Improving methods of communicating climatic uncertainties to aid decision-making

Project report and guidelines prepared for Future Climate for Africa

Contributing authors:

Kenny R. Coventry School of Psychology, University of East Anglia, UK.

Jordan Harold School of Psychology and Tyndall Centre for Climate Change Research, University of East Anglia, UK.

Irene Lorenzoni School of Environmental Sciences, Tyndall Centre for Climate Change Research, and Science, Society and Sustainability (3S) Research Group, University of East Anglia, UK.

Jessica Kavonic ICLEI - Local Governments for Sustainability, Africa Secretariat, Cities Biodiversity Center, South Africa.

Ismahan Soukeyna Diop Department of Philosophy, Cheikh Anta Diop University Dakar, Senegal.

Emma Visman VNG Consulting Limited and King's College London, UK.

FUTURE CLIMATE FOR AFRICA

Acknowledgements:

This work was kindly supported by a research grant from Future Climate for Africa (FCFA), Applied Research Fund Second Call (ARF2).

We would also like to thank Joseph Daron (Met Office, UK), Gino Fox (University of Sussex, UK), Christopher Jack (University of Cape Town, South Africa), Ndjido Kane (Senegalese Institute for Agricultural Research), Dom Kniveton (University of Sussex, UK), Alice McClure (University of Cape Town, South Africa), Anna Steynor (University of Cape Town, South Africa), Benjamin Sultan (Institut de recherche pour le Développement, France), Chris Taylor (Centre for Ecology & Hydrology, UK), and Tanya Warnaars (Centre for Ecology & Hydrology, UK) for their input to the project, as well as the contributions of participants who took part in research interviews.

Contents

Page

1. Executive summary

Improving methods of communicating climatic uncertainties to aid decision-making

There is inherent uncertainty about how the climate will change into the future, yet projections from climate models can provide informative and actionable information relevant to issues that are affected by the climate. Understanding uncertainties in such information is important if decision-makers in society (e.g. government officials, organisations, farmers, engineers, etc.) are to make informed decisions when drawing on the available scientific knowledge.

Drawing on interviews with stakeholders and scientists/researchers involved in climate change projects in West Africa and Southern Africa (namely the Future Climate for Africa AMMA-2050 and FRACTAL projects), we identified issues, constraints and opportunities associated with the communication of climate information containing uncertainties:

Issues and constraints	**Opportunities**
Many of the stakeholders use weather and seasonal information, but were much less likely to use climate information.	Identifying, articulating and demonstrating the relevance for using climate information could afford improved uptake of climate information.
The term ‘uncertainty’ is often interpreted as ‘not knowing’, or a ‘lack of accuracy’, and hence climate information containing uncertainty may not be trusted.	Developing shared understanding and mutual trust between scientists/researchers and stakeholders could support use of climate information containing uncertainty in decision-making.
Traditional formats for communication, e.g. scientific graphs, are generally perceived to be difficult to understand and to extract information to aid decision-making.	Incorporating decision-makers’ needs and contexts in the design of communications that represent uncertainties can be achieved using co-production.
Engagement in co-production of communications requires a large investment in time and resource.	Drawing on best practices and developing methodological tools could help formalise processes of engagement between scientists/researchers and stakeholders when ‘full’ co-production is not possible.

Recommendations:

The report identifies recommendations and guidelines to support those in the communication of climatic uncertainties for decision-making. The recommendations below are primarily aimed at the AMMA-2050 and FRACTAL communities (in which the research informing the recommendation took place), but they are also relevant to those in the broader FCFA community and broader climate change communities, who are tasked with communicating climate information containing uncertainties. Below we present the main recommendations. A set of ten associated guidelines, with practical tips, are provided in the main report (Section 8).

Communication formats should transparently convey the nature of uncertainty being communicated and be readily comprehensible to ensure that decisions can be made based on an understanding of the uncertainties. Traditional, scientific formats for communicating uncertainty, such as technical graphs, can be difficult for non-scientists to comprehend. Although simplified information may be more easily understood, it may not provide sufficient depth of information to inform decisions. Finding the right balance may be best achieved using co-production (see section 7.1 and 7.3 for further context).

Trust in climate information and those who communicate information should be measured and evaluated to assess how communication and engagement activities influence trust in information. Stakeholders often equate uncertainty with ‘not knowing’ and/or a lack of accuracy. This can reduce trust in using the information and in turn prevent action. Measuring trust can help identify communication approaches that foster shared understandings of uncertainty (see section 7.2 for further context).

Co-production methods should be used to create communications materials/formats to help ensure information and associated uncertainties are context relevant and support decision-making. Although highly desirable, co-production can be time and resource intensive, making it difficult to apply in all communication contexts. Complementary approaches, such as protocols that help elicit key information needs in a structured and efficient manner, and which draw on co-production principles and learnings, can be used where constraints to full co-production exist (see section 7.4 for further context).

Decision-makers’ understandings of uncertainty should be evaluated throughout the creation of communications, and the development of materials/activities should start with an understanding of information needs and existing knowledge. Iterative design and evaluation of communication materials and activities not only supports comprehension of information, but can also check that information is relevant and positively informs decision-making, so that climate information containing uncertainties is more likely to be acted upon.

2. Project context and aims

(Adapted from project proposal and literature review - see Annex A)

Communicating uncertainty

In the context of understanding uncertainties in relation to climate science, and specifically in relation to projecting how climate change will affect human and natural systems, there are multiple sources of uncertainty which can be conceptualised as a ‘cascade’ or ‘chain’ of uncertainty (New & Hulme, 2000; Pidgeon & Fischhoff, 2011). It has been argued that the key to being able to use scientific research to inform decisions or choices “requires knowing how much uncertainty surrounds it” (Fischhoff & Davis, 2014, pp. 13664). Without such understanding, decision makers may not place enough, or may place too much, confidence in scientific research findings, thus potentially facing unexpected issues or missing opportunities. Further, uncertainties may be seen as a barrier to action, in which decisions might be delayed or avoided altogether (Moser, 2016; Moser & Ekstrom, 2010).

Relevance to FCFA projects

Future Climate for Africa (FCFA) is a research programme that aims to advance climate knowledge in Africa, supporting the long-term goals of reducing disruption and damage from climate change, and safeguarding economic development and poverty eradication efforts.

The FCFA projects ‘African Monsoon Multidisciplinary Analysis’ (AMMA-2050, see amma2050.org) and ‘Future resilience for African cities and lands’ (FRACTAL, see fractal.org.za) incorporate assessments of uncertainties within their scientific outputs and integrate communications to enable the application of scientific information to help inform decision-making within African societies, with the goal of increasing the resilience of African peoples and infrastructure to future climate variability and changes. While the contexts, communication approaches and stakeholder engagement of these two projects differ, they both present contexts in which to better understand the constraints and opportunities associated with the communication of climate information containing uncertainties.

The FRACTAL consortium identified in 2016 that “disagreements between products producing contradicting messages of past and future change” was an important issue, and an area within which further research is required. In particular, the disparities between climate data products, and the consequences that such contradictions have for decision-making, need to be better understood. Furthermore, the FRACTAL-lead organisation, Climate Systems Analysis Group (CSAG), led an FCFA pilot study looking at co-production of climate information for Maputo, Mozambique, and Accra, Ghana, which identified the difficulty of communicating uncertain climate information with urban decision makers, even in a collaborative co-production environment.

In addition, at the project inception meeting of AMMA-2050 in Senegal, bringing together national and regional (sub-state) government representatives, farmers, and network organisations, there was agreement on the need to strengthen stakeholder capacities to better integrate climate change information in their decision-making.

Enhancing understandings of uncertainties and guiding decision-makers on how uncertainties might be incorporated into their decision-making therefore has the potential for improved decision-making.

The current project

The current project recognises the opportunity of drawing on the cognitive and psychological sciences, together with existing scientist and stakeholder engagement within AMMA-2050 and FRACTAL, to better understand the constraints and opportunities associated with the communication of climate information containing uncertainties with decision makers.

The aim of the current project is to identify key challenges in the communication of climate change uncertainties in the context of AMMA-2050 and FRACTAL communications activities, identify best practice, and provide recommendations on how climate communication could be further improved.

Both AMMA-2050 and FRACTAL embed a range of communication formats and stakeholder engagement activities as part of their research programmes. These include printed materials, meetings, workshops, and participatory games. However, within the current project, we focus on two specific types of communication formats – scientific slide-set materials employing traditional scientific data visualisations (drawing on an example developed within AMMA-2050) and conversational climate risk narratives co-produced between stakeholders and researchers (drawing on examples developed within FRACTAL). These exemplars represent contrasting communication formats in which to investigate the communication of climate information containing uncertainties. Examples of these communication formats are provided in the next section below.

It is hoped that recommendations emerging from the current project help support the communication of information produced by AMMA-2050 and FRACTAL teams. Furthermore, the insights, findings and recommendations are expected to also be of interest to others in FCFA and beyond who are involved in the communication of climatic uncertainties for decision-making.

Through semi-structured interviews, we identify key issues from the perspectives of scientists/researchers and stakeholders. We then draw on knowledge from the psychological sciences to help inform and address the identified issues, and provide a set of guidelines for communicating uncertainty.

Slide-sets with data visualisations – scientific representations

Slide presentations, given by scientists/researchers to interested audiences, are a common format for communicating scientific and technical information. Data visualisations are typically used within slides to demonstrate the outputs of scientific research and support understanding of key messages with a range of audiences. Such data visualisations may typically be reproduced, adapted or inspired by figures initially created for scientific audiences. For example, Figure 1 shows a slide used to support communication of future climate in a range of contexts (e.g. online, at face-to-face meetings, at workshops, etc.).

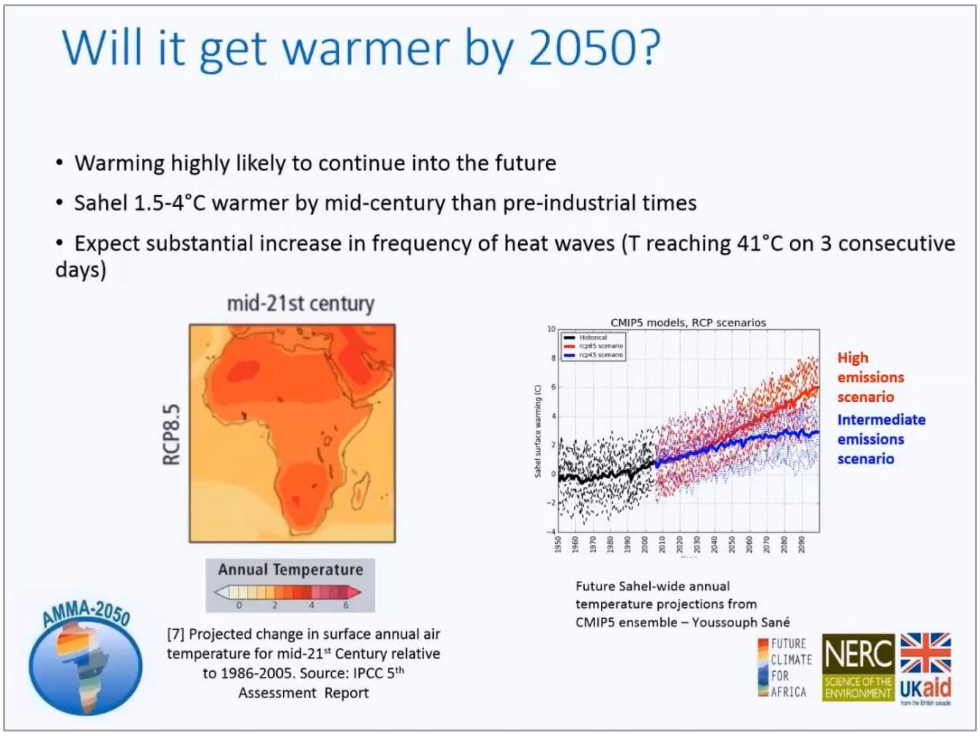

Figure 1: Example slide communicating scenarios of future climate change for the Sahel, showing outputs of climate models in data visualisations, including model spreads and multi-model means for different scenarios. Example from AMMA-2050 project. [Source: https://www.youtube.com/watch?v=vQ9OTpQE1ho]

Climate risk narratives – stories of plausible futures

In recognition that people often communicate complex information in their everyday lives through stories, climate risk narratives aim to distil and capture the uncertainty of future climate scenarios in an intuitive and familiar format. Climate risk narratives provide short stories, one for each plausible future identified from climate modelling, to convey the different possibilities of what the future climate might hold. The FRACTAL project has developed climate risk narratives with a number of cities using a co-production approach with city decision-makers. The aim of the narratives is to convey scientifically robust information, tailored to specific contexts in which decision-makers work, to start conversations between scientific and decision-maker communities (Figure 2).

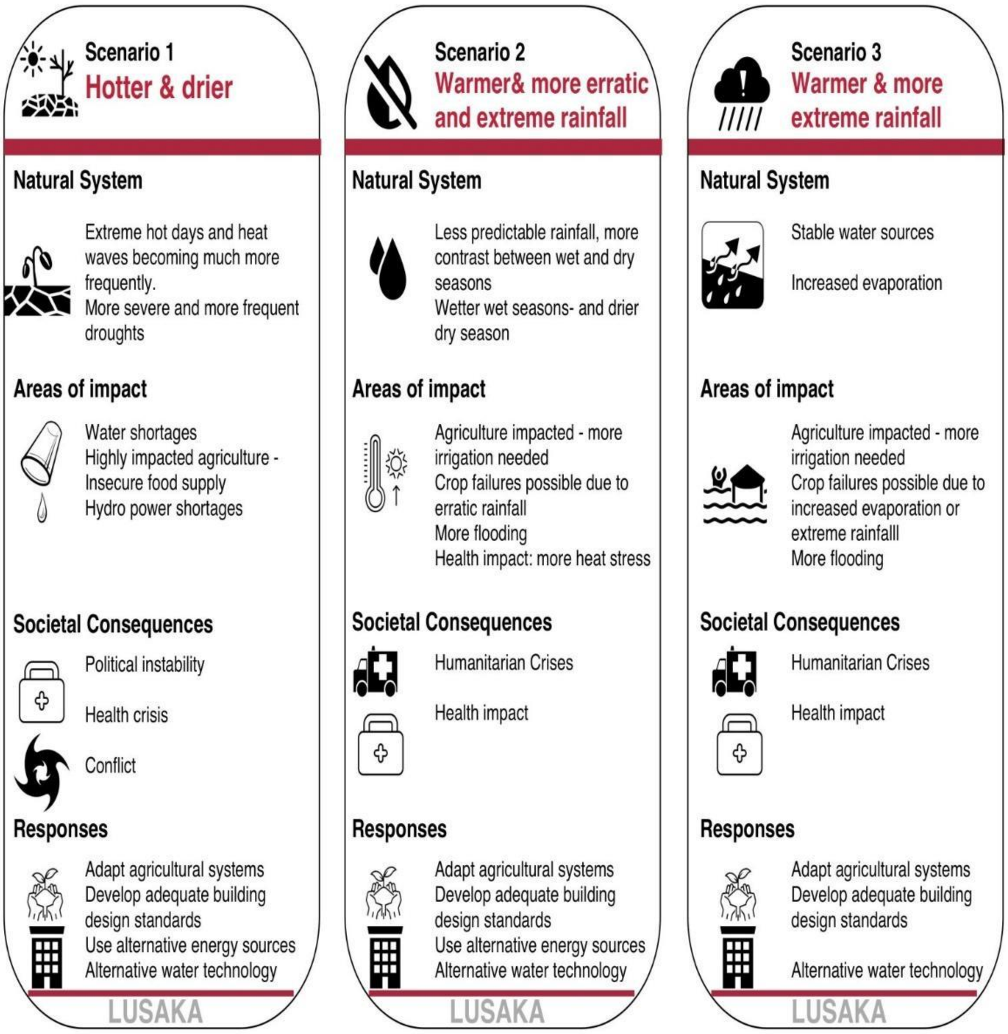

Figure 2. Example of climate risk narratives for a city, captured as an infographic, depicting three plausible futures (scenarios) and the associated impacts, consequences and responses relevant to each. Example from FRACTAL project. [Source: http://blogs.reading.ac.uk/weather-and-climate-at-reading/2018/a-newcomers-reflections-on-the-fourth-lusaka-learning-lab/]

3. Psychology of communicating and understanding uncertainties

Prior to undertaking new research, we conducted a review of psychological science literature to understand the existing evidence-base regarding how difficult uncertainty information is for humans (including experts) to comprehend, and theoretically why this is the case. In addition, we reviewed the complexities of uncertainty within climate science, and the challenges that climate scientists face when communicating nested levels of uncertainty to a wide range of audiences.

A summary of the key points identified from this literature review is provided below (per section 6 of the literature review, Annex A). Numbers in brackets in the list below relate to the relevant sections within Annex A.

Key insights identified by the literature review

1. The communication of uncertainties in climate information is important and therefore solutions need to be developed to support their effective communication (see A5.1).
2. Uncertainty information can be challenging to comprehend for both experts and non-experts.
3. People often make decisions using fast and frugal heuristics; while these can be effective strategies in day-to-day contexts (see A2.3.1), they can result in biases and poor decision-making when interpreting, and making decisions regarding, uncertainties (see A2.2).
4. If uncertainty information can be correctly understood in line with existing knowledge and expectations of the user, present information in a way that does so.
5. Where uncertainty information is complex and does not match existing knowledge and expectations, information should be presented to engage analytical processing (see A2.4).
6. Choice of specific formats, be they language or visuals, can influence comprehension of uncertainties (see A3.1-A3.3, A5.4); although general guidance exists for effective communication, testing and evaluating formats with users is important to ensure uncertainty information is comprehended as intended (see A4).
7. There are multiple sources of uncertainty and individuals may not correctly attribute these – complexity may be best handled by understanding the aspects of uncertainty that are most relevant to the users of the information (see A5.2).
8. Audiences of climate information containing uncertainties are rich and diverse – hence there is a need to prioritise audiences, layer information and involve users in the design and creation of information (co-production) (see A5.3).
9. Where possible, active dialogue between producers and users of climate information containing uncertainties is important to enhance the effectiveness of communication.

While these insights provide indications of how to approach the communication of uncertainty, it is important to understand the specific contexts in which stakeholders and scientists/researchers involved with AMMA-2050 and FRACTAL operate. This can then enable the development of tailored guidance and recommendations that address the challenges and opportunities in seeking to strengthen the climate resilience of a diverse range of decision making processes, with differing sectoral focus, across countries and regions in Africa.

4. Research interviews to inform guidance

In support of understanding the contexts and perspectives of those associated with AMMA-2050 and FRACTAL, we undertook interviews with stakeholders and scientists/researchers to elicit their perspectives on the communication of climate information containing uncertainties.

Aims and methodology

Qualitative semi-structured research interviews with stakeholders and researchers associated with the AMMA-2050 and FRACTAL projects were conducted. Two main groups were considered; stakeholders who may have a need to work with climate information in decision-making contexts, and scientists/researchers who are involved in generating and/or communicating climate information relevant to decision-making contexts, particularly in the context of the two communication formats being considered – slide-sets employing data visualisations, and co-produced climate risk narratives.

Among stakeholders working with climate information, the interviews set out to understand to what extent they use climate information, and to what extent they consider the uncertainties in the information. Interview questions were developed to specifically identify:

- To what extent is climate information relevant to stakeholders?
- What *types* of climate information are relevant and useful to stakeholders?
- To what extent are *uncertainties* relevant and important to stakeholders?
- What are their preferences in communication approaches regarding uncertainties?

Among scientists and researchers, the interviews set out to understand why uncertainties in climate information are important to communicate with stakeholders, what types of audiences they communicate with, and the communication formats they use. Interview questions were developed to specifically identify:

- To which audiences is information communicated with?
- What is the purpose of including uncertainties in climate information for decision-making?
- What types of uncertainties are included?
- What communication formats have been employed for communicating climatic uncertainties?
- What feedback has been received on these from the intended audiences?

Sectoral/geographic scope

AMMA-2050 is working in West African countries with particular pilot activities in Senegal and Burkina Faso that will contribute to improved decision-making in sectors related to agriculture, food security (in Senegal), urban development and flooding (in Burkina Faso). FRACTAL is focussed on southern African city regions, with main engagements taking place in Lusaka, Maputo and Windhoek and secondary engagements in Blantyre, Harare, Gaborone, Cape Town, Johannesburg and Durban. Through these engagements, FRACTAL is contributing to improved decision-making related to water and energy in city-regions.

The current project leveraged planned engagement activities and existing contacts among AMMA-2050 and FRACTAL partners to gain perspectives of stakeholders based in Senegal, Blantyre, Gaborone and Windhoek, together with the perspectives of consortia partners (scientists/researchers) based in Europe and Africa. In the aforementioned literature review, it emerged that there was a paucity of research regarding the psychology of the communication and comprehension of uncertainty conducted in African contexts, and therefore the current interviews provide an opportunity to elicit insights relevant to a range of contexts in Southern and West Africa.

Method

Two sets of interview questions were developed to explore the questions outlined above – one for use with stakeholders and one for use with scientists/researchers. Interview protocols were developed in English and then translated into French. French translations were then reviewed and cross-checked against the English version to check consistency in meaning; any identified discrepancies in meaning were discussed and resolved by consensus between project members. Interviews were primarily conducted in person or remotely via Skype or telephone. However, a subset of respondents chose to respond to the interview questions in writing. Interviews were conducted between January and June 2018, and were conducted either in English or French. Ethics were approved by the University of East Anglia, School of Psychology Ethics Committee.

Participants

A total of 50 interviews were conducted – 17 with scientists/researchers, and 33 with stakeholders. Participants were invited to take part in the interviews in the context of their existing engagement with AMMA-2050 or FRACTAL projects. Twenty-one interviews were undertaken in the context of AMMA-2050, and 29 interviews were undertaken in the context of FRACTAL. A further breakdown of the participants by project is next provided.

Participants associated with AMMA-2050

Ten stakeholders and seven scientists/researchers were interviewed in person in Senegal, in French. Participants ranged from researchers and scientists, consultants, government officials, NGOs, community associations to development agencies. Furthermore, four AMMA-2050 scientists/researchers involved in the delivery of AMMA-2050 were interviewed via Skype in English.

Participants associated with FRACTAL

Ten stakeholders and two researchers were interviewed in person in Blantyre, Gaborone and Windhoek. One additional interview was conducted with a small group of FRACTAL researchers who had recently visited a key stakeholder to elicit relevant insights. A further 11 stakeholders chose to complete the interview questions as written responses. Participants ranged from city officials, national government bodies, academics (primarily in the water sector), NGOs, community groups (water users associations), consultants, journalists, and officials from the respective in-country meteorological offices. In addition, five FRACTAL scientists/researchers involved in the delivery of FRACTAL were interviewed via Skype.

Semi-structured interview protocols

The semi-structured interview protocols were developed to help ensure a level of consistency across the interviews, but which also provided flexibility in light of the varied contexts in which the participants work, and the specific issues raised in conversation by the interviewees.

The stakeholder interview protocol first elicited the longest timescale that stakeholders currently consider in their work, working backwards from climate ('how the climate may change in the decades ahead'), to seasonality ('climate projections or weather forecasts covering the next 3-12 months ahead', to weather ('weather forecasts covering the next few days'). Subsequent interview questions were asked in the context of the longest timescale that the participant used.

Questions covered the following topics:

- how information is accessed and used in their work, together with any associated challenges;
- the extent to which information typically contains information about uncertainty;
- how information about uncertainty affects their decision-making;
- formats in which information about uncertainty is communicated.

See Annex B for the full interview protocol.

The scientist/researcher interview protocol questions were asked in the context of either AMMA-2050 or FRACTAL work, and covered the following topics:

- the purpose of including uncertainty information;
- types of uncertainties that need to be communicated;
- the types of audiences that uncertainties are communicated with;
- the communication formats (materials and/or activities) used to communicate uncertainties that they have employed.

Both the AMMA-2050 and FRACTAL project employ a range of communication formats. However, to provide focus and to contrast different approaches, scientists/ researchers from AMMA-2050 primarily considered experiences when communicating with slide-set materials incorporating data visualisations, whereas scientists/researchers from FRACTAL primarily considered experiences in the development of co-produced climate narratives.

See Annex C for the full interview protocol.

Procedure

Participants were approached to take part primarily via email or phone through existing networks and connections to the AMMA-2050 and FRACTAL projects. Participants were provided with information sheets about the research project and there was an opportunity for any questions or clarifications. Participants gave informed consent prior to the start of the interview. Where participants agreed, interviews were audio recorded to assist with note-taking and analysis. Interviews lasted approximately 30 minutes.

The appropriate interview protocol was followed to guide the overall structure of the interview. Key questions in the protocol were prioritised to enable insights relevant to the project aims to be elicited where time did not allow all questions to be asked. Where appropriate, follow-up questions were asked by the interviewers in order to explore answers in more depth. At the end of the interview, participants were offered the opportunity to add any additional comments or clarifications, debriefed and thanked for their participation.

5. Analyses and results of interviews

Analytical approach

Transcriptions or detailed notes were made for each interview to capture the responses of interviewees. To identify the predominant patterns in the data, the interviews were analysed qualitatively using coding schemes based on the project aims and objectives, and key aspects included in the interview protocol.

In recognition of the diverse contexts of the participants, four units of analysis were conducted, corresponding to AMMA-2050 stakeholders, AMMA-2050 scientists/researchers, FRACTAL stakeholders and FRACTAL scientists/researchers. Application of the coding scheme was implemented manually (paper based) for all units of analysis, except for AMMA-2050 stakeholders, where it was implemented using Nvivo (QSR International Pty Ltd). Overarching themes across units were reviewed to identify commonalities and key differences.

a) AMMA-2050 stakeholders

Key themes identified from interviews with AMMA-2050 stakeholders are provided below. Further details and a summary of these interviews can be found in Annex D.

Emphasis on seasonal and daily forecasts: All of the ten stakeholders underlined the relevance of seasonal and daily forecasts for farming and fishing communities, who rely on this information for their livelihoods (when to go out to sea, when to plant crops in view of maximising yields especially during the rainy season).

Importance of communication networks: Information is most accessible verbally, in local languages, e.g. via local groups, and considered most relevant when ‘reliable’, ‘accurate’ and ‘credible’, pertinent to local circumstances. Brief written communications (sms) are also used widely.

Uncertainty not communicated: in the aforementioned types of communication, interviewees indicated that uncertainty information was not communicated as they felt that recipients would lose trust in the messengers and sources of information were this to be perceived as inaccurate. Maintaining trust is thus key.

Some acknowledgement of longer-term climate projections: Some of the stakeholders indicated the importance of longer-term climate projections, available through international initiatives or national projects, which may be re-interpreted to the national or regional contexts in order to inform or complement longer-term decision-making.

Limitations of existing communication formats: A commonly held perspective was that climate information is mainly in written format. This, alongside any illustrative visuals that may accompany it, can be difficult to access. For example, use of SMS messages was mentioned by several stakeholders, with some identifying that such information is inaccessible to those who are illiterate. Reinterpretation of the information is sometimes required, which raises issues about its comprehensibility and accessibility.

b) AMMA-2050 scientists/researchers

Key themes identified from interviews with AMMA-2050 scientists/researchers based in Senegal are provided below. Further details and a summary of these interviews can be found in Annex D.

Use of climate information: most referred to the use of longer-term climate information at strategic national level for planning and adaptation.

Importance of uncertainty: Interviewees emphasised the importance of including and considering uncertainty, referred to as a general term, in such information; some training is provided on how to interpret uncertainty in relation to longer-term priorities.

Use of shorter-term information: Shorter-term weather and seasonal forecasts (largely provided by the national civil aviation and meteorological agency) are used by farmers and fishers, who are interested in the accuracy and reliability of the information (corresponding to findings from the stakeholder/user interviews).

Key themes identified from interviews with AMMA-2050 scientists/researchers based in the EU or outside the project focus countries but directly involved in the delivery of AMMA-2050 are provided below. Further details and a summary of these interviews can be found in Annex E.

Emphasis on model uncertainty: Model uncertainty, scenario uncertainty, and uncertainty related to natural variations and processes were all identified as being relevant to communicate, but model uncertainty was emphasised in the context of AMMA-2050. Also acknowledged by some interviewees was that, more broadly, there is ‘uncertainty in knowledge’.

Maintaining credibility: Model uncertainty was seen to be an issue because it poses a risk to the perception of credibility and hence there is a need to convince people that the models are credible and communicate where there is more and less certainty.

Broad audiences: In the context of communication using slide-sets in AMMA-2050, potential audiences were perceived to be diverse, both in terms of who they are and their informational needs. Various possible audiences were mentioned, including planners, politicians, and famers, but no specific groups were identified as being a primary audience.

Influence on decision-making unknown: It was acknowledged that there is a knowledge gap on how stakeholders would use information in slide-sets in their decision-making, or what level of information would be of most use to stakeholders.

Scientific communication formats: Current representations of uncertainty follow traditional scientific formats (e.g. graphs, box plots, time-series, pdfs, maps), which are seen to be scientifically defensible and require an expert to guide the audience's comprehension.

Challenges in tailoring communications: There was acknowledgement of the need to engage with individuals and tailor communications to specific contexts, but also recognition of the time and resource needed to do this effectively.

c) FRACTAL stakeholders

Key themes identified from interviews with FRACTAL stakeholders are provided below. Further details and a summary of these interviews can be found in Annex F.

Emphasis on weather rather than climate: The majority of city officials do not use climatic data in decision making but rather observational data as well as weekly weather forecasts. At the local level, there appears to be a slight misunderstanding between climate change and seasonality.

Discomfort in discussing uncertainties: During the interviews, a large majority of participants seemed uncomfortable during the questions around uncertainty and communicating uncertainty. Typically, interviewees appeared unfamiliar in considering 'uncertain' aspects or in considering how uncertainty might affect the use of information. Consequently, further clarification of this question was required, as well as giving interviewees time to reflect before answering. Even when clarification was given, answers here lacked clarity.

Perceptions of lack of access to climate information: Access to climate information emerged as the primary challenge for using climate information. (Note: This may be the reason for the limited feedback regarding uncertainty, as the need for information likely supersedes the concerns of inaccuracy).

Decision-making: Despite the limited feedback regarding uncertainty, the need for more accurate information as well as the role of uncertainty in decision-making processes appeared to be well understood. An example of where the need for greater accuracy was articulated, and appreciation of uncertainty identified, related to rainfall forecasts - when interpreting a forecast, the geographic area mentioned can be broad, and so while rainfall may then occur in one location in that area, it may not in another location.

Communications access: Most participants receive information from the in-country meteorological offices. Access to information is primarily in written form or received over the radio (i.e. weather forecasts); In addition, the process for acquiring seasonal and climate information is through requests made directly to the MET offices. The process for acquiring the needed information appears to be limited and an area of focus needed in future climate change planning.

Precipitation uncertainty: Areas of uncertainty that are important to communicate seem to be largely linked to precipitation; which seem largely limited to the written form.

d) FRACTAL scientists/researchers

Key themes identified from interviews with FRACTAL scientists/researchers are provided below. Further details and a summary of these interviews can be found in Annex E.

Scientific representations of uncertainty avoided in narratives: In the context of using narratives, the approach is to move away from traditional scientific approaches to communication of uncertainty in order to better engage and collaborate with stakeholders. However, narratives do not transparently map back to variability, modelling uncertainty, or scenario uncertainty.

'Familiar' communication formats: Use of narratives and 'likelihood' language described as being more familiar to audiences and easier to understand than scientific formats; recognition that these approaches involve value judgements and the optimal approach to implementation is still emerging.

Experiential communication: Positive experiences articulated in the use of games / experiential exercises enabling individuals to actively experiment with reality and see consequences of their decisions.

Collaboration and co-production: Emphasis placed on importance of shared understandings of the different contexts and values in which scientists and stakeholders work, together with the need for providing spaces for shared understanding and relationships to be developed.

Stakeholder relevant timescales: Considered that stakeholders largely operate on shorter decision-making timescales than climate change timescales, but that there are opportunities to bring climate change in to conversations when making short-term decisions, where choices have consequences in the long-term.

Audience and context relevant: Specific sectors were identified within each city context (e.g. Maputo – water sector), with learning labs described as bringing together associated stakeholders from local government, industry and civil society, allowing communications to be tailored to the needs of the group.

6. Key insights from interviews to inform guidelines

Drawing from the themes identified in the preceding four units of interview analysis, we next present four overarching themes together with associated insights and implications that represent key constraints and opportunities associated with the communication of climate information containing uncertainties with decision makers.

1. Majority of stakeholders consider weather and/or seasonal information to some extent, but not climate information. Possible reasons include a lack of perceived relevance of climate information to their decision-making context, and/or a lack of accessible information that they can integrate within their decision-making processes. [Theme: Relevance and accessibility]

Implications: stakeholders may have limited experiences in thinking about climate related uncertainties in their day-to-day decisions, and so it is difficult to elicit their perspectives on the communication of these uncertainties in the context of their decision-making. A further challenge is reconciling the diversity of stakeholders' information needs and contexts with a limited number of communication formats/activities. These issues suggest that the case for using climate information, and associated uncertainties, first needs to be identified, articulated and demonstrated with stakeholders groups. One approach to demonstrate opportunities here might be to use archetypal success stories, i.e. case studies, which ties in with narrative/storytelling methods. In addition, the use of analogies when communicating information could also support demonstrating the relevance of information to stakeholders.

2. Representations of uncertainties in climate information is important from the perspective of scientists/researchers for the purposes of rigour and transparency, but among stakeholders, the concept of 'uncertainty' can open up issues in relation to values of trustworthiness and credibility. Stakeholders may interpret 'uncertainty' as 'not knowing'. [Theme: Trust]

Implications: relationships between stakeholders and scientists/researchers need to be developed based on mutual trust and an openness to work through and discuss issues in collaboration. It is interesting to note that aspects related to trust emerged despite the fact that stakeholder interviewees were actively engaged with outputs from AMMA-2050 or FRACTAL. Trust might be even more of an issue for stakeholders who are less willing to engage with climate information. Differences in scientific literacy (e.g. of model-based predictions, and/or statistical models) between researchers and stakeholders may mean information and terminology are interpreted differently. If information is to be trusted and used for decision-making, it is important to develop shared-understandings. As a starting point, it would be beneficial to measure and evaluate trust in the data and trust in different information sources as relationships between stakeholders and scientists/researchers develop to assess how different communication and engagement activities influence trust.

3. Traditional scientific communication formats, e.g. scientific graphs, are perceived as being difficult for stakeholders to understand, and require expert interpretations to explain content (including the uncertainties). The information in these formats is *broadly considered difficult to integrate with decision-making. [Theme: Formats to support practice]*

Implications: co-production of accessible formats for the communication of uncertainty, bringing together stakeholders and scientists/researchers, provides an opportunity to enable information to better impact decision-making. Scientific assessments of uncertainty are of course key to underpinning the contributions of the scientific community. However, practitioner-based assessments of decision-making may not be fully integrated as a source of information to feed-in to communication and co-production. Eliciting stakeholder contexts, information needs, and decisions therefore presents an opportunity to further improve co-produced formats for communicating uncertainty.

4. Engagement between stakeholders and scientists/researchers is considered to be integral to develop successful formats for communicating climate information containing uncertainties, i.e. so that outputs are useful in individual decision-making contexts. Furthermore, engagement is needed so that available knowledge and expertise can be shared and relevant information accessed. However, this requires a large investment of time and resource, and is not easily scalable. [Theme: Scalability of Co-production]

Implications: while co-production methods are desirable, they may not be sustainable over the long-term (i.e. beyond the end of project funding). Consequently, methods to capture best practices and learnings, together with the creation of methodological tools to streamline future co-production, could improve efficiency of such stakeholder and scientist/researcher engagement. In addition, formalising better processes of engagement could improve the sharing and accessibility of climate information.

The four identified themes of ‘Relevance and accessibility’, ‘Trust’, ‘Formats to support practice’, and ‘Scalability of co-production’ are next considered by drawing on psychological theory, and methods.

7. Towards the development of guidelines: unpacking themes and implications

7.1 Theme 1: Relevance and accessibility

The common message emerging from the interview data is that there is a lack of understanding of uncertainty, reflected in the difficulties stakeholders had in the interviews articulating uncertainties relevant to their decision making. Here we consider the approaches to the communication of uncertainty in slide-sets with data visualisations and future climate narratives with respect to the main findings from the literature review as a bridge to the presentation of guidelines and recommendations.

'One size fits all' approaches to communication are often a pragmatic use of limited resources, but may not maximise engagement with diverse groups of stakeholders. Choices of communication content and format should be informed by, and where possible tailored to, the different types of stakeholders engaging with climate information and associated uncertainties. This can enable communications to be matched with information needs and prior knowledge (Harold et al., 2016) and take into account audience values and their social context (Bostrom, Böhm & O'Connor, 2013). Hence, it is important to identify who the audience is, segment the audience into meaningful groups, and tailor content where feasible to do so (Bostrom, Böhm & O'Connor, 2013).

As a starting point, it is important to note that people understand new information by mapping that information onto existing knowledge states. One method often employed in education, and grounded in scientific findings from the cognitive sciences, is to use analogy as a means of making new models and data more understandable. For example, Gentner and Gentner (1983) showed that children's understanding of physics problems involving electric circuits with batteries, resistors, etc. was significantly enhanced by indicating that electricity from a battery is like a water tank with water flowing, or alternatively, imagine lots of tiny people running around a corridor (the leads). Such "flowing waters" or "teeming crowds" analogies were found to improve understanding of electricity problems compared to children not given such analogies, and moreover provided a foundation for understanding on which to build more abstract knowledge and understanding. More broadly, the process of analogical mapping has been documented by Gentner (1983), and may provide a valuable tool for climate scientists in the explanation of uncertainty.

An example analogy for thinking about the uncertainties of climate change is that of the uncertainties in the progression of diseases and their treatment. Raimi, Stern & Maki (2017) identify the following elements of diseases that are analogous to attributes for climate change:

- *the risks are often caused or aggravated by human behaviour;*
- *the processes are often progressive;*
- *the processes produce symptoms outside the normal range of past experience;*

- *the processes have uncertainties in prognosis of future events;*
- *the treatment of diseases often involves trade-offs such as side-effects;*
- *and the most effective approach is often to treat the underlying disease rather than alleviating symptoms;*
- *some diseases, though not all, are hard to reverse.*

(adapted from Raimi, Stern & Maki, 2017, *pp* 4)

Particular analogies may be better suited to certain contexts and/or with certain audiences than others, and so choice of analogy may be best identified through co-production.

Explaining uncertainty

One approach, adopted in the slide-set developed by AMMA-2050, is consistent with the approach adopted by the IPCC, which involves being *explicit* about the uncertainties inherent in the models. This is sometimes done using language, visual presentation, or through a combination of the two. As we have noted earlier, there are issues surrounding this explicit type of communication. The former (using language to map onto defined uncertainty values) suffers from potential mismatches between the language used and its interpretation. For example, the IPCC has spent a considerable amount of time standardising the language used to describe uncertainty (Mastrandrea et al., 2010); the term 'Unlikely' refers to a 0-33% likelihood of the outcome (probability) while 'Very Unlikely' is associated with 0-10% likelihood and 'Very likely' is 90-100%. But such precise correspondence between vague quantifiers does not map onto how people comprehend such terms (Moxey & Sanford, 1993), and indeed Budescu et al. (2014) have tested the IPCC mapping between language and likelihoods on over 13,000 people across 25 countries and 18 languages, finding significant variations in interpretation of verbal terms across individuals and cultures.

The use of visualisations of uncertainty provides a different set of challenges from using language. While the use of language terms, such as vague quantifiers, on the face of it appears easy to understand for non-experts, adding information about uncertainty to visual representations of data can make them cluttered and extremely hard to comprehend (e.g. Harold et al., 2016; McMahon, Stauffacher & Knutti, 2015).

For example, McMahon, Stauffacher & Knutti (2015) found, using a graph from the IPCC Fourth Assessment Report that shows temperature projections under different future scenarios through to the year 2100, that non-experts typically failed to identify that the main source of uncertainty depicted in the graph was due to unknown societal choices. Instead, individuals typically attributed the uncertainty to climate models. So while it is acknowledged that a greater understanding of uncertainty information relevant to individuals' decision-making could lead to better decisions and actions, and consequently there is a need to enhance existing communications (Pidgeon & Fischhoff, 2011), the types of visualizations typically used often lead to comprehension difficulty.

Use of traditional scientific data visualisations is very much in line with the approach of the IPCC, and exhibits many of the issues identified in the literature on climate change figure comprehension associated with difficulty in understanding. The following points can be noted (referring to the example of the AMMA-2050 "Climate Change in the Sahel" slide-set - Figure 1):

1) The figures used typically show features of figures already identified as difficult to comprehend. In summary, issues include:
    a. The frequent use of complex line graphs; these could be easily replaced with pictograms and even histograms to make them easier to comprehend.
    b. Sometimes that are several complex figures on the same slides, without language being linked to the relevant visual.
2) The use of language such as "extremely likely" and "highly likely" in the slides is somewhat vague and risks variability in interpretation.
3) The contradictions between model outcomes is hard to reconcile for stakeholders.
4) Overall, the use of a slide-set format:
    a. is somewhat removed from stakeholders
    b. does not afford identification with the scientists involved (i.e. it is hard to trust information without information about the people and sources it emanates from)
    c. is associated with difficulties in holding viewer attention and processing complex information

In summary, slide-sets using scientific data visualisations to communicate uncertainty is consonant with that adopted by the IPCC, with the use of figures and text that is subject to the critique of such materials discussed in the literature review and elsewhere.

One approach to enhancing such materials would be to apply the 'MADE' principle, and associated guidelines, to the visuals (see Table 1 and Table 2), as adopted by the IPCC (see https://climateoutreach.org/resources/ipcc-communications-handbook/.

The 'MADE' principle – an acronym for Message, Audience, Design, Evaluation - was developed as an easy to use guide for the production of effective data visuals of scientific evidence, synthesising findings in the cognitive and psychological sciences regarding how people process and comprehend visual information (see Harold et al., 2016; Harold et al., 2017). Using MADE could enhance the materials in the slides, making them easier for stakeholder to comprehend. However, there are other options worth considering; we return to those in light of consideration of the other themes below.

Table 1: The MADE principle (Harold et al., 2017).
http://guidance.climatesciencecognition.com/

Message	Does the figure communicate a clear message?
Audience	Is the figure appropriate for the intended audience(s)?
Design	Does the figure use evidence-based design principles?
Evaluation	Has the figure been tested with the audience(s)?

Table 2: The twelve MADE guidelines (Harold et al., 2017).
http://guidance.climatesciencecognition.com/

1. Identify your main message
2. Asses your audience's prior knowledge
3. Consider how your audience 'thinks'
4. Choose visual formats familiar to your audience
5. Reduce complexity where possible
6. Build-up information to provide structure
7. Integrate and structure text
8. Avoid jargon and explain acronyms
9. Use cognitive design principles
10. Consider cognition for animation and interaction
11. Consider cognition when communicating uncertainty
12. Test visuals to check comprehension

Avoiding explicit mention of uncertainty

Climate narratives adopt a rather different approach to communication of uncertainty compared to scientific data visualisations. The narrative approach favours dispensing with any mention of uncertainty explicitly, and instead working with stakeholders initially to identify the themes surrounding uncertainty that are important for them, and then distilling the relevant science down to a series of possible scenarios that are easier to understand for potential stakeholders, but do not focus explicitly on uncertainty or likelihoods of occurrence.

The partnership of scientists and stakeholders working together is one that chimes with models of good practice in decision making, affording maximal buy in and trust from those taking part (see for example Bovaird & Loeffler, 2012 for general discussion; see also Lemos & Morehouse, 2005). However, this approach is labour intensive from the perspectives of stakeholders and scientists alike, and the longevity of such approach is dependent on long-term funding to maintain such activity (see below). Moreover, the scenarios produced, while affording an easily comprehensible means to consider the consequences of particular possibilities, presents potential problems for people not involved in the brokering process in terms of understanding the scenarios. As McMahon and colleagues (McMahon, Stauffacher & Knutti, 2016) have noted, there is a potential trade-off between ease of accessibility (of visualisations) of data and trust in the science behind it. While consideration of possible scenarios allows stakeholders to engage about the consequences of the scenarios, the extent to which those same stakeholders trust the science behind it is not known (an issue we discuss in detail below). This is something that would be of value to investigate.

Moreover, a perspective identified in the FRACTAL researcher interviews was the need to supplement the narratives with additional uncertainty information (somewhat explicitly done in the communication approach in slide-sets identified in the AMMA-2050 researcher interviews). It was acknowledged by several researchers that narratives are intended to be a starting point for discussions, i.e. conversation starters, after which more technical/tailored information can be provided to support specific stakeholder needs. Extrapolating from the findings of McMahon et al. (2016), while the presentation of the scenario narratives may be beneficial in terms of ease of comprehension and engagement, there may be a loss of trust with the presentation of contradictory outcomes in conflicting scenarios without any information about their relative likelihood of occurrence.

Uncertainty in the climate narratives is captured by virtue of the different plausible futures that they outline. However, the narratives do not convey likelihoods nor confidence regarding which scenarios captured in the narratives are thought be more likely than others. Consequently, stakeholders might not associate the narratives as conveying uncertainty in the same way they might associate probability ranges (which might be a more familiar way of expressing uncertainty). This may explain why, when FRACTAL stakeholders involved in the coproduction of the narratives were interviewed, they tended not to mention the narratives when asked about different formats they were aware of in which climate uncertainties are communicated. Hence there may be different conceptualisations of ‘uncertainty’ between scientists/researchers and stakeholders. Further follow-up would be needed to understand to what extent such differences in conceptualisation do or do not affect the usefulness and trustworthiness of narrative information for decision-making, and what types of supplementary information to the narratives is most useful for stakeholders.

In summary, the co-production model in many ways is a model of good practice with respect to approach. But three points remain: 1) the need to layer in more context to the uncertainty information to support stakeholders (if identified as being useful to stakeholders in their decision-making) 2) the need for scalability of co-production (see theme discussion below), and 3) the need to empower stakeholders as drivers of the co-production process (that is, as far as possible to get stakeholders to take a lead in co-production through early buy-in).

7.2 Theme 2: Trust

One of the key themes identified from the interview data is the issue of trusting data, and the sources who produce/provide it. It is important for the users of the data to be confident that the information provided to them is both accurate and understood appropriately; stakeholders often associated the term 'uncertainty' with 'not knowing', or 'a lack of accuracy'. A perceived failure of accuracy can reduce trust in the information and the source of the information (and uncertainty in scientific models is sometimes misunderstood as a lack of accuracy). This issue presents a major problem for scientists wanting to be transparent regarding the various kinds of uncertainties in models. Models simply are not crystal balls able to give accurate predictions about future climate, and therefore understanding the parameters within which estimates are made may help to understand the models.

There are many approaches to dealing with the communication of uncertainty, reviewed above. However, given the theme of trust emerging from the interviews, it is important to review how uncertainty information is communicated and trusted in order to maximise trust in future projections and in those who provide them.

Conceptualising trust

Trust is a multifaceted concept, and unpacking that concept is both useful, and we believe, illuminating for the communication of uncertain information. Trust is thought to be pivotal for how science is perceived and used in society. Advances in scientific knowledge, and the application of scientific knowledge, have resulted in complex societal systems (Luhmann, 1979, 1988; Giddens, 1990), for example in contexts such as agriculture, healthcare, and energy use. In other words, people have to trust scientists more and more as it is becoming increasingly difficult and time consuming to engage directly with the science. Moreover, trust is critical to increasing the likelihood with which stakeholders feel able to *act* on that information. For example, Slovic (1993) argues that lack of trust was a crucial factor in explaining failures in the management of hazards, such as storage of nuclear waste (e.g. Bella, Mosher & Calvo, 1988). Furthermore, trust in experts has been shown to be a predictor of the perception of risk across countries (e.g. Flynn, Burns, Mertz & Slovic., 1992; Viklund, 2003).

Trust as a concept has been defined in many ways (e.g. McAllister, 1995; Rotter, 1980; Uslaner, 2002; Rousseau, Sitkin, Burt & Camerer, 1998) but they share several core features. As a starting point, perhaps McAllister's (1995) definition is most practical in the present context: "The extent to which a person is confident in, and willing to act on the basis of, the words, actions and decisions of others." Inherent to most definitions are a set of common themes. For example, Hall and colleagues (Hall, Dugan, Zheng & Mishra, 2001) identify *vulnerability* as a key component to trust; the greater the risk to the individual or organisation, the greater the potential for either trust or distrust. In the present context, the vulnerability of different stakeholder groups within and between regions is likely to vary considerably and understanding of the extent to which stakeholders understand and recognise vulnerability may be variable.

Another parameter that affects trust is the credibility of the person (e.g. scientist) or process (e.g. science) associated with the views/advice expressed (see for example Butler, 1991). Credibility, however, is not just about the scientific track records and credentials of the scientists, but also includes the extent to which the scientists can be identified with, how likeable they are, and the extent to which they share a world view that concurs with the users of that information. Exactly the same parameters apply in the domain of persuasion (e.g. Aronson, 2003), such as trying to get consumers to buy a product. In that domain the most effective combination of characteristics include *identifiability of the source* (that is, knowing the source, including being able to put a face to him/her; see for example Redelmeier & Tversky 1990), *track record* (i.e. qualifications and domain experience), and *appeal to emotion* (source displays characteristics of empathy towards the users).

Following the MADE principles, and outcomes of the interviews, understanding the extent and nature of vulnerabilities is critical to understanding and building trust between stakeholders and scientists. Gauging the extent of vulnerability may itself require discussions of case studies and uncertainties prior to consideration of mitigation. What is clear from the trust literature is that increased trust is often associated with increased likelihood of action – the ultimate measure of success for AMMA-2050 and FRACTAL regarding impact. So how does one gauge and measure trust prior to understanding how one can build it?

Measuring trust

There are many ways in which trust can be measured, spanning both qualitative and quantitative methods. Here we focus on the latter on the assumption that standardisation can be most easily achieved using quantitative measures, and such data can also be collected quickly, efficiently and remotely without interfering with communication.

Trust has been measured using questionnaires with varying degrees of rigour, from a single questionnaire item in large-scale public surveys (e.g. Ipsos MORI, 2011) to the development of domain-specific longer measures with multiple items (e.g. Hall et al., 2001; Nadelson et al., 2014). For example, Nadelson et al. (2014) have developed a 21-item trust measure to gauge (generic) trust in scientists and science, including generic items tapping the extent to which respondents trust scientists and scientific theories (e.g. “we should trust the work of scientists”; “When scientists are hypothesising they are just guessing”) to questions on the scientific integrity (e.g. “Scientists will protect each other even when they are wrong”; “Scientists don’t value the ideas of others”).

In the context of communicating uncertainty, several short trust questions could easily be adopted, focussing on the components of vulnerability, trust in models, trust in the science and the scientists behind those models, and trust in sources who provide and/or communicate information. In addition, it could be insightful to compare trust levels in different types of knowledge, i.e. scientific research generated knowledge compared with local practice-based knowledge. In a similar vein, trust questions could also be utilized to gauge trust in/with the stakeholders on behalf of the scientists (where relevant). We suggest a few questions for use in the guidelines/recommendations sections that follow (below).

Methods to enhance trust (and communication of uncertainty)

One of the consequences of the co-production (for example, as used in the development of climate narratives) is likely to be increased trust in the scientists and science through contact with scientists. It has been well established that contact with groups increases trust and acceptance of those groups (see for example Pettigrew & Tropp, 2006; Brown & Hewstone, 2005). In the absence of direct contact, there is also evidence that *imagined* contact can also positively impact one’s perceptions and actions (see for example (Crisp, Husnu, Meleady, Stathi, & Turner, 2010). Therefore, while a co-production model may well foster high levels of trust between stakeholders and scientists, direct contact may not be necessary to do so. Information about the scientists, who they are and what they do, may facilitate trust and engagement if appropriate information is provided about the scientists and science behind the work.

When using slide-sets containing scientific data visualisations, trust could be fostered in climate models by including information about the scientists and science in the slide materials (see Figure 3). This could include pen sketches and photographs of the scientists involved; such simple additions have been found to increase trust in the literature and, more broadly, on decision making under conditions of uncertainty (see for example Brown, 2000, for theory and application). In tandem, measuring and monitoring trust as part of the ongoing refinement of methods and materials is good practice and will afford feedback to AMMA-2050 and FRACTAL regarding the effectiveness of communication methods.

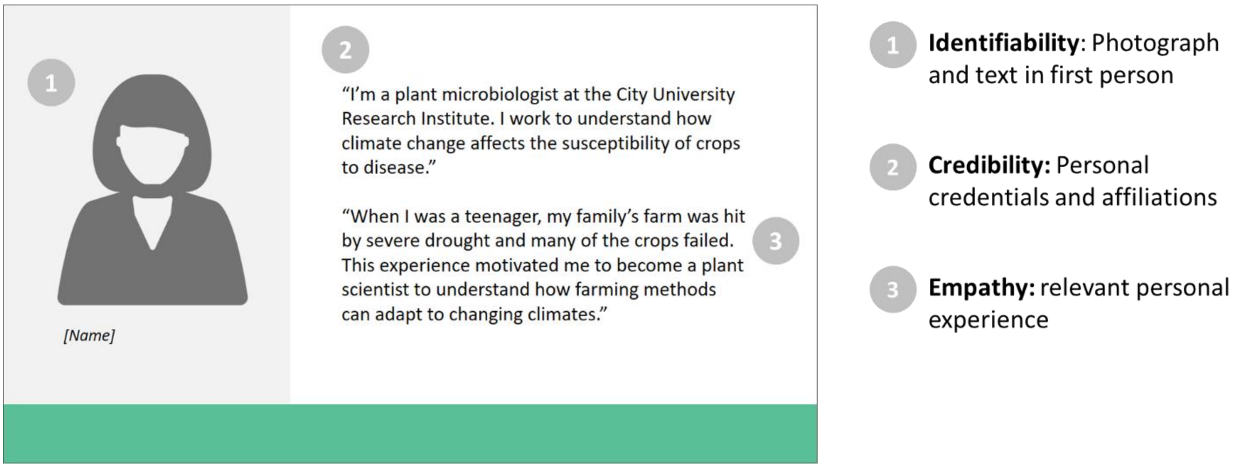

Figure 3. Template example of how information about a scientist/researcher can be provided to help increase trust.

7.3 Theme 3: Formats to support practice

We have already commented above (in the section on relevance and uncertainty) that language and visualizations used to communicate uncertainty can be difficult to comprehend, particularly visualizations, but at the same time, scientists in the interviews have acknowledged the desire to communicate uncertainty.

The examples of the slides containing scientific data visualisation can be difficult to understand, yet retain detailed uncertainty information. Thus they might be associated with high trust (by virtue of demonstrating transparency - i.e. showing the data), but low comprehension. In contrast, the climate narratives have the advantage of being easy to understand and engage with, and can support dialogue and foster learning, but do not explicitly convey uncertainty (at least from the perspective of stakeholders) and provide only an initial layer of information, i.e. by not including deeper evaluation or contextualisation of the uncertainty, which some scientists expressed as being important to communicate following initial use of the narratives to start conversations.

It is important to note here that the relative likelihoods of scenarios reflected in climate risk narratives developed from model ensembles cannot, in general, reliably be probabilistically quantified (for a discussion, see Collins et al., 2013; Knutti, et al., 2010). As such, part of the uncertainty of future climate relates to uncertainty of the relative likelihoods of the plausible futures captured in the narratives. Unpacking contextual information regarding the sources of uncertainty, and the extent to which they can or cannot be quantified, could help enhance transparency, trust and understanding. Hence, when discussing the narratives, the difficulty of attributing probabilistic likelihoods to scenarios should be acknowledged upfront and information quantifying impacts and consequences of impacts should be included where it is feasible to do so.

Where visual formats are used, and specifically where figures are used, the principles already developed through synthesis of the psychological and cognitive science literatures regarding how people process and comprehend information (Harold et al., 2017) can readily be adopted to aid the enhancement and refinement of visualizations where needed. More generally, as we outline in the guideline section below, the four pillars of the MADE principle – Message, Audience, Design, Evaluation – can be utilized as a broader framework within which to develop effective communication of uncertainty.

The interviews conveyed how stakeholders are currently working with the scientists to help the scientists identify narratives and scenarios that are more appropriate to use. These conversations could broaden to include the use of formats to support more information and discussion about the vulnerabilities stakeholders identify and the specific decisions they need to make; this may further enhance their engagement with such processes and may be integrated into FRACTAL and AMMA-2050 approaches.

7.4 Theme 4: Scalability of co-production

Climate narratives produced in the context of FRACTAL are a result of scientists working closely with relevant stakeholder in co-production. This results in different possible narratives for different stakeholder groups with varying needs and decision-making foci. It is important to note that within the FRACTAL project, the co-production approach has not only helped to communicate information, but also helped to foster learning (among both researchers and stakeholders), support capacity development and build understanding of expertise across sectors for responding to the multifaceted problems associated with climate variability and change. When considering the dynamic, emergent problems that will continue to arise as climate variability and change intersects of rapidly growing southern African cities, the value of building foundations for society and academia to collaboratively frame and respond to complex problems shouldn't be underestimated. Such face-to-face engagement and interaction is considered instrumental by the team for establishing these effective long-term partnerships.

However, in the specific context of communicating climate change uncertainties, the long-term sustainability of the approach may be in question. Stakeholders (and scientists) have limited time to spend in such an endeavour, and as a result, not all stakeholders as a result necessarily buy-in to the process. So developing methods of co-production that are less labour intensive may be desirable.

One approach to doing this is to assemble protocols that stakeholders can work through in their own time, without requiring meetings (or reducing the frequency of meetings) to elicit the information about stakeholder needs and interests that scientists require to develop scenarios. This type of approach is well established in the field of expert systems (see for example Cooke, 1994) and can take many forms. For example, based on previous experience of co-production, question sets could be produced that could be given to stakeholders to work through (these are often in the form of flowcharts), enabling them to identify the areas or key themes they feel are needed to inform scenario production and development.

The producers of the scenarios would take these into account in their production of the scenarios, and convey in a transparent way which key areas or themes have been considered and used as the basis for scenario development and which have not, and why. Discussion of the outputs (scenarios) and the process could then constitute the basis for continued interaction and co-production.

8. Guidelines

In many ways, climate narratives and slide-sets with scientific data visualisations offer complementary approaches to working with stakeholders. We suggest that the identification of elements of good practice in each project, gleaned through the interview data (see sections above), in tandem with consideration of materials and approaches informed by psychological perspectives, provides insights to develop more general guidelines for communication of uncertainty. We propose that these guidelines, as illustrated in the sections below, can be informed by the application of the MADE principle (Message, Audience, Design, Evaluation). The MADE principle was previously devised for effective communication of climate science in visualisations/figures, and here it is used as a framework to inform solutions to the key issues identified through the findings of the current research project – i.e. enhancing relevance and accessibility, supporting trust, choosing formats to support practice, and facilitating scalability of co-production)

Message and audience

Co-production is an excellent means with which to engage with the audience, involving them directly in the construction of the message, and also in the representation format of the message as it progresses from conceptualisation to design. The interview data clearly indicated that the climate narratives are an example of co-production good practice when it comes to working with the potential audience in the articulation of the message.

We propose that communication of uncertainty for decision-making can be enhanced through the following:

Guideline 1:

Adopt co-production throughout projects as good practice for the most effective articulation of the message, through iterative understanding of and engagement with the audiences.

i. Consider co-production as an explicit strategy (see Meadow, Ferguson, Guido, Horangic, Owen & Wall, 2015).
ii. Involve stakeholders in co-production from project inception.
iii. Continually review the effectiveness of co-production.

Guideline 2:

Identify the target audience and segment the audience into meaningful groups based on differences between information needs, degree of prior knowledge, and/or values and motivations. Where there are important differences between groups, tailor communications regarding uncertainty to match audience characteristics, where feasible to do so.

i. In the context of co-production, align inputs from specific stakeholders with tailored communications targeting the specific group or groups to which they belong (see also guideline 4).
ii. If co-production is not feasible, capture each audience group in user personas - these are short summaries of typical users for each group – and use the personas to help guide the design of communications.

Guideline 3:

Explore the level of *vulnerability* to weather and climate related impacts of the audience at an early stage (as discussed earlier in relation to interview findings). This may serve to support co-production (if adopted as a model of good practice) for information provision and communication, as well as help to gauge levels of trust, and hence the extent to which trust needs to be built and monitored as the collaboration and dialogue unfolds between scientists and stakeholders. Vulnerability can be explored with stakeholders by considering:

i. To what extent have particular stakeholder groups being affected by climate change in the past (especially the recent past)?
ii. To what extent is the income stream and associated value systems of stakeholders potentially affected by climate change?
iii. To what extent do stakeholders acknowledge the possible consequences of climate change directly? (e.g. “To what extent are you concerned that climate change might affect your life, business and community?”)

Guideline 4:

For maximal effectiveness, ensure that co-production operates in an equal, open and responsive partnership, with stakeholders equally driving the process. Practitioner-based assessments of decision-making can be fully integrated as a source of information to feed-in to communication and co-production. Eliciting stakeholder contexts, information needs, and decisions therefore presents an opportunity to further improve co-produced formats for communicating uncertainty.

i. Set-up a representative stakeholder-scientist working group from the start, and ensure the processes and governance of the group facilitates free iterative dialogue.
ii. Ensure that the group is at least co-chaired by a representative stakeholder with good links to key stakeholder groups.

While co-production is a model of good practice, it is also labour intensive on the part of both stakeholders and scientists, requires long-term funding, and it may be impractical to involve all stakeholders in co-production. Therefore, the following guideline relates to the scalability of co-production.

Guideline 5:

Consider methods that mirror the co-production process if time/resource constraints prevent face-to-face co-production. Such an approach could:

i. systematize (perhaps using flow-charts/decision trees) the vulnerabilities/challenges/decision points that stakeholders deal with;
ii. reach stakeholders who may be limited in participating in co-production processes (e.g. due to resource, time or accessibility constraints). This would assist the scientists in eliciting and assessing the relevance of climate change information for those stakeholder groups without the need to meet.

Guideline 6:

Be clear at the message level regarding the *types* of uncertainty that are necessary for the audience to understand in order to enhance appropriate actions being taken (e.g. by stakeholders). Such necessity needs to be established in line with the vulnerabilities stakeholders identify and the decision points they face.

i. Provide transparent communication about the nature of the uncertainties and associated limitations to knowledge (for example about uncertainties that can be quantified/estimated and those that cannot).
ii. Map how the uncertainties and the nature of the uncertainties could be taken into account in decision-making contexts, i.e. through co-production.

Design

Guideline 7:

Design a means to communicate uncertainty that retains or enhances (i.e. does not diminish) trust and engagement with the data (e.g. the scenarios being considered) and trust in the producers and communicators of information. This can be done in several ways.

i. Use pen portraits (i.e. descriptions) of researchers to introduce a human side to uncertainty in models, for example via short films/podcasts or through the use of bubbles/photographs on a slide. Selection of the researchers represented also deserves careful consideration.
ii. Use analogy to explain uncertainty in a way that people understand (make communication of uncertainty chime with their experience of another domain). The use of analogies can also enable individuals to identify why the information might be relevant to them. During the early stages of co-production, work with stakeholders to source a relevant familiar domain as a possible analogy to facilitate understanding of uncertainty.
iii. Use concrete illustrations of uncertainty using past human experiences of scenarios where events occurred that seemed unforeseen based on recent experience of climate/weather from the point of view of the stakeholders involved.

Guideline 8:

Ensure visualisations are easy to comprehend. Adopted guidelines developed elsewhere (e.g. MADE principle) can be used as a means to enhance the comprehensibility of visualizations. These guidelines provide the opportunity of building on the co-production processes outlined earlier.

i. Consider whether the visual communicates a clear message or not. Write down the main message that you wish to communicate to guide the creation of the visual (Message)
ii. Use knowledge of the audience to inform the design of the visual so that it is appropriate for the intended audience(s) - see guideline 2. (Audience)
iii. Use evidence-based design principles when creating a visual, for example use familiar graph formats such as bar graphs, reduce visual complexity and integrate text with the visual to guide a reader's understanding (Design)
iv. Test the visual with the audience(s) to check what does and doesn't work, and identify how the design could be improved to support understanding – see also guideline 10.

Evaluation

Guideline 9:

Assess key procedural elements of communication processes (i.e. co-production, testing of materials). Elicitation of trust in the processes, and their outcomes, information, and messengers, can be achieved using a variety of question formats, and could focus specifically on trust in the scientific models; trust in scientists; likelihood of behaviour change as a result of scientific input. For example:

i. Simple questions involving 'Likert' scales to survey trust in scientists and science can be used iteratively. Some of the items from existing scales could be adapted for specific projects (e.g. items from Nadelson et al., 2014).
ii. Integrate discussion about trust, and measure trust, within and throughout co-production activities.

Guideline 10:

Evaluate the effectiveness of the materials through iterative testing with stakeholders (throughout the co-production process and during the use of the materials). Iterative evaluation can take many forms, using a variety of methods (e.g. focus groups, questionnaires, eye-tracking, etc.). Methods that are quick and easy to implement, such as short questionnaires provided to stakeholders as part of existing engagement activities, may be particularly feasible and scalable in a variety of contexts. While it can be difficult to evaluate the extent to which specific communications influence real-world decision-making in the complex contexts in which decisions often take place, evaluating understanding and trust is a pragmatic starting point.

i. Embed evaluation activities throughout the process of creating and communicating climate change information containing uncertainties.
ii. Ask users to interpret and communicate back what they understand from the communication material/activity to check their level of comprehension and identify any misinterpretations.
iii. Use insights generated from such evaluations to inform how a communication can be adapted to better support understanding and/or decision-making.
iv. Provide multiple methods for participants to provide feedback and contribute ideas. Asking people to draw sketches of their ideas can enable other participants to see the idea and comment and build on it - this can be especially useful when co-producing data visualisations.

9. Recommendations

The recommendations below provide a summary of the over-arching key aspects considered in this report. The recommendation are primarily aimed to the AMMA-2050 and FRACTAL communities (in which the research informing the recommendations took place), but they are also relevant to those in the broader FCFA community and broader climate change communities, who are tasked with communicating climate information containing uncertainties.

These recommendations below should be considered in relation to the guidelines/points provided in section 8.

1. Methods for communicating uncertainty need to be developed that make clear what the nature of uncertainty is. Materials should provide a balance of information about uncertainty without compromising trust in the materials and the science underpinning those communications.

2. Measurement of trust in materials communicating uncertainty should be a priority throughout their development, given that a recurrent theme in the interviews is the association of uncertainty with ‘not knowing’, which has the potential to reduce trust in the scientific data and in those communicating the data.

3. Co-production, as per that used in the example of the creation of climate narratives, is good practice. Where there are time/resource constraints that limit the extent of co-production, elements of co-production should be combined with the development of less labour and time intensive approaches while maintaining the needs of, and buy-in from, stakeholders.

4. At all stages, evaluation should be built in to ensure that the materials being developed are understood by stakeholders, meet their needs, are refreshed according to changing needs and scientific understanding, improve their relevance, and inform decision making, so that they are more likely to be acted upon.

References

Aronson, E. (2011). *The Social Animal.* Worth Publishers: USA.

Bella, D., Mosher, C. D., & Calvo, S. N. (1988). Technocracy and trust: Nuclear waste controversy. *Journal of Professional issues in Engineering, 114,* 27-39.

Bostrom, A., Böhm, G., & O'Connor, R. E. (2013). Targeting and tailoring climate change communications. *WIREs Climate Change*, *4*, 447-455.

Bovaird, T., & Loeffler, E. (2012). From engagement to co-production: The contribution of users and communities to outcomes and public value. *VOLUNTAS: International Journal of Voluntary and Nonprofit Organizations, 23(4),* 1119-1138.

Brown, R. (2000). Social Identity Theory: past achievements, current problems, and future challenges. *European Journal of Social Psychology, 30*, 745-778.

Brown, R., & Hewstone, M. (2005). An integrative theory of intergroup contact. *Advances in Experimental Social Psychology, 37,* 255-343.

Butler, J. K. (1991). Toward understanding and measuring conditions of trust: Evolution of a conditions of trust inventory. *Journal of Management, 17,* 643-663.

Budescu, D. V., Por, H. H., Broomell, S. B., & Smithson, M. (2014). The interpretation of IPCC probabilistic statements around the world. *Nature Climate Change, 4(6)*, 508-512.

Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner, 2013: Long-term Climate Change: Projections, Commitments and Irreversibility. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Cooke, N. J. (1994). Varieties of knowledge elicitation techniques. *International Journal of Human-Computer Studies, 41,* 801-849.

Crisp, R. J., Husnu, S., Meleady, R., Stathi, S., & Turner, R. N. (2010). From imagery to intention: A dual-route model of imagined contact effects. *European Review of Social Psychology, 21,* 188-236.

Fischhoff, B., & Davis, A. L. (2014). Communicating scientific uncertainty. *Proceedings of the National Academy of Sciences*, *111*(Supplement 4), 13664-13671.

Flynn, J., Burns, W., Mertz, C. K., & Slovic, P. (1992). Trust as a determinant of opposition to a high-level radioactive waste repository: Analysis of a structural model. *Risk Analysis, 12,* 417-429.

Gentner, D. (1983). Structure mapping. A theoretical framework for analogy. *Cognitive Science, 7*, 155-170.

Gentner, D. & Gentner, D. R. (1983). Flowing waters or teeming crowds: Mental models of electricity. In D. Gentner & A. L. Stevens (Eds.), *Mental Models.* New York: Psychology Press.

Giddens, A. (1990). *The Consequence of Modernity.* Oxford: Oxford Polity Press.

Hall, M. A., Dugan, E., Zheng, B., & Mishra, A. K. (2001). Trust in physicians and medical institutions: What is it, can it be measured, and does it matter? *The Milbank Quarterly, 79(4),* 613-639.

Harold, J., Lorenzoni, I., Coventry, K. R., & Minns, A. (2017). *Enhancing the accessibility of climate change data visuals: Recommendations to the IPCC and guidance for researchers.* Report published by the Tyndall Centre for Climate Change Research, Norwich, UK.

Harold, J., Lorenzoni, I., Shipley, T. F., & Coventry, K. R. (2016). Cognitive and psychological science insights to improve climate change data visualisation. *Nature Climate Change, 6*, 1-11.

Ipsos MORI (2011). *Public attitudes to science 2011.* Department for Business, Innovation and Skills.

Knutti, R., Furrer, R., Tebaldi, C., Cermak, J., & Meehl, G. A. (2010). Challenges in combining projections from multiple climate models. *Journal of Climate*, *23(10)*, 2739-2758.

Lemos, M. C., & Morehouse, B. J. (2005). The co-production of science and policy in integrated climate assessments. *Global Environmental Change, 15(1),* 57-68.

Luhmann, N. (1979). *Trust and Power*. Chichester, UK: John Wiley & Sons.

Luhmann, N. (1988). Familiarity, confidence, trust: Problems and alternatives. In D. Gambetta (Ed.), *Trust: Making and Breaking Cooperative Relations* (pp. 94-108). Oxford: Basil Blackwell.

Mastrandrea, M. D., Field, C.B., Stocker, T.F., Edenhofer, O., Ebi, K.L., Frame, D.J., Held, H., Kriegler, E., Mach, K.J., Matschoss, P.R., Plattner, G.-K., Yohe, G. W., & Zwiers, F.W. (2010). *Guidance note for lead authors of the IPCC Fifth Assessment Report on consistent treatment of uncertainties.* Intergovernmental Panel on Climate Change (IPCC). Available from https://www.ipcc.ch/pdf/supporting-material/uncertainty-guidance-note.pdf. Accessed 6 August 2018.

McAllister, D. J. (1995). Affect- and cognition-based trust as foundations for interpersonal co-operation in organisations. *Academy of Management Journal, 38(1),* 24-59.

McMahon, R., Stauffacher, M., & Knutti, R. (2015). The unseen uncertainties in climate change: reviewing comprehension of an IPCC scenario graph. *Climatic Change, 133(2)*, 141-154.

McMahon, R., Stauffacher, M., & Knutti, R. (2016). The scientific veneer of IPCC visuals. *Climatic Change, 138(3-4),* 369-381.

Meadow, A. M., Ferguson, D. B., Guido, Z., Horangic, A., Owen, G., & Wall, T. (2015). Moving toward the deliberate coproduction of climate science knowledge. *Weather, Climate, and Society, 7(2)*, 179-191.

Moser, S. C. (2016). Reflections on climate change communication research and practice in the second decade of the 21st century: what more is there to say? *Wiley Interdisciplinary Reviews: Climate Change*, *7*(3), 345-369.

Moser, S. C., & Ekstrom, J. A. (2010). A framework to diagnose barriers to climate change adaptation. *Proceedings of the National Academy of Sciences*, *107*(51), 22026-22031.

Moxey, L. M., & Sanford, A. J. (1993). Prior expectation and the interpretation of natural language quantifiers. *European Journal of Cognitive Psychology, 5(1)*, 73-91.

Nadelson, L., Jorcyk, C., Yang, D., Jarratt Smith M., Matson, S., Cornell, K., & Husting, V. (2014). I just don’t trust them: The development and validation of an assessment instrument to measure trust in science and scientists. *School Science and Mathematics, 114(2),* 76-86.

New, M., & Hulme, M. (2000). Representing uncertainty in climate change scenarios: A Monte-Carlo approach. *Integrated Assessment*, *1*(3), 203-213.

Pettigrew, T. F., & Tropp, L. R. (2006). A meta-analytic test of intergroup contact theory. *Journal of Personality and Social Psychology, 90,* 751-783.

Pidgeon, N., & Fischhoff, B. (2011). The role of social and decision sciences in communicating uncertain climate risks. *Nature Climate Change*, *1*(1), 35-41.

Raimi, K. T., Stern, P. C., & Maki, A. (2017). The promise and limitations of using analogies to improve decision-relevant understanding of climate change. *PloS ONE*, *12(1)*, e0171130.

Redelmeier, D. A., & Tversky, A. (1990). Discrepancy between medical decisions for individual patients and for groups. *New England Journal of Medicine, 322(16)*, 1162–1164.

Rotter, J. B. (1980). Interpersonal trust, trustworthiness, and gullibility. *American Psychologist, 35,* 1-7.

Rousseau, D. M., Sitkin, S. B., Burt, R. S., & Camerer, C. (1998). Not so different after all: a cross-discipline view of trust. *Academy of Management Review, 23(3),* 393-404.

Slovic, P. (1993). Perceived risk, trust, and democracy. *Risk Analysis, 13,* 675-682.

Uslaner, E. (2002). *The Moral Foundation of Trust*. New York: Cambridge University Press.

Viklund, M. J. (2003). Trust and risk perception in Western Europe: A cross-national study. *Risk Analysis, 23(4),* 727-738.

List of Annexes (provided as accompanying documents)

Annex A: Literature review

Annex B: Stakeholder interview protocol

Annex C: Scientist/researcher interview protocol

Annex D: Summary of AMMA-2050 stakeholder and scientist/researcher interviews conducted in Senegal

Annex E: Summary of AMMA-2050 and FRACTAL scientist/researcher interviews

Annex F: Summary of FRACTAL stakeholder interviews