning be improved?

There are no set guidelines for creating a good set of climate projections. That said, the results from this study have shown there is sometimes an; insufficient number of models or scenarios used, limited representation of uncertainty and an overreliance on average changes, as well as a lack of clarity on which models are being used and how. Meanwhile, decision-makers' climate science needs are not always being met, highlighting that the usability gap remains an issue. Although climate projections were present in all NCs, there was a clear disconnect between the climate projections and the impacts and adaptation sections. In some cases, it appears that adaptation options are informed by current issues (such as flooding, drought and water security). Whilst in-country current priorities are crucial, adaptation planning may fail to account for emerging risks without greater consideration of changing risks. It is also important to note that these findings are all embedded into a wider context of; complex decision-making, underfunded and understaffed government departments; wider issues with funding projects and power or leadership dynamics and immediate development needs (Harvey et al., 2019; Sova & Schipper, 2019; Vincent et al., 2020a; Vincent et al., 2020b).

Climate scientists and boundary agents could play a greater role to identify and communicate best practice in the use of climate model data. There are ongoing discussions to explore what is meant by 'robust' and 'quality' information, as well as how to distil climate research to ensure it meets societal needs (Baldissera Pacchetti et al., 2024). Within the NCs challenges in technical capacity are noted, which climate scientists could assist in overcoming. Additionally, climate service standards and frameworks have been developed in some contexts which could be used for NCs (Golding et al., 2025). Finally, the development of new methods and adoption of scenario planning, stress-testing and storylines could promote climate information which is useful for the decision-maker.

Boundary agents are key players in linking science and policy within climate services (Steynor et al., 2016; Taylor et al., 2021; Vincent et al., 2017) They also influence the flow of climate information, as they too decide what is passed on to decision-makers and how to communicate uncertainty. That said, not all boundary agents have the skill and technical knowledge to do this effectively (Jones et al., 2015), a worry highlighted by some interviewees. Given that 70% of the South African climate change policies from 2004 to 2022 were developed or funded by consultancies and global or private firms (Khavhagali et al., 2024), it is important that boundary agents have high technical capacity. If boundary agents have an increasing role in policy formulation, it is important they have the skilled technical knowledge to do this at a high quality, whilst also conveying the levels of uncertainty.

5. Conclusions

The analysis of the National Communications and interviews have provided insight into how climate projections are used in southern Africa. Climate projections in the NCs rely on long-term mean changes in rainfall and temperature, and model averages, potentially masking the range of future and extreme events. This climate model analysis is often disconnected from the rest of the NC, which highlights current risks, especially flooding, drought and water security, with limited recognition of uncertainty. This suggests that there is potential for maladaptation, as important risks from climate change (such as heat stress and sea level rise), may be unforeseen. On the other hand, NCs and NAPs are not always considered the most important adaptation processes in the country and we heard examples from interviewees of progress in adaptation activities in business and local government, including highly collaborative processes and an important role for boundary agents.

Ensuring decision-makers have the information they need and can understand, whilst also acknowledging the uncertainties, remains a challenge. The improvement of communicating and interpreting climate projections and the associated uncertainties requires an effort from everyone involved in climate adaptation planning. We argue that overcoming this challenge is not the responsibility of decision-makers. Conversely, the problem will not be solved by the development of more sophisticated climate projections that decision-makers might not need or understand. Nor will it be solved by initiatives that concentrate their efforts on generating visualization using web portals or training users to analyse climate models but do not provide training to allow people to accurately interpret the complex outputs. Without the ability to interpret the data in the context of the real world, data and visualizations alone will not improve understanding or decision-making. Instead, we suggest that climate scientists working in adaptation planning should improve their understanding of the decision-making and political context or utilize boundary agents. Decision-makers and planners should be aware that the climate projection analysis that features in some of the current NCs (e.g. using long-term mean changes in rainfall and temperature, model averages and having a limited recognition of uncertainty) may not capture the range of plausible climate futures and as such unforeseen climate risks and extreme events may not properly be planned for To improve the integration of climate risk into NCs and NAPs, it is important that adaptation planners are able to understand how climate change might influence their local context, and how it might interact with changing populations, economies and societies. Policymakers, boundary agents and climate scientists alike must engage in and develop, collaborative processes to explore alternative futures distil and interpret climate projections; to inform polices and plans to help countries and their populations adapt to future climate risks.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the UKRI through the Future Leadership Fellowship [grant number MR/W013223/1].

ORCID

Ailish Craig http://orcid.org/0000-0003-2780-9670
Rachel A. James http://orcid.org/0000-0001-5738-1092

Emma Archer http://orcid.org/0000-0002-5374-3866
Joseph Daron http://orcid.org/0000-0003-1917-0264
Alan T. Kennedy-Asser http://orcid.org/0000-0001-5143-8932
Christopher Shaw http://orcid.org/0000-0001-5684-9386
Katharine Vincent http://orcid.org/0000-0003-3152-1522

References

Baldissera Pacchetti, M., Dessai, S., Risbey, J. S., Stainforth, D. A., & Thompson, E. (2024). Perspectives on the quality of climate information for adaptation decision support. *Climatic Change*, *177*(11), 163. https://doi.org/10.1007/s10584-024-03823-1

Bednarek, A. T., Wyborn, C., Cvitanovic, C., Meyer, R., Colvin, R. M., Addison, P. F. E., Close, S. L., Curran, K., Farooque, M., Goldman, E., Hart, D., Mannix, H., McGreavy, B., Parris, A., Posner, S., Robinson, C., Ryan, M., & Leith, P. (2018). Boundary spanning at the science–policy interface: The practitioners' perspectives. *Sustainability Science*, *13*(4), 1175–1183. https://doi.org/10.1007/s11625-018-0550-9

Bhave, A. G., Conway, D., Dessai, S., Dougill, A. J., & Mkwambisi, D. (2022). Stress-testing development pathways under a changing climate: Water–energy–food security in the lake Malawi-Shire river system. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *380*(2221), 20210134. https://doi.org/10.1098/rsta.2021.0134

Born, L., Prager, S., Ramirez-Villegas, J., & Imbach, P. (2021). A global meta-analysis of climate services and decision-making in agriculture. *Climate Services*, *22*, 100231. https://doi.org/10.1016/j.cliser.2021.100231

Bornemann, F. J., Rowell, D. P., Evans, B., Lapworth, D. J., Lwiza, K., Macdonald, D. M. J., Marsham, J. H., Tesfaye, K., Ascott, M. J., & Way, C. (2019). Future changes and uncertainty in decision-relevant measures of east African climate. *Climatic Change*, *156*(3), 365–384. https://doi.org/10.1007/s10584-019-02499-2

Clarkson, G., Dorward, P., Poskitt, S., Stern, R. D., Nyirongo, D., Fara, K., Gathenya, J. M., Staub, C. G., Trotman, A., Nsengiyumva, G., Torgbor, F., & Giraldo, D. (2022). Stimulating small-scale farmer innovation and adaptation with participatory integrated climate services for agriculture (PICSA): Lessons from successful implementation in Africa, Latin America, the Caribbean and south Asia. *Climate Services*, *26*, 100298. https://doi.org/10.1016/j.cliser.2022.100298

Coventry, K. R., Harold, J., Lorenzoni, I., Kavonic, J., Soukenya Diop, I., & Visman, E. (2019). *Improving methods of communicating climatic uncertainties to aid decision-making*. Future Climate for Africa.

Creswell, J. (2014). *Research design: Qualitative, quantitative and mixed methods approaches* (4th ed.). Sage.

Daron, J., Lorenz, S., Taylor, A., & Dessai, S. (2021). Communicating future climate projections of precipitation change. *Climatic Change*, *166*(1), 23. https://doi.org/10.1007/s10584-021-03118-9

Dessai, S., & Hulme, M. (2004). Does climate adaptation policy need probabilities? *Climate Policy*, *4*(2), 107–128. https://doi.org/10.1080/14693062.2004.9685515

Dilling, L., & Lemos, M. C. (2011). Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. *Global Environmental Change*, *21*(2), 680–689. https://doi.org/10.1016/j.gloenvcha.2010.11.006

Dinku, T., Thomson, M. C., Cousin, R., del Corral, J., Ceccato, P., Hansen, J., & Connor, S. J. (2018). Enhancing national climate services (ENACTS) for development in Africa. *Climate and Development*, *10*(7), 664–672. https://doi.org/10.1080/17565529.2017.1405784

Fischhoff, B., & Davis, A. L. (2014). Communicating scientific uncertainty. *Proceedings of the National Academy of Sciences*, *111*, 13664–13671. https://doi.org/10.1073/pnas.1317504111

Goddard, L., Kumar, A., Solomon, A., Smith, D., Boer, G., Gonzalez, P., Kharin, V., Merryfield, W., Deser, C., Mason, S. J., Kirtman, B. P., Msadek, R., Sutton, R., Hawkins, E., Fricker, T., Hegerl, G., Ferro, C. A. T., Stephenson, D. B., Meehl, G. A., … Delworth, T. (2013). A verification framework for interannual-to-decadal predictions experiments. *Climate Dynamics*, *40*(1), 245–272. https://doi.org/10.1007/s00382-012-1481-2

Golding, N., Lambkin, K., Wilson, L., Troch, R. D., Fischer, A. M., Hygen, H. O., Hama, A. M., Dyrrdal, A. V., Jamsin, E., Termonia, P., & Hewitt, C. (2025). Developing national frameworks for climate services: Experiences, challenges and learnings from across Europe. *Climate Services*, *37*, 100530. https://doi.org/10.1016/j.cliser.2024.100530

Grossi, A., & Dinku, T. (2022). Enhancing national climate services: How systems thinking can accelerate locally led adaptation. *One Earth*, *5*(1), 74–83. https://doi.org/10.1016/j.oneear.2021.12.007

Harvey, B., Jones, L., Cochrane, L., & Singh, R. (2019). The evolving landscape of climate services in Sub-Saharan Africa: What roles have NGOs played? *Climatic Change*, *157*(1), 81–98. https://doi.org/10.1007/s10584-019-02410-z

Hewitson, B., Waagsaether, K., Wohland, J., Kloppers, K., & Kara, T. (2017). Climate information websites: An evolving landscape. *WIREs Climate Change*, *8*(5), e470. https://doi.org/10.1002/wcc.470

Hewitt, C. D. (2020). Climate services in the UK Met office – Challenges and solutions. *Journal of Southern Hemisphere Earth Systems Science*, *70*(1), 139–142. https://doi.org/10.1071/ES19030

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

Jack, C. D., Marsham, J., Rowell, D. P., & Jones, R. G. (2021). Climate information: Towards transparent distillation. In D. Conway, & K. Vincent (Eds.), *Climate Risk in Africa: Adaptation and Resilience* (pp. 17–35). Springer International Publishing.

James, R., Washington, R., Schleussner, C.-F., Rogelj, J., & Conway, D. (2017). Characterizing half-a-degree difference: A review of methods for identifying regional climate responses to global warming targets. *WIREs Climate Change*, *8*(2), e457. https://doi.org/10.1002/wcc.457

Jones, L., Dougill, A., Jones, R. G., Steynor, A., Watkiss, P., Kane, C., Koelle, B., Moufouma-Okia, W., Padgham, J., Ranger, N., Roux, J.-P., Suarez, P., Tanner, T., & Vincent, K. (2015). Ensuring climate information guides long-term development. *Nature Climate Change*, *5*(9), 812–814. https://doi.org/10.1038/nclimate2701

Khavhagali, V., Reckien, D., Biesbroek, R., Mantlana, B., & Pfeffer, K. (2024). Understanding the climate change adaptation policy landscape in South Africa. *Climate Policy*, *24*(4), 458–472. https://doi.org/10.1080/14693062.2023.2268576

Lazenby, M. J., Todd, M. C., Chadwick, R., & Wang, Y. (2018). Future Precipitation Projections over Central and Southern Africa and the Adjacent Indian Ocean: What Causes the Changes and the Uncertainty? *Journal of Climate*, *31*(12), 4807–4826.

LDC. (2012). *National adaptation plans: Technical guidelines for the national adaptation plan process*. LDC Expert Group. UNFCCC.

Lemos, M. C., Kirchhoff, C. J., & Ramprasad, V. (2012). Narrowing the climate information usability gap. *Nature Climate Change*, *2*(11), 789–794. https://doi.org/10.1038/nclimate1614

Lennard, C. J., Nikulin, G., Dosio, A., & Moufouma-Okia, W. (2018). On the need for regional climate information over Africa under varying levels of global warming. *Environmental Research Letters*, *13*(6), 060401. https://doi.org/10.1088/1748-9326/aab2b4

Lu, X. (2015). *Applying climate information for adaptation decision-making*. National Communications Support Programme UNDP-UNEP-GEF.

McSweeney, C. F., & Jones, R. G. (2016). How representative is the spread of climate projections from the 5 CMIP5 GCMs used in ISI-MIP? *Climate Services*, *1*, 24–29. https://doi.org/10.1016/j.cliser.2016.02.001

McSweeney, C., New, M., Lizcano, G., & Lu, X. (2010). The UNDP climate change country profiles. *Bulletin of the American Meteorological Society*, *91*, 157–166. https://doi.org/10.1175/2009BAMS2826.1

Munday, C., & Washington, R. (2018). Systematic climate model rainfall biases over Southern Africa: Links to moisture circulation and topography. *Journal of Climate*, *31*(18), 7533–7548. https://doi.org/10.1175/JCLI-D-18-0008.1

Nyamwanza, A. M., New, M. G., Fujisawa, M., Johnston, P., & Hajat, A. (2017). Contributions of decadal climate information in agriculture and food systems in east and Southern Africa. *Climatic Change*, *143*(1), 115–128. https://doi.org/10.1007/s10584-017-1990-4

Pidgeon, N., & Fischhoff, B. (2011). The role of social and decision sciences in communicating uncertain climate risks. *Nature Climate Change*, *1*(1), 35–41. https://doi.org/10.1038/nclimate1080

Porter, J. J., & Dessai, S. (2017). Mini-me: Why do climate scientists' misunderstand users and their needs? *Environmental Science & Policy*, *77*, 9–14. https://doi.org/10.1016/j.envsci.2017.07.004

Rigby, J. M., Yohannis, M. A., Preist, C., Singer, M. B., Waema, T. M., Wausi, A. N., & Michaelides, K. (2022). Climate services for the greater horn of Africa: Interviews exploring practitioner perspectives from Kenya and beyond. *Climate and Development*, *15*(3), 1–13. https://doi.org/10.1080/17565529.2022.2074350

Shepherd, T. G., Boyd, E., Calel, R. A., Chapman, S. C., Dessai, S., Dima-West, I. M., Fowler, H. J., James, R., Maraun, D., Martius, O., Senior, C. A., Sobel, A. H., Stainforth, D. A., Tett, S. F. B., Trenberth, K. E., van den Hurk, B. J. J. M., Watkins, N. W., Wilby, R. L., & Zenghelis, D. A. (2018). Storylines: An alternative approach to representing uncertainty in physical aspects of climate change. *Climatic Change*, *151*(3), 555–571. https://doi.org/10.1007/s10584-018-2317-9

Singh, C., Daron, J., Bazaz, A., Ziervogel, G., Spear, D., Krishnaswamy, J., Zaroug, M., & Kituyi, E. (2018). The utility of weather and climate information for adaptation decision-making: Current uses and future prospects in Africa and India. *Climate and Development*, *10*(5), 389–405. https://doi.org/10.1080/17565529.2017.1318744

Skelton, M., Porter, J. J., Dessai, S., Bresch, D. N., & Knutti, R. (2019). Customising global climate science for national adaptation: A case study of climate projections in UNFCCC's national communications. *Environmental Science & Policy*, *101*, 16–23. https://doi.org/10.1016/j.envsci.2019.07.015

Sova, C. A., & Schipper, E. L. F. (2019). Adaptation policy and planning in developing countries. In E. C. H. Keskitalo & B. L. Preston (Eds.), *Research handbook on climate change adaptation policy* (pp. 250–272). Edward Elgar Publishing.

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

Steynor, A., & Pasquini, L. (2022). Using a climate change risk perceptions framing to identify gaps in climate services. *Frontiers in Climate*, *4*, 1–15. https://doi.org/10.3389/fclim.2022.782012

Tall, A., Coulibaly, J. Y., & Diop, M. (2018). Do climate services make a difference? A review of evaluation methodologies and practices to assess the value of climate information services for farmers: Implications for Africa. *Climate Services*, *11*, 1–12. https://doi.org/10.1016/j.cliser.2018.06.001

Taylor, A., Pretorius, L., McClure, A., Iipinge, K. N., Mwalukanga, B., & Mamombe, R. (2021). Embedded researchers as transdisciplinary boundary spanners strengthening urban climate resilience. *Environmental Science & Policy*, *126*, 204–212. https://doi.org/10.1016/j.envsci.2021.10.002

Terry, G., Hayfield, N., Clarke, V., & Braun, V. (2017). Thematic analysis. In *The SAGE handbook of qualitative research in psychology* (2nd ed., p. 664). SAGE Publications Ltd.

Theokritoff, E., & Lise D'haen, S. A. (2022). How is science making its way into national climate change adaptation policy? Insights from Burkina Faso. *Climate and Development*, *14*(9), 857–865. https://doi.org/10.1080/17565529.2021.2018985

Vaughan, C., & Dessai, S. (2014). Climate services for society: Origins, institutional arrangements, and design elements for an evaluation framework. *WIRES Climate Change*, *5*(5), 587–603. https://doi.org/10.1002/wcc.290

Vaughan, C., Dessai, S., & Hewitt, C. (2018). Surveying climate services: What Can We learn from a bird's-Eye view? *Weather, Climate, and Society*, *10*(2), 373–395. https://doi.org/10.1175/WCAS-D-17-0030.1

Vaughan, C., Hansen, J., Roudier, P., Watkiss, P., & Carr, E. (2019). Evaluating agricultural weather and climate services in Africa: Evidence, methods, and a learning agenda. *WIRES Climate Change*, *10*(4), e586. https://doi.org/10.1002/wcc.586

Vincent, K., Archer, E., Henriksson, R., Pardoe, J., & Mittal, N. (2020a). Reflections on a key component of co-producing climate services: Defining climate metrics from user needs. *Climate Services*, *20*, 100204. https://doi.org/10.1016/j.cliser.2020.100204

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

Vincent, K., Dougill, A. J., Dixon, J. L., Stringer, L. C., & Cull, T. (2017). Identifying climate services needs for national planning: Insights from Malawi. *Climate Policy*, *17*(2), 189–202. https://doi.org/10.1080/14693062.2015.1075374

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

Weaver, C. P., Lempert, R. J., Brown, C., Hall, J. A., Revell, D., & Sarewitz, D. (2013). Improving the contribution of climate model information to decision making: The value and demands of robust decision frameworks. *WIRES Climate Change*, *4*(1), 39–60. https://doi.org/10.1002/wcc.202

Wigley, T. M. L. (2008). *MAGICC/SCENGEN 5.3: USER MANUAL* (version 2). Colorado.

Wilby, R. L., & Dessai, S. (2010). Robust adaptation to climate change. *Weather*, *65*(7), 180–185. https://doi.org/10.1002/wea.543

Wilby, R., & Lu, X. (2022). Tailoring climate information and services for adaptation actors with diverse capabilities. *Climatic Change*, *174*(3–4), 1–13. https://doi.org/10.1007/s10584-022-03452-6