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UNCERTAINTY IN MODELLING CLIMATE CHANGE

The possibilities of co-production through knowledge pluralism[1]

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Introduction

Uncertainty is at the core of the climate change problem. Uncertainty is defined by the Intergovernmental Panel on Climate Change (IPCC) as 'a state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable' (Barros *et al.* 2012: 128). Considered to be a 'super-wicked problem' by scientists and policy-makers (Curry and Webster 2011; van der Sluijs 2005), climate change policy-making is often dominated by efforts to minimise and control uncertainty, and 'attempts to quantify it in one way or another' (Hallegatte *et al.* 2012: 10). This approach has been increasingly critiqued for not providing a useful basis for meaningful policy responses (Vogel and Olivier 2019; Shackley and Wynne 1996), and at the same time it does not reflect the lived realities of local people, who are often at the frontline of climatic uncertainty but far removed from the decision-making processes. In the *Fifth Assessment Report*, the IPCC (2014) acknowledges that there are uncertainties that we will never know and that the best response is to understand and cope with them. In this light, alternative perspectives have emerged over recent years that focus on embracing uncertainty through 'robust' decision-making (Lemos *et al.* 2016) or engaging with and integrating local or indigenous understandings through citizen science (D'Souza and Kale 2018; Panda 2016).

Why is this important? Decisions are made today that will affect future vulnerabilities – and, in turn, impacts – from extreme environmental change, including climate change. There is a growing recognition that the global, national and sub-national responses to uncertainty have been inadequate (Stirling *et al.* 2007; Wynne 1992). The largely Northern-focused literature of science and technology studies has been critical in elucidating the narrow ways in which uncertainty is often conceptualised by modellers, scientists and planners (Mehta *et al.* 2019; Wynne 1992).

Despite the increasing recognition of growing complexity, dynamism and uncertainties, decision-making is still predominantly driven by techno-managerial solutions that may either falter in the face of local social dynamics and uncertainties or end up harming certain groups, usually the poor (Leach *et al.* 2010; Mehta *et al.* 1999). These top-down processes fail to take into account more embodied experiences of uncertainty, which culminate from the broader political-economic and historical experiences of exploitation, discrimination and dispossession. They tend to privilege 'modernist' environmental practices and disparage other forms of knowledge as primitive, irrational or vernacular (Arora 2019; Ranganathan and Bratman 2019).

In this chapter, we focus on how uncertainties are characterised in scientific models, explore their inherent limitations and argue that responding to climate-related uncertainties requires a combination of different knowledges and methodological approaches. We first begin by conceptualising uncertainty in climate change. This is followed by a discussion of the limitations that arise out of modelling, and the practices of working with uncertainty, focusing on how uncertainty is negotiated, maintained and represented in forecasting models. Using the case of two projects in South Asia, we explore the opportunities and challenges of knowledge co-production between the scientific, policy and lay communities. Our core proposition is that investigating and unpacking the gaps in diverse conceptions of uncertainty can facilitate processes that embrace rather than eliminate uncertainty. This is because, as Melissa Leach *et al.* (2010) and Andy Stirling *et al.* (2007) argue, subjective judgements, multiple knowledges and diverse interpretations around uncertainty are inevitable and must be central to responses to uncertain situations, in turn shaped by historical and socio-cultural processes (Lyons *et al.* 2019).

Conceptualising uncertainty in climate change

Climate shocks and stresses, such as cyclones, floods, droughts, changing rainfall patterns and extreme temperatures are some examples of uncertainties that planners and local people in the global South regularly confront. Climate-related uncertainty refers to the inability to predict the scale, intensity and impact of climate change on human and natural environments (Curry and Webster 2011). Uncertainties in climate change projections remain particularly high and, combined with economic and political drivers of change, they make local-level effects difficult to predict (Barros *et al.* 2012).

Thus, there is now a growing acknowledgement that climate science is better at dealing with uncertainties arising due to macro trends, such as temperature extremes and sea level rise, than understanding the effects at the local level, due to downscaling challenges (Bhave *et al.* 2016). These local-level effects include the impacts of land use change, water management trends and socio-political and economic processes that can increase uncertainties for local people (Swart *et al.* 2009). These are what Robert Wilby and Suraje Dessai refer to as 'the envelope of uncertainty' (Wilby and Dessai 2010: 181), which intersects with social, political, economic, cultural and scientific domains.

Warren Walker *et al.* define uncertainty as 'any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system' (Walker *et al.* 2003:5). Three types of uncertainties are relevant for our discussion. First, aleatoric uncertainty, referring to natural fluctuations, a high degree of variability and disequilibrium dynamics having unknown effects (cf. Achutarao 2016). Second, knowledge or epistemic uncertainties, which refers to indeterminate knowledge about changes and their impacts (Barros *et al.* 2012). Third, uncertainties linked to larger political economy conditions, including unanticipated outcomes due to socio-political interventions, and how they are experienced by diverse groups (Mehta *et al.* 1999; Wynne 1992). All these uncertainties are experienced, framed and interpreted differently by different actors and are linked to relations of power that justify different institutional practices and responses (Rein and Schön 1993). While acknowledging aleatoric uncertainty, our focus in this chapter is on epistemic uncertainty and the interaction with wider institutional and socio-political processes.

Given the 'deep uncertainty' (Hallegatte *et al.* 2012: 4) presented by climate change, new approaches are needed as it is difficult to 'eliminate' uncertainty all together. This has given rise to a growing 'family of approaches' focused on providing robust outcomes in the face of a range of possible changes, ranging from large computer-based models to qualitative assessments. Approaches include a focus on 'no regrets', reversibility and flexibility in the face of uncertainty, building in safety margins, and reducing decision-making time horizons (Hallegatte *et al.* 2012), alongside approaches that emphasise the importance of more bottom-up methods of climate assessment and adaptation (Conway *et al.* 2019). Common to these approaches is that they acknowledge and embrace uncertainty, rather than trying to avoid or minimise it. However, despite these good intentions, there is still a tendency to manage uncertainty through top-down, techno-managerial practices and framings in contemporary climate discourse and practice: for example, through the current notions of the 'climate emergency' and a 'war on climate change'. As argued by Mike Hulme (2020) and Sinichiro Asayama *et al.* (2019), portraying climate change as 'black and white' obscures both deep uncertainties in science as well as the local-level impacts, concealing the inherently political nature of the term. In the worst case, the 'emergency' could be used as a justification for techno-managerialism on a massive scale, such as solar geo-engineering or authoritarian forms of regulation.

We recognise that knowledge about climate is co-produced alongside the social orders in which it is shaped and driven (cf. Jasanoff 2009). Hence, our notion of co-production does not principally relate to bringing different groups of people together to create new knowledge (cf. Ostrom 1996): rather, it is more about teasing out forms of knowledge that are often overlooked or undervalued by more traditional forms of knowledge-making. This includes embodied, emotional and tacit ways of knowing and representing the world. This requires a pluralist sensitivity to and appreciation for a persistent diversity of understandings (Stirling *et al.* 2018). We contend that transformative change – that is non-linear, involves deep-seated structural change and challenges the *status quo* of existing development

structures (O'Brien 2012; Pelling 2011) – is only possible if such plural pathways of knowledge-making are facilitated and encouraged.

Can we know better? Modelling for climate change

Climate change involves such complex systems that one of the few, but fundamentally pervasive, ways to deal with it is through computer models. Models are simplified representations of complex systems, and as such are never the 'real' thing – a fact that is often ignored. Computer models of climate change are often riddled with uncertainty and may not fully represent the complexity of climate processes. While model structure uncertainty refers to uncertainty about the form of the model itself, technical uncertainty arises from the implementation of these models. Other challenges include attempts to synthesise disparate sources and sets of data, and the impossibility of using experimentation to test hypotheses (Swart *et al.* 2009). Therefore, several choices need to be made while constructing a climate model and deciding how these processes are represented. These choices also concern the parameters chosen and the values attributed to these parameters. Other sources of uncertainty in climate projections and modelling include internal variability and natural fluctuations, model uncertainty (i.e., that different models simulate different responses in the climate), and scenario uncertainty (e.g., demographic change, emissions pathways) (Hawkins and Sutton 2009).

Social scientists studying the 'social life of models' tell us that climate modelling takes place according to diverse reasoning and across different scales (Hastrup 2013). In this process, nature is conceptualised and futures are reimagined. At the centre of the scientific practice is the creation of boundaries and distinct binaries (Douglas 1986) between the subjective and the objective, between the abstract climate and the particularities of weather (Heymann 2019; Hulme 2017). The abstract and supposedly 'objective' is represented by the hard science of modelling, which can ignore or externalise the subjective dimensions of uncertainties or neglect their political dimensions (cf. Jasanoff 2009). Such scientific approaches are just one of the many ways people anticipate and prepare for the future, and they need to be viewed together with the day-to-day strategies used by people who live with the uncertainties of climate (Hastrup 2013). However, a certain politics of knowledge results in particular domains (especially so-called hard science) gaining authority over others. Yet, all forms of knowledge (including so-called expert knowledge) are culturally and socially embedded and moulded by particular social, power and gender relations. Models are also embedded in narratives and storylines about a future based on certain assumptions (cf. Hajer, 1995), but, through a range of political practices and boundary-ordering devices, they gain authority over other forms of knowledge (Heymann 2019; Shackley and Wynne 1996).

Historically, local communities have developed practices and strategies to plan for and live with ecological uncertainty and variability (Hastrup 2013). These practices include seasonal mobility, crop diversification or risk-averse behaviours to cope with resource fluctuations. However, climatic change presents a radical rupture with

what communities have been attuned to in the past. Thus, following Lyla Mehta *et al.* (2019), we distinguish between uncertainty from 'above' and uncertainty from 'below', recognising that there are overlaps and nestings between these two relational categories. We also recognise that bridging these two domains requires actors and knowledge systems that can translate across the domains, hence the notion of the 'middle', representing actors and space(s) of negotiation of knowledges and practices.

Uncertainty from 'above' is represented by climate scientists, policy elites and decision-makers. The standard approach for conceptualising uncertainty is to quantify it in terms of probabilities (e.g. Sigel *et al.* 2010), reducing it to risk through statistical models that accommodate sophisticated data with multiple variables across a range of spatial and temporal scales (Edwards 2001). Of course, many modellers acknowledge the limits to models and their predictions due to limited understandings of the climate system (Curry and Webster 2011), although there will be hierarchies and multiple rationalities within these systems (Curry and Webster 2011).

Uncertainty from 'below' concerns the framings of lay people, as differentiated by gender, class and caste. It is experiential, non-official knowledge – not necessarily played out verbally or articulated formally but instead a more 'practical' or 'tacit' form of knowledge (cf. Bourdieu 1977). While our concern is largely with marginalised groups and perspectives, lay knowledge can also be linked to a very heterogeneous group consisting of both rich and poor, more powerful and powerless people. A wide literature from anthropological, sociological and political ecology traditions has demonstrated how local people live with and adapt to uncertainty (e.g. Scoones 2019; Hastrup 2013). Many indigenous knowledge systems evolve through adaptive learning based on developing a complex knowledge base of the environment and lessons from past mistakes – a version of 'post-normal' science (cf. Funtowicz and Ravetz 1993). Thus, such knowledges not only complement more macro perspectives but perhaps also reveal aspects that can be missed by more macro and global perspectives.

We, of course, acknowledge that climate change and uncertainty from 'above' and 'below' have different relative strengths and epistemological entry points, and have potential for complementarity. Both are culturally and socially embedded in local institutions, practices and power relations. Both, however, tend to approach temporal and spatial concerns differently, as we discuss further below. Neither scientists nor local people are homogenous and we do not intend to privilege one form of knowledge over the other. There are clear power differentials between the two, and power relations shape these categories and their relations with each other. That said, there is potential space for collaboration and bridging, where knowledges are negotiated across actors. As Hulme (2020) points out, such differences can be worked out iteratively, through negotiation within power structures and institutional processes.

We now turn to how stakeholder dialogues and roundtables that seek to break down political power and disciplinary divides can provide diverse actors with

opportunities to engage with and learn from diverse perspectives (Bhatt *et al.* 2018). Such emerging dialogues stress the importance of bringing to the fore hidden and alternative perspectives and solutions, while highlighting the need to address the power imbalances that prevent the application of alternative ways of valuation and epistemic diversity, which are so urgently required to address growing climate-related uncertainties. We highlight two such experiments below, and the challenges and opportunities that they present for the co-production of knowledge.

Starting a dialogue with different perspectives: experiments in bridging through roundtables on climate change uncertainty

Climate change is like an elephant in the story, and while people see different things (e.g. ear, tail, trunk), we need to look at it as one whole animal (Roundtable participant, Gandhinagar 2018). This quote from an NGO participant in a roundtable discussion nicely summarises the many ways in which climate and its associated uncertainties are characterised by actors from the above, middle and below. Although epistemic divides can lead to confrontational politics, they can also open up possibilities and opportunities for learning from diverse perspectives (Bhatt *et al.* 2018). We convened four roundtables in different settings in India and Europe.[2] The objective was to bring together perspectives and experiences of government officials, academics, scientists, practitioners and activists on climatic uncertainty in order to examine how discourses on uncertainty from 'below' and 'above' are contested, accommodated or hybridised in these politically charged spaces.

The Oslo roundtable was organised as a dialogue between natural scientists and social scientists, while the other three roundtables, which were organised in India, were rooted in their site-specific contexts (the dryland dynamics of Kutch in Gujarat; the rapidly urbanising context of the metropolis Mumbai and the deltaic islands of the Indian Sundarbans). All the roundtables ended up being quite distinct in both orientation and scope. This was due to the different locations (e.g., whether at a university, a government institute or a neutral seminar venue) and the role played by the local partners and co-hosts. For example, in Oslo, we largely had researchers from different disciplinary backgrounds and just two policy-makers. In Mumbai, the audience at the Indian Institute of Technology–Bombay largely comprised natural and social scientists, with some NGOs and local fisher activists. In both of these settings the discussions were preoccupied with academic discourses on uncertainty. By contrast, the Gujarat meeting, perhaps due to its location in the state capital (Gandhinagar), was dominated by government officials and policy-makers from different departments, who welcomed the opportunity to engage with each other's work, alongside many researchers and NGOs. Similarly, in Kolkata, the meeting had a good mix of different scientists, researchers and NGOs, as well as government officials. In all cases, but in different ways, power differentials were evident.

The roundtables played a key role in highlighting different understandings of uncertainty, while simultaneously opening up opportunities for sharing and learning. For some participants, the roundtable was a new experience and they appreciated the opportunity to engage with and learn from diverse perspectives. For others, the roundtable rehearsed well-known diverse views and brought to the fore the challenge of reconciling these plural perspectives (Mehta 2018).

Several key messages emerged. First, the importance and relevance of social science perspectives as regard challenging the dominant positivist framings of climate science. For example, sea level rise and flooding in Mumbai gets more complex once you start to unpack the social and political dimensions of these challenges, such as the grabbing of land on the coastline – including fragile mangrove ecosystems – by property developers and a total disregard of the natural creeks and rivers that offer natural drainage for the city. Second, issues related to scale and modelling. For local people, who are focused on uncertainty from 'below', there is more engagement with local weather variability (or everyday change) (cf. Hulme 2017), and they draw on multiple rationalities and intersecting explanations. Climate scientists, by contrast, are concerned with long-term climate change and short-term forecasting, but usually construct understandings statistically and not experientially. This is also exemplified in the quote below from a natural scientist at the Oslo roundtable:

> There is a complete mismatch between what people think uncertainty means and what scientists think uncertainty means, so if we could talk about certainty instead it would help a lot. The climate models are made to look at effects of emissions or scenarios, and those changes or these differences only come into play after about 30 years, so every uncertainty before that is not really dealt with. Such models should be used only for things that are relevant at that kind of time scale – for instance, should we build a dam in this site or that. Going to the local level, where people are uncertain about some things, the models do not help. There is a fundamental misconception that climate models can do anything in the here and now, locally (Oslo roundtable, August 2017).

Third, policy-makers prefer to rely on scientific expertise to understand climate change, rather than the subjective understandings of local people, which they often dismiss as anecdotal evidence – as occurred in the Gandhinagar roundtable. We also observed that policy-makers argue for the use of 'certain' 'evidence', because uncertainty, they believe, creates policy paralysis. This was explained by a senior bureaucrat in Gujarat:

> Policy-makers usually like to be certain about the course of action and they can work with likely scenarios but not with something that is highly uncertain. We need to justify our decisions. Uncertainty creates policy chaos, and the decision cannot be taken if the range of uncertainty is too high (Paraphrased, Gujarat roundtable, January 2018).

While the climate scientists and meteorologists admitted to the limits of working with uncertainty, we observed resistance on the part of the bureaucrats, who preferred to 'control' and 'minimise' and, if possible, 'eliminate' uncertainty as much as possible.

Fourth, several field-level bureaucrats also argued that discussions of climate change usually suffer from an elite bias because most of the deliberation and scientific investigations are conducted in English, ignoring understandings of climate uncertainty in the local vernacular. For many policy-makers, we found that the local level was a black box and uncertainty was messy and not clearly articulated.

As mentioned earlier, the roundtables were not designed to resolve or harmonise these differences: rather, they served as a platform to bring these differences to the fore and to demonstrate how discursive, social and institutional power shapes the understanding and framing of climate uncertainty. They did indeed help bring to the surface many different possibilities and issues. We started with the idea of 'bridging', but this seemed too restrictive, suggesting a link between similar groups. Instead, we began to think in terms of crossroads or junctions, which suggest meeting points and confluence between different actors and perspectives. Here too the importance of bringing to the fore diverse ways of valuation and epistemic diversity is key. Whose voices and priorities are privileged over others (as none of these spaces are power-neutral)? For example, is it possible for a camel herder in Kutch to have a seat around the table with policy-makers, and, if it is, how will different expressions of uncertainty interact with the institutional hierarchies and structural inequalities? Convening such spaces may open up the possibility of experiments with Habermasian communicative rationality, participation and deliberation (Dryzek 2002; Honneth and Joas 1991), but the hidden and invisible dimensions of power also need to be addressed as we bring these perspectives into dialogue with each other. This requires methodological innovations, not only to engage in dialogue but also to facilitate synergies in knowledge production.

Moving towards transformative change through co-production

Co-production involves the negotiation of knowledge as well as power; through co-production both new knowledges and social orders are produced (Jasanoff 2004). In roundtables, as in other forms of engaged research, knowledge is produced through relations of power and their intersection with historical, social and economic processes. For example, in another project, TAPESTRY,[3] we focus on how bottom-up transformation takes place in marginal environments that are facing high levels of uncertainty associated with droughts, floods and cyclones, influenced by the uneven impacts of capitalist expansion that is threatening people's well-being and sense of place and identity in India and Bangladesh. Across these sites, alliances between hybrid actors – local communities, NGOs, scientists and some state agencies – are seeking socially just and ecologically sound alternatives, based on local people's plural understandings of what transformation entails. In each of the sites, the team is facilitating an engaged process of situated learning, working

with locally based partners who both research and also co-produce transformative action with local communities. For example, fishers in Mumbai are challenging the growth-led paradigms of urban expansion, while also carving out ways to address plastic pollution, which is damaging their fishing habitats. Equally, in the deltaic Sundarbans in India and Bangladesh, climatic threats have undermined many islanders' well-being and collaborative efforts between civil society organisations, local communities and scientists are helping to restore ecology and livelihoods. Meanwhile, in the drought-prone drylands of Kutch in Gujarat, India civil society organisations and villagers are challenging dominant state paradigms regarding drylands and pastoralism, while also improving poor people's quality of life and enhancing biodiversity.

Although such initiatives provide the scope to re-imagine nature–society relations in uncertain, marginal environments, these emergent processes may be resisted by incumbent players, and may not always challenge underlying inequalities associated with class, ethnicity, gender or caste. They also involve a delicate power relationship between civil society organisations and diverse communities, begging the question who is imagining what, and for whom? We must equally ask: how does one ensure that the voices of the most marginalised, who are at the forefront of climatic uncertainty, are able to come to the fore? In response, we need to think of methodologies and consider the ethics around these experiments in co-production, while we re-imagine uncertainty as an opportunity.

Communicating uncertainty: reflections on methods

Creative and participatory methods can potentially open up new and existing conversations that otherwise might be impeded by hierarchical social structures, such as caste traditions or gender inequities. These may include storytelling, mural paintings, photovoice, photostories and a range of methods that seek to address power imbalances and ensure that hidden and subaltern perspectives are central. For example, we used the community-based participatory action research method photovoice to capture the embodied experiences of uncertainty.[4] Although scientists and policy-makers may see uncertainty in the form of coastal erosion or warming temperatures, local people experience uncertainty in more tacit and affective ways. This manifests itself in loss of culture, place and identity due to threats to traditional pastoralist livelihood practices due to a decline in the camel population and changing access to their traditional grazing lands on mangrove islands. Besides capturing these responses, the photovoice methodology also opens up ways of communicating understandings of uncertainty to different stakeholders. This is because visual images can break down language and disciplinary barriers, which often impede climate change communication and knowledge co-production and engagement.

All roundtables began with a powerful photovoice presentation highlighting the precarity of ordinary people in regard to climate change-related uncertainties, illustrating how they make sense of, live with and adapt to them. The visual stories demonstrated how uncertainties at these local scales are further compounded by

wider socio-economic changes, such as industrialisation along with the coast or port developments, which often destroy the commons, whether grazing lands, mangroves or fishing habitats. The interlinkages between resources, livelihoods and socio-economic change are often bypassed in siloed mainstream policy processes, through departmental jurisdictions and policy programming. Photovoice thus helped in revealing some of these blind-spots in climate policies and implementation.

For example, as part of our research on climatic uncertainty in pastoral communities in the border district of Kutch in Gujarat, India, we organised a photovoice series to understand the gendered experiences of uncertainty, focusing on the lives of women within these communities. In this context, photovoice played a transgressive role in two key ways. First, within the mainstream scholarship on pastoralism, women's role is under-represented and under-theorised. Hence, the focus on women brought to light powerful images of the 'invisible' care economy that sustains the pastoral system on a day-to-day basis. Second, in contrast to the dominant framings of climatic uncertainty in the form of high temperatures, erratic patterns of rainfall and sea level rise, the photovoice method revealed more embodied, socially and culturally embedded experiences of uncertainty. Some examples include frequent trips to drying wells in the summer, picking fodder leaves, milking buffaloes and washing the calves, and the role of faith and religion in coping with climatic uncertainties. Thus, through photovoice, we were able to tease out tacit and embedded forms of knowledge and experience that are often undervalued and overlooked by traditional forms of research and top-down policy processes.

Our experience with photovoice shows that the use of such methods provides agency to local actors to frame problems in ways that are seen as relevant and appropriate to their knowledge and lived experiences. These embodied understandings can also facilitate dialogue with scientists and policy-makers. For instance, women from the Sundarbans used photovoice to make a representation of their demands to the Sundarbans Development Board in West Bengal (Ghosh *et al.* 2019). Such iterative learning can provide new insights and perspectives in combining diverse knowledge, can challenge and reframe mainstream narratives and can also open up possibilities for dialogue and communication between a range of actors.

Conclusion

In this chapter, we have highlighted the divergent framings of uncertainty in relation to climate science, and how these come to be negotiated, maintained and shaped in forecasting models, through scenarios and projections, as well as in their interactions with science and policy processes. We have also highlighted the epistemic disjuncture in the framing of uncertainty and drew on the heuristic of the 'above', 'middle' and 'below' to demonstrate the divergent frames and understandings that shape these cognitive lenses. Drawing on creative methodological experiments, we argued that there is a potential to harness this diversity to facilitate practices of engagement and co-production between diverse stakeholders. Such emerging dialogues stress the importance of bringing to the fore hidden and alternative perspectives and

solutions, while highlighting the need to address the power imbalances that prevent the application of alternatives ways of valuation and epistemic diversity, which are so urgently required for transformative change.

Roundtables present a potentially fruitful way of bringing divergent perspectives into dialogue with each other. However, as we have shown, these spaces are politically charged and disagreements about the use of the term uncertainty abound. Although the interactions with climate scientists in some of these spaces have been fruitful – encouraging them to open up to the experiences of others – the majority of the scientists involved had reservations. Especially in India, the sentiment persisted that 'we can teach people, but have nothing to learn from them'. The roundtables were not envisaged as spaces of harmonisation and reconciliation, but were meant to allow us to bring the diversity of perspectives to the fore, as well as to observe the workings of power and how these are negotiated and shape understandings of uncertainty.

The use of visual methods such as photovoice and photostories can effectively capture lived and tacit experiences of uncertainty. Besides providing agency to local people, who have often been categorised as 'subjects' of research, such approaches provide a voice to vulnerable and marginalised communities, making them active participants in research and the creation of knowledge. Such co-produced research can potentially empower people to shape the conditions of their lives, creating spaces to produce and disseminate knowledge and actively shape development and research processes. However, sustained engagement is required in building relations of trust and reciprocity, as well as addressing power relations – and also in the research process.

Hence, co-production of climate knowledge will require altering the modernist and homogenising frame of knowledge production and dissemination that has long colonised practices through target-oriented top-down framings. This means embracing more decentralised and plural ways of knowing, with the aim of co-producing both new knowledges and social orders. In this chapter, we have also outlined the challenges involved in such processes when tackling existing power relations and existing social and gender inequities. This makes it important to develop methodologies and practices that open up new forms of dialogues among a diversity of actors and knowledges. These must both challenge existing social orders and embrace the multiple modalities of future-making and the plural practices of anticipation and living with uncertainty.

Notes

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3 TAPESTRY is short for Transformation as Praxis: Exploring Socially Just and Transdisciplinary Pathways to Sustainability in Marginal Environments. TAPESTRY is financially supported by the Belmont Forum and NORFACE Joint Research Programme on Transformations to Sustainability, which is co-funded by Economic and Social Research Council, Research Council of Norway, Japan Science Technology Agency, International Science Council and the European Commission through Horizon 2020. https://steps-centre.org/project/tapestry/.
4 https://steps-centre.org/project-related/photovoiceuncertainty/.

References

Achutarao, K. (2016) 'Uncertainty from Above: Can it be Reduced?', paper presented at workshop on Climate Change and Uncertainty from Above and Below, New Delhi, January 2016, www.slideshare.net/Stepscentre/krishna-achutarao-uncertainty-from-above-can-it-be-reduced

Arora, S. (2019) 'Admitting Uncertainty, Transforming Engagement: Towards Caring Practices for Sustainability Beyond Climate Change', *Regional Environmental Change* 19.6: 1571–1584

Asayama, S., Bellamy, R., Geden, O., Hulme, M. and Pearce, W. (2019) 'Why Setting a Climate Deadline is Dangerous', *Nature Climate Change* 9: 570–574

Barros, V., Dahe, Q., Field, C. and Stocker, T. *et al.* (eds) (2012) *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation,* A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC), New York: Cambridge University Press

Bhatt, M.R., Mehta, L., Bose, S., Adam, H.N., Srivastava, S., Ghosh, U., Movik, S., Narayanan, N.C., Naess, LO., Parthasarathy, D., Wilson, C. and Pathak, V. (2018) *Bridging the Gaps in Understandings of Uncertainty and Climate Change: Round Table Reports*, Experience Learning Series 76, Ahmedabad: All India Disaster Mitigation Institute

Bhave, A., Conway, D., Dessai, S. and Stainforth, D. (2016) 'Barriers and Opportunities for Robust Decision Making Approaches to Support Climate Change Adaptation in the Developing World', *Climate Risk Management* 14.1: 1-10

Bourdieu, P. (1977) *Outline of a Theory of Practice*, Cambridge: Cambridge University Press

Conway, D., Nicholls, R.J., Brown, S., Tebboth, M.G., Adger, W.N., Ahmad, B., Biemans, H., Crick, F., Lutz, A.F., De Campos, R.S., Said, M., Singh, C., Zaroug, M.A.H., Ludi, E., New M. and Wester, P. (2019) 'The Need for Bottom-up Assessments of Climate Risks and Adaptation in Climate-Sensitive Regions', *Nature Climate Change* 9: 503–511

Curry, J. and Webster, P. (2011) 'Climate Science and the Uncertainty Monster', *Bulletin for the American Meteorological Society* 92.12: 1667–1682

D'Souza, M. and Kale, E. (2018) *Using Transformative Scenario Planning to Think Critically About the Future of Water in Rural Jalna, India*, Second TSP Report, www.uct.ac.za/sites/default/files/image_tool/images/138/South_Asia/WOTR/WOTR%20Overall%20TSP%20Report%20-%20Aug%202018_For%20Online%20FINAL.pdf

Douglas (1986) *How Institutions Think*, New York: Syracuse University Press

Dryzek, J.S. (2002) *Deliberative Democracy and Beyond: Liberals, Critics, Contestations*, Oxford: Oxford University Press

Edwards, P. (2001) 'Representing the Global Atmosphere: Computer Models, Data and Knowledge about Climate Change', in P. Edwards and C. Miller (eds) *Changing the Atmosphere: Expert Knowledge and Environmental Governance*, Cambridge MA: MIT Press

Funtowicz, S. and Ravetz, J. (1993) 'Science for the Post Normal Age', *Futures* 25.7: 739–755

Ghosh, U., Bose, S. and Sen, B. (2019) 'Photo Voice as a Participatory Approach to Influence Climate Related Health Policy in the Sundarbans', *The Lancet Planetary Health* 3: S22, doi.org/10.1016/S2542-5196(19)30165-2

Hajer, M.A. (1995) *The Politics of Environmental Discourse: Ecological Modernization and Policy Process*, Oxford: Clarendon Press

Hallegatte, S., Shah, A., Lempert, R., Brown, C. and Gill, S. (2012) *Investment Decision Making Under Deep Uncertainty: Application to Climate Change*, World Bank Policy Research Working Paper 6193, Washington DC: The World Bank

Hastrup, K. (2013) 'Anticipating Nature: The Productive Uncertainty of Climate Models', in K. Hastrup and M. Skrydstrup (eds) *The Social Life of Climate Change Models: Anticipating Nature*, London: Routledge

Hawkins, E and Sutton, R. (2009) 'The Potential to Narrow Uncertainty in Regional Climate Predictions', *Bulletin of the American Meteorological Society* 100: 12

Heymann, M. (2019) The Climate Change Dilemma: Big Science, the Globalizing of Climate and the Loss of the Human Scale, *Regional Environmental Change* 19.6: 1549–1560

Honneth, A. and Joas, H. (eds) (1991) *Communicative Action: Essays on Jürgen Habermas's The Theory of Communicative Action*, Cambridge, MA: MIT Press

Hulme, M. (2020) 'Is it too Late (to Stop Dangerous Climate Change)? An Editorial', *WIREs Climate Change* 11, https://doi.org/10.1002/wcc.619

—— (2017) *Weathered: Cultures of Climate*, London: Sage

Intergovernmental Panel on Climate Change (2014) *Climate Change 2014: A Synthesis Report*, Switzerland: Intergovernmental Panel on Climate Change, www.ipcc.ch/report/ar5/syr/ (19 January 2017)

Jasanoff, S. (2009) *The Fifth Branch: Science Advisers as Policymakers*, Cambridge MA: Harvard University Press

—— (2004) 'The Idiom of Co-Production. States of Knowledge: The Co-Production of Science and Social Order', in S. Jasanoff (ed) *States of Knowledge: The Co-Production of Science and the Social Order*, London: Routledge

Leach, M., Scoones, I. and Stirling, A. (2010) *Dynamic Sustainabilities: Technology, Environment, Social Justice*, London: Earthscan

Lemos, M.C., Lo, Y-J., Nelson, D.R., Eakin, H. and Bedran-Martins, A.M. (2016) 'Linking Development to Climate Adaptation: Leveraging Generic and Specific Capacities to Reduce Vulnerability to Drought in NE Brazil', *Global Environmental Change* 39: 170–179

Lyons, I., Hill, R., Deshong, S., Mooney, G. and Turpin, G. (2019) 'Putting Uncertainty Under the Cultural Lens of Traditional Owners from the Great Barrier Reef Catchments', *Regional Environmental Change* 19.6: 1597–1610

Mehta, L. (2018) 'Overview', in M.R. Bhatt, *et al.* (ed) *Bridging Gaps in Uncertainty and Climate Change*, Experience Learning Series 76, Ahmedabad: All India Disaster Mitigation Institute

Mehta, L., Leach, M., Newell, P., Scoones, I., Sivaramakrishnan, K. and Way, SA. (1999) *Exploring Understandings of Institutions and Uncertainty: New Directions in Natural Resource Management*, Institute of Development Studies Discussion Paper 372, Brighton: Institute of Development Studies

Mehta, L., Srivastava, S., Adam, H.N., Bose, S., Alankar, Ghosh, U. and Kumar, V.V. (2019). 'Climate Change and Uncertainty from "Above" and "Below": Perspectives from India', *Regional Environmental Change* 19.6: 1533–1547

O´Brien, K. (2012) 'Global Environmental Change II. From Adaptation to Deliberate Transformation', *Progress in Human Geography* 36.5: 667–676

Ostrom, E. (1996) 'Crossing the Great Divide: Coproduction, Synergy, and Development', *World Development* 24.6: 1073–1087

Panda, A. (2016) 'Exploring Climate Change Perceptions, Rainfall Trends and Perceived Barriers to Adaptation in a Drought Affected Region in India', *Natural Hazards* 84.2: 777–796

Pelling, M. (2011) *Adaptation to Climate Change: From Resilience to Transformation*, Oxon: Routledge

Ranganathan, M. and Bratman, E. (2019) 'From Urban Resilience to Abolitionist Climate Justice in Washington, DC', *Antipode,* https://doi.org/10.1111/anti.12555

Rein, M. and Schön, D. (1993) 'Reframing Policy Discourse', in F.J. Fischer and J. Forester (eds) *The Argumentative Turn in Policy Analysis and Planning*, London: Duke University Press

Scoones, I. (2019) *What is Uncertainty and Why Does it Matter?*, STEPS Working Paper 105, Brighton: STEPS Centre

Shackley, S. and Wynne, B. (1996) 'Representing Uncertainty in Global Climate Change Science and Policy: Boundary-Ordering Devices and Authority', *Science, Technology, & Human Values* 21.3: 275–302

Sigel, K., Klauer, B. and Pahl-Wostl, C. (2010) 'Conceptualising Uncertainty in Environmental Decision-Making: The Example of the EU Water Framework Directive', *Ecological Economics* 69.3: 502–510

Stirling, A., Leach, M., Mehta, L., Scoones, I., Smith, A., Stagl, S. and Thompson, J. (2007) *Empowering Designs: Towards More Progressive Appraisal of Sustainability*, STEPS Working Paper 3, Brighton: STEPS Centre

Stirling, A., Marshall, F. and Ely, A. (2018) 'How is Transformative Knowledge "Co-Produced?"', *Integration and Implementation Insights,* https://i2insights.org/2018/04/03/co-producing-transformative-knowledge/ (accessed 17 January 2020)

Swart, R., Bernstein, L., Ha-Duong, M. and Petersen, A. (2009) 'Agreeing to Disagree: Uncertainty Management in Assessing Climate Change, Impacts and Responses by the IPCC', *Climate Change* 92: 1–29

Van Der Sluijs, J. (2005) 'Uncertainty as a Monster in the Science–Policy Interface: Four Coping Strategies', *Water Science Technology* 52.6: 87–92

Vogel, C. and Olivier, D. (2019) 'Re-imagining the Potential of Effective Drought Responses in South Africa' *Regional Environmental Change* 19.6: 1597–1610

Walker, W.E., Harremoës, P., Rotmans, J., van der Sluijs, J., van Asselt, M.B., Janssen, P. and Krayer von Krauss, M.P. (2003) 'Defining Uncertainty: A Conceptual Basis for Uncertainty Management in Model-Based Decision Support', *Integrated Assessment* 4.1: 5–17

Wilby, R.L. and Dessai, S. (2010) 'Robust Adaptation to Climate Change', *Weather* 65.7: 180–185

Wynne, B. (1992) 'Uncertainty and Environmental Learning: Reconceiving Science and Policy in the Preventive Paradigm', *Global Environmental Change* 2.2: 111–127