Environmental Science and Policy 80 (2018) 125–131

Contents lists available at ScienceDirect

Environmental Science and Policy

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

Science advice for global challenges: Learning from trade-offs in the IPCC

Warren Pearce[a,*], Martin Mahony[b], Sujatha Raman[c]

[a] iHuman, Department of Sociological Studies, University of Sheffield, United Kingdom
[b] School of Environmental Sciences, University of East Anglia, United Kingdom
[c] Institute for Science and Society, School of Sociology & Social Policy, University of Nottingham, United Kingdom

A R T I C L E I N F O

keywords:
Science advice
Global challenges
Antimicrobial resistance
IPCC
Climate change
Scientific assessment

A B S T R A C T

In the context of ongoing debates about the place of knowledge and expertise in the governance of global challenges, this article seeks to promote cross-sectoral learning about the politics and pitfalls of global science advice. It begins with the intertwined histories of the Intergovernmental Panel on Climate Change (IPCC) and the global climate policy regime, before examining the politics of different 'framings' of the climate problem and the challenges of building and communicating scientific consensus. We then identify three important trade-offs which the IPCC has had to negotiate: global versus local; scientific disinterestedness versus policy-relevance; and consensus versus plurality. These lessons are especially timely as global institutions begin to convene knowledge to address urgent sustainable development challenges posed by anti-microbial resistance (AMR). While the IPCC experience does not provide a wholly transportable model for science advice, we show why similar trade-offs need to be addressed at an early stage by architects of advisory systems for AMR as well as other global challenges.

1. Introduction

The need for integrating different sources of knowledge is a major theme in contemporary debates on environmental policy. Given the prominence of biophysical sciences in characterizing environmental problems, the job of knowledge integration is often associated with institutions at the science/policy interface tasked with providing science advice (Wesselink et al., 2013). Modelled on national science advisory bodies, such institutions are meant to fulfil the role of assessing the state of research on a given issue and synthesizing relevant evidence for policymaking. However, there is growing recognition of the need to open up these institutional arrangements to scrutiny so as to understand how different inputs are integrated in practice (Borie and Hulme, 2015; Scoones, 2009) and to consider ways of bridging scientific inputs with those from other disciplines and from stakeholders. The case for 'opening up' is set out in work calling for inter/trans-disciplinary research (Miller et al., 2014) and a broader notion of environmental expertise (Sörlin, 2013) befitting the complexity of environmental challenges.

In this paper, we identify lessons for global environmental science advice from the history of the most influential institution in this domain, the Intergovernmental Panel on Climate Change (IPCC). The IPCC has pioneered new ways of assessing scientific knowledge across a broad range of disciplines and interconnected topics, helping to cement climate change within international policy agendas. A number of scholars have written about the challenges of the IPCC 'model', for example, in: adequately representing marginal peoples, places and knowledges (Bjurstrom and Polk, 2011; Ford et al., 2016); delivering authoritative and usable knowledge to policy-makers (Haas and Stevens, 2011; Mitchell et al., 2006); and generating trust across diverse social groups and political cultures (Beck, 2011; Jasanoff, 2011). The IPCC's apparent success in at least partially overcoming these challenges prompted the establishment of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) in 2012 (Beck et al., 2014; Montana, 2017) and calls for similar bodies to provide advice for other global challenges such as antimicrobial resistance (Woolhouse and Farrar, 2014), which is rapidly emerging as a major issue at the environment/health interface (Antimicrobials in agriculture and the environment: reducing unnecessary use and waste, 2015).

Observers from other grand policy challenges may envy the IPCC's undoubted symbolic power (Hughes, 2015). Yet attempting to transfer this model of knowledge production to other issues is problematic without detailed analysis of the IPCC's role in both climate science and politics and how this might inform science advice in other cases. There is therefore an urgent need for scholars of the science-policy interface to work across different domains. This paper helps fulfil this need, joining emerging work generating comparative perspectives and lessons (Beck et al., 2014; Esguerra et al., 2017; Jabbour and Flachsland, 2017;

* Corresponding author.
E-mail address: warren.pearce@sheffield.ac.uk (W. Pearce).

https://doi.org/10.1016/j.envsci.2017.11.017
Received 7 October 2017; Received in revised form 29 November 2017; Accepted 29 November 2017

Kowarsch and Jabbour, 2017).

The paper begins with the emergence of the IPCC and the global climate regime (Section 2), an analysis of the framing of the climate problem (3), and the conceptualisation of science advice as consensual (4). From these, we identify three trade-offs that require attention when developing advice: '***global vs local'***, '***scientific disinterestedness vs policy relevance'*** and '***consensus vs plurality'*** (5). We then examine the implications of these trade-offs for a contemporary example, antimicrobial resistance (AMR) (6) before returning to the wider implications for science advice. Our focus on AMR is timely as it is now acknowledged as an urgent challenge for sustainable development and efforts to synthesise scientific evidence for global policy recommendations are emerging (WHO, 2017). We combine key findings from many years of published qualitative research on climate science and the IPCC, with original social research on how AMR is being understood as an environmental phenomenon.

2. Emergence of the IPCC and the global climate regime

The IPCC is widely regarded as a successful example of global science advice. Its voluminous assessment reports are produced by thousands of volunteer scientists working across three Working Groups dealing with physical science (WGI), social and ecological impacts and adaptation (WGII), and mitigation options (WGIII). Both report outlines and final content are approved by government representatives, and are intended to form the scientific basis for governmental policy-making.

The IPCC was formed in 1988 under the World Meteorological Organisation (WMO) and the United Nations Environment Program (UNEP). Strong consensus statements emerged from scientific conferences on climate change in the mid-1980s, but it was perceived by many that the political complexity of climate change was such that more was needed to drive political action. In light of dissatisfaction with the Advisory Group on Greenhouse Gases, a small, underfunded advisory group set up in 1986 by WMO, UNEP and the International Council of Scientific Unions which was arguably too distant from the policy process to be effective, calls were made for a more comprehensive international assessment effort (Agrawala, 1998). Following complex negotiations between WMO and the US Government, the road was paved for the creation of the IPCC.

The IPCC's emergence coincided with, and reinforced, a reconceptualization of 'climate' as a complex, *global* system. This followed decades of scientific work on general atmospheric circulation, on the data and modelling infrastructures required to study it (Edwards, 2010), and the emergence of new ideas about the management of environmental problems through global cooperation (Miller, 2004). It was the novelty of the latter which arguably drove the desire for an *intergovernmental* institution, with various competing actors, not least across different US Government departments, keen to ensure governmental oversight of such consequential knowledge-making (Agrawala, 1998).

The initial focus was to provide a comprehensive assessment of climate change and its potential impacts, while debating the relative merits of possible responses. A number of developing countries expressed unease at this positioning of the IPCC across the science-policy interface, fearing that the Western dominance of climate science would enable them to dictate the terms of global climate policy. In 1990 the Intergovernmental Negotiating Committee was formed as a separate setting for drafting what would become the UN Framework Convention on Climate Change (UNFCCC). Post-1990, the IPCC reverted more to scientific assessment, promising policy neutrality across its three Working Groups. IPCC Assessment Reports consist of each Working Group's own report, plus a succinct, collaborative Synthesis Report. Five Assessment Reports have been completed between 1990 and 2014, with preparations for a sixth beginning in 2015. These assessments inform parties to the UNFCCC and underpin UN negotiations.

The IPCC's core task is to assess all the available science and issue consensus statements about the present and future states of anthropogenic climate change. The IPCC has also addressed direct policy questions, such as the potential meanings of 'dangerous' climate change and has provided focused assessments of topical questions like extreme weather (IPCC, 2012), renewable energy (IPCC, 2011) and the impacts of 1.5 °C of warming in Special Reports (IPCC, 2016).

3. Framing the climate problem

The most widely discussed findings of the five Assessment Reports have concerned global mean temperature rises to date and in future, and scientists' ability to attribute these rises to human activities. This may seem normal now, but it wasn't to many in the 1980s. Russill (2016) has argued that this period saw a struggle to 'frame' climate change as either a question of global trend detection and management, or as a question of local climate-society interactions and bottom-up risk management. Trend detection won out, due in part to the new dominance of global models, but also, Russill suggests, to contemporary US energy politics where the management of global trends was a dominant mode of thought across science and politics. Similar preoccupations with the global also emerged in other domains including that of 'emerging infectious diseases' which paved the way for conceptualizing health policies in terms of security (King 2002). However, in the IPCC's evolution over the next two decades, we can trace a shift in framings from climate change as a problem of additional carbon dioxide and temperature, to a problem of risk management, albeit at an increasingly global scale. In recent WGII reports in particular, some of the concerns of the dissenting 1980s scientists, who lobbied for risk management rather than trend detection/management approaches, are starting to be addressed, through approaches which marry top-down framings of vulnerability with bottom-up, contextualised understandings of climate-society relationships (O'Neill et al., 2017).

Implicit in any framing of climate change as a problem of global trend management is the assumption that climate change is a well-structured technical problem, within which scientific advice could act as a trigger for international policy agreement (Hoppe et al., 2013). However, many social scientists have argued that climate change is actually an unstructured, or 'wicked' problem at the global level, spanning both social and climate systems and containing deep cultural and political differences over values, goals and meanings (Demeritt, 2001; Hoppe et al., 2013). Framing climate change as a global problem with global solutions has been a natural progression of trends in both science and politics, but the result has been a heavily centralised supply of scientific advice that neglects the need for geographically differentiated and plural policy approaches (Hoppe et al., 2013).

Problem framings have powerful effects on how solutions are conceptualised. Some have worried that the IPCC's emphasis on global trend detection has pushed adaptation to the end of a chain of accumulating impacts where it functions as the social cost of failed mitigation (Beck, 2010; Hulme, 2011). Some have argued for more concerted thinking about adaptation to already evident climatic extremes, and less about determining their direct cause (Hulme et al., 2011). Certain framings may also play better in different political cultures. For example, trend and/or risk management may appeal in North America, where the burden of proof is often placed on proponents of environmental regulation, but may not sit so well with more precautionary attitudes in Europe (Jasanoff, 2005; Mahony, 2015). In the global South, the IPCC has also faced controversy in the way it has framed Southern forests as 'empty' spaces available to suck up the global North's carbon pollution (Fogel, 2005), and in its valuing of Southern lives at lower levels than Northern lives (Masood, 1995). This shows that in controversial issues like climate change, scientific claims may not be simply 'neutral'. Rather, they shape the contours of how we think – politically, ethically, culturally – about responding to the issue at hand. Institutions like the IPCC exert great political and symbolic power (Hughes, 2015), and therefore face dilemmas about how to frame scientific issues in ways which are credible, legitimate and salient

(Mitchell et al., 2006) to a wide range of audiences.

The IPCC has responded by broadening the disciplinary make-up and forms of knowledge going into its assessments. However, repeated criticisms have been made of the under-representation of social science and humanities disciplines (other than economics, which is well represented), despite their capacity to provide vital knowledge about the key drivers and potential victims of climate change: human beings and their societies (Bjurstrom and Polk, 2011; Minx et al., 2017). The IPCC has also been dominated by scientists from the global North (Ho-Lem et al., 2011), leading to worries of bias towards problems and framings which are of greatest concern to Northern scientists and politicians (Orlove et al., 2014). In the case of India, low participation of both scientific and political actors has been attributed to both a lack of governmental interest in the science (as opposed to the politics) of climate change, and to a deeper distrust of institutions such as the IPCC as potential vehicles of western diplomatic power (Biermann, 2001; Lahsen, 2007). Indeed, it was for this reason that India was among those calling for the IPCC's pre-1990 policy negotiation function to be removed (Miller, 2009). However, such patterns are not purely national. Distinctive epistemic communities exist within both India and Brazil, with some scientists from independent, elite research institutions are often directly connected to international networks of scientific collaboration and assessment, while others are tied to national research institutions focusing on more on localised research questions (Lahsen, 2009, 2007; Mahony, 2014).

The IPCC's treatment of the social complexities of climate change impacts has nonetheless evolved over time, even if concepts like inequality or justice are yet to become key organising concerns. Debates have ranged over how to bring in the knowledges and experiences of people on the 'frontline' of climate change, for instance, in the Arctic. This might mean revising how expert authors are selected and included (Ford et al., 2016; Yamineva, 2017), or how different types of knowledge are rendered credible and thus proper for inclusion. The IPCC's controversial 2010 mistake regarding the timescale for Himalayan glaciers melting away brought to the fore questions about the inclusion of 'grey literature' in assessments − literature which may not have been through the vetting procedures of scientific peer review, but which may nonetheless feature important insights from places where accredited scientists may have yet to tread (Mahony, 2014). The subsequent tightening of the IPCC's guidelines on utilising grey literature has introduced new quality control measures. This may enable certain findings to receive the kind of validation usually bestowed by peer review, but it may also risk the exclusion of certain forms of knowledge − and thus people and places – from the assessment process.

4. Science advice as consensus

The IPCC has, since its first assessment report, sought to deliver to policymakers a consensus statement on the state of climate science. Consensus has become the hallmark of the IPCC process, achieved through the processes of collective authorship among large groups of scientists, a lengthy expert and government review process, and in lively plenary sessions where government representatives offer their approval (or disapproval) of the key findings. For many, this presentation of a unified scientific voice has been central to the IPCC's authority to frame the global debate (Pearce et al., 2015). There is a symbolic power to the IPCC'S self-positioning as the voice of a singular scientific community, labouring for many years to offer universal truths unto the altar of politics, where they may either be lauded as sacrosanct, or sacrificed to the higher gods of political ideology and material interest. However, while consensus-seeking may bring symbolic and political power, it may also tarnish the process of producing objective assessments. A famous case concerned the estimation of end-of-century sea level rise in the 2007 report, wherein new modelling techniques suggested much higher rates of change than previous assessments. However, the unreliability of these results, owing to their comparatively new underlying methodology, meant that consensus could not be reached on them, and they were excluded in favour of more conservative statements (O'Reilly et al., 2012). Here, a question arises of whether policy-makers would be better served by being informed of not only what everyone can agree on, but of the likelihood – however low, controversial, or difficult to quantify – of high-magnitude future events, like rapid sea level rise, that carry great societal implications (Hansen, 2007; Oppenheimer et al., 2007).

Consensus also raises important questions about how best to represent uncertainty. There are many forms and sources of uncertainty – incomplete understandings, observational and model error, expert disagreement, and so on – which are hard to communicate in a single language. The IPCC developed a set of likelihood and confidence statements with the aim of formalising uncertainty communication, and of encouraging authors to more systematically evaluate uncertainty. Consensus is therefore about agreement and disagreement, with uncertainty guidance urging communication of levels of agreement on particular findings as low, medium or high. These practices have slowly worked their way across the Working Groups, but have been shown to be incompletely understood, particularly by non-scientific audiences (Barkemeyer et al., 2016; Budescu et al., 2014)

The challenges of consensus and communication also relate to problem framing, and the frequent inseparability of the epistemic and the normative in climate change science. The IPCC's attempts to produce state of the art, 'policy-neutral' scientific observations of the world are perhaps commonsensical, but they sometimes mean overlooking the societal values and processes that underlie the very processes they seek to describe. One example of the intermingling of facts and values is the recent controversy over so-called 'negative emissions' technologies in IPCC scenarios. These technologies, at this point untested, were crucial in generating scenarios in which the world stayed below the agreed upon threshold of dangerous climate change. However, questions of the social and political feasibility of these technologies, which would involve giving huge swathes of land over to bioenergy production, were side-stepped by the IPCC and science advisors, and the centrality of these technologies to the scenarios underplayed (Geden, 2015). There are important questions here about how scientists should negotiate the links between questions of technical and social feasibility of new technologies, for example, but also about how transparent they should be about the assumptions and values underpinning descriptions of the world as it is, and predictions of the world as it could – or ought – to be. For many, closer forms of knowledge 'co-production' (or collaboration between knowledge makers and users in assessment processes) is key to tackling these complexities, especially as bodies like the IPCC seek to move to more 'solution-oriented' approaches (Kowarsch and Jabbour, 2017; Tollefson, 2015).

5. Three trade-offs in the IPCC

The IPCC is an extraordinary institution – perhaps the largest exercise in scientific cooperation ever embarked upon, and the producer of knowledge claims which have underpinned the steady push for global policy action. It is therefore unsurprising that policy actors in other global challenge domains have called to emulate it. For example, in biodiversity (Beck et al., 2014), biotechnology risks (Bowerman, 2014), food (Maxwell, 2015), water (World Water Week, 2017) and AMR (Woolhouse and Farrar, 2014). But since global emissions continue to rise and some still publicly question the reality of climate change, questions have been asked about whether the incremental increases in top-line certainty in IPCC reports on global warming trends and anthropogenic causation, are worth the years of effort of thousands of scientists. It is therefore important to reflect on this history and draw lessons from it, both for the IPCC and for science advisory processes with similar ambitions. In particular, there are trade-offs to consider in designing similar institutions and processes of scientific assessment and advice. We highlight three:

*i) **global vs local:*** between scientific knowledge that speaks of abstract global systems to a global audience, and knowledge that pertains more closely to local settings where the drivers and impacts of global change are more directly experienced. This dynamic plays out differently across the IPCC's Working Groups, and reflects global distributions of expertise and knowledge which the IPCC cannot itself do much to change. However, regionally-focused assessments could help integrate more locally relevant information into the IPCC process.

*ii) **scientific disinterestedness vs policy relevance***: between processes which aim to stay firmly on the science side of the science-politics boundary, sticking to the norm of scientific disinterestedness, and processes which engage more directly with value-laden policy questions. The former strategy may help enhance the scientific authority of a process, but perhaps at the cost of direct policy relevance. The IPCC has long guarded the norm of 'policy relevant, never policy prescriptive', but steering clear from values-based questions has diminished IPCC reports' practical utility. particularly within adaptation and mitigation where 'is' and 'ought' are often entangled. For example, scientific disinterestedness resulted in CO2 emissions being treated as homogenous in early discussions of climate change. Subsequently, a distinction made between 'subsistence' and 'luxury' emissions showed that CO2 emission measures are inflected with social and normative meaning (Agarwal and Narain, 1991).

*iii) **consensus vs plurality***: between unitary, consensus statements and the representation of conflicting views (Kowarsch et al., 2017). Consensus-seeking may enhance scientific authority, and please policymakers who value non-ambiguous statements (Mahony, 2013) but can also, as shown above, lead to important omissions of uncertain findings, or of conflict and disagreement. Social science research has shown that it is wrong to assume that decision-makers value only unanimity and certainty (Stirling, 2010), and that scientific consensus provides a poor starting point for political progress (Pearce, 2014; Pearce et al., 2017). Mediating between conflicting opinions and handling uncertainty is the bread and butter of politics; and scientific advisory processes may benefit from acknowledging points of disagreement. Indeed, their role of knowledge appraisal, properly understood, calls for expanding the range of alternative policy options and clarifying what underlies them rather than prematurely closing down what is considered feasible or desirable (Stirling, 2008).

Hence, the IPCC model is not easily transferable to other global challenges. Global (as opposed to national) science advice involves different design and problem framing choices that should be openly considered by a range of actors, and at the earliest available opportunity. As we have illustrated through the three trade-offs above, there are no perfect solutions when providing policy-relevant global science advice. However, awareness of the issues that have repeatedly surfaced during the IPCC's history provides a sound platform for decision-making and future learning. In the next section, we work through the implications of our analysis for one of the most urgent global policy challenges: AMR.

6. The case of AMR

We examine the case of AMR for three reasons. First, it is widely regarded as an urgent global policy challenge requiring multi-state cooperation (United Nations, 2016). Second, AMR is significant as it affects multiple sustainable development goals, much like climate change (Jasovský et al., 2016; United Nations, 2016). Third, there is rising interest in evidence synthesis to inform AMR policy, notably, around the use of antibiotics for food animals (Review on Antimicrobial Resistance, 2015; WHO, 2017). However, there is little evidence of reflections on approaches and methods of evidence assessment for AMR policy. We now show why this is needed since science is unsettling conventional boundaries between AMR in humans and environmental phenomena (Singer, 2017) and AMR is being redefined as a multi-sectoral challenge for food security and sustainable livelihoods as well as health (Jasovský et al., 2016).

In 2016, United Nations members pledged to implement the World Health Organization's (WHO) 2015 Global Action Plan on AMR, one of whose objectives is to strengthen the knowledge and evidence base for action. Hopes that this knowledge can help broker global policy cooperation and action rest in part on the assumption that "the science around antimicrobial resistance is less contested than that of climate change" ("Antibiotic resistance: only global co-operation will succeed against this deadliest of threats," 2014). But just as global versus local framings of climate science vied for influence in the 1980s (Russill, 2016), similar debates are likely on how to understand the influence of different human activities on AMR. Already there is an emerging question on distinguishing the impact of anthropogenic uses of antibiotics versus resistance 'in the wild' (Allen et al., 2010). The WHO's (2017) guidelines on reducing animal antibiotic use are framed around what it says is 'low quality evidence', thus inviting controversy. To minimise intractable science-focused debate and encourage wider discussions on underlying frames of assessment (Morris et al., 2016), advisory institutions for AMR must be better prepared to learn the lessons of the IPCC model.

Viewed as an environmental phenomenon, AMR arises from the collective fate of antibiotics, genes encoding resistance, and other pollutants in the air, soil and water. In the late 1990s, the European Commission's scientific steering committee reviewed research on AMR which they described as a phenomenon of global genetic ecology *tout court*. They specified four ecological components in the transmission of resistance: humans, animals, plants and soil-water (Opinion of the Scientific Steering Committee on Antimicrobial Resistance, 1999). In addition to antimicrobials and bacteria, they underlined the significance of horizontal gene transfer of resistance traits between domains. The study of resistance genes in soil and water samples opened up new questions for scientists on the role of different environmental selection pressures in AMR (Salyers and Amábile-Cuevas, 1997). In addition to animal antibiotics, other matters of concern are emerging, including linkages between AMR, antibiotic residues in antibiotic manufacturing effluent and in sewage, heavy metals and widely used biocides (Martinez, 2009; Singer, 2017; Wellington et al., 2013)

Such relationships are challenging to pin down, not least because antibiotics are already present in nature. Precisely because of this complexity, more attention is needed to the question of what is expected from science and how different sources of knowledge might be brought together to inform decision-making. Here, we return to our three trade-offs from the IPCC, demonstrating their relevance for AMR.

i.) *global vs local:* That bacteria do not respect national borders is at the heart of recent articulations of AMR as a *global* threat. UK and other global North-led policy documents (Davies and Gibbens, 2013) refer to the incursion of antibiotic-resistant bacterial strains into their territories – but rarely acknowledge the capacity for flows in the other direction. From an environmental perspective, cross-border flows relate not only to resistant bacteria but to horizontal transfer of resistance genes and antimicrobial residues that have not been fully metabolized in the body or other hosts. These may be linked to the movement of goods as well as of people, calling attention to patterns of global trade.

In an echo of experiences with climate models, two tensions between universal and local frameworks of meaning are emerging in the AMR science/policy interface. First, at the national level there is already evidence of disjuncture between i) global policy aspirations to restrict the use of antibiotics in livestock on the basis that evidence of a link to human health is sufficient (Antimicrobials in agriculture and the environment: reducing unnecessary use and waste, 2015) and ii) statements from, for example, the UK government which interprets evidence as pointing only to the role of human antibiotic use (Davies and Gibbens, 2013). Second, experts highlight a paucity of comparable cross-national data on antibiotic usage, resistance profiles, and transmission of AMR (Grace, 2015). As international and national agencies develop systems of AMR surveillance and risk management in accordance with the WHO AMR Action Plan, it will be important to consider how data-collection methods are standardised and how countries manage the diversity of norms and practices even within their borders.

ii.) *scientific disinterestedness vs policy relevance:* Advisors will need to explore the value-laden questions shaping scientific assessments of AMR risks and the formulation of science advice. As with CO2, the physical properties of antimicrobial agents may be universal, but their social properties are not. The influential Review on Antimicrobial Resistance (2015) recommends setting targets on livestock antibiotic use in the form of 50 mg/kg of meat. Whether and how this would work on a global scale needs more discussion in light of potential consequences of antibiotic restrictions on smallholders or subsistence farmers who may already find it difficult to access the drugs. Equally, the impact on antibiotic use of global drivers towards intensification of farming will need to be considered.

There is some evidence of such discussions amongst AMR experts. For example, efforts to promote industrialisation and intensification of agriculture in low- and middle-income countries will need to be re-assessed if they are likely to create a 'lock-in' effect of embedding antibiotic use for higher productivity. The UN's Food and Agriculture Organisation recommends priority action on restricting prophylactic use of antibiotics in intensive farming but places this within a broader assessment of options for supporting livestock development to meet the Sustainable Development Goals (Grace, 2016). Also, a recent review by the International Livestock Research Institute suggests a willingness to acknowledge that scientific evidence alone is not enough, and that normative questions can help steer the kinds of evidence that are worth generating. Given the strong possibility that some antibiotic uses "could cause irreversible harm*, what actions are appropriate and which require further evidence?*" (Grace, 2015). Such trade-offs will require more scrutiny.

iii.) *consensus vs plurality:* As scientific interest in applying new techniques to understand AMR grows, it is not surprising that AMR is emerging as an epistemically complex phenomenon with the potential for diverse criteria governing what counts as acceptable evidence for particular claims. Again, there are parallels with climate change and other environmental assessments, illustrated by a recent exchange in *Nature Reviews Microbiology* on methods for ranking the risk of antibiotic resistance genes in the environment.

One scientific team (Martínez et al., 2015) offers rules for defining the relative risks for human health associated with different candidate resistance genes. They suggest that these rules should focus on the likelihood of genes being acquired by human pathogens. In response, another group (Bengtsson-Palme and Larsson, 2015) argues that this framework overly emphasises the risk of resistant pathogens arising from *known* resistance genes in the environment and underplays the greater threat of *novel* genes. By contrast with this focus on science-based risk assessment, other scientists altogether acknowledge the limits of 'knowing' AMR fully and argue for socially-inflected responses, notably precaution (Boerlin and Reid-Smith, 2008; Kümmerer, 2009). Advisory institutions for global AMR policy will need to engage with these different epistemic lenses, their ability to bring to light different aspects of a complex phenomenon and reflect on how to deal with such diversity in scientific assessment and advice.

7. Conclusion

Knowledge produced for policy advice is based on different standards to those of academic science (Jasanoff, 1990). Our analysis suggests that given significant trade-offs in knowledge assessments for global challenges, advisory institutions must consider better ways of building 'serviceable truths' (Jasanoff, 1990). Their credibility is co-produced with their institutional arrangements for handling key trade-offs and engaging different parties (Guston, 2001), and the ability of their normative commitments to speak to wider concerns about how policy impacts are distributed within and across societies. At a time when expertise is in question, bodies such as the IPCC, and their successors in fields such as AMR, could be bolder about describing the nature and value of their work in terms of collaborative truth-building, rather than a narrow appeal to 'science'.

In both climate change and AMR, this requires transforming the culture of science advice to enable meaningful public and stakeholder engagement, particularly where this helps elicit and test different problem framings, expand the scope of possible solutions, and take differential vulnerability seriously (Jasanoff, 2003). To fulfil their critical role at the interface of science and policy at a range of scales, advisory institutions must move beyond scientific inputs alone. IPBES is starting to show the different models that are available (Esguerra et al., 2017; Montana 2017). The language of carbon-dioxide emissions or resistance-genes has helped call attention to global challenges, but is inadequate for developing solutions. Wider engagement can strengthen accountability of science advice in negotiating the trade-offs inevitably encountered when assessing knowledge for global challenges.

Acknowledgements

The authors acknowledge the support of the University of Sheffield's Faculty of Social Science in making this article Open Access. Sujatha Raman acknowledges the funding support of the Leverhulme Trust Making Science Public programme (RP2011-SP-013). We also thank the International Network for Government Science Advice (INGSA) for inspiring the original idea for this article.

References

Agarwal, A., Narain, S., 1991. Global Warming in an Unequal World: A Case of Environmental Colonialism. Centre for Science and Environment, New Delhi.
Agrawala, S., 1998. Context and early origins of the Intergovernmental Panel on Climate Change. Clim. Change 39, 605–620.
Allen, H.K., Donato, J., Wang, H.H., Cloud-Hansen, K.A., Davies, J., Handelsman, J., 2010. Call of the wild: antibiotic resistance genes in natural environments. Nat. Rev. Microbiol. 8, 251–259. http://dx.doi.org/10.1038/nrmicro2312.
Anon, 1999. Opinion of the Scientific Steering Committee on Antimicrobial Resistance. Directorate General XXIV Consumer Policy and Consumer Health Protection.
Anon, 2014. Antibiotic Resistance: Only Global Co-operation Will Succeed Against This Deadliest of Threats [WWW Document]. The Guardian.
Anon, 2017. World Water Week 2017 [WWW Document]. French Water Partnership. URL www.partenariat-francais-eau.fr/en/calendar/evenement/semaine-mondiale-de-leau-de-stockholm-2017/ (Accessed 21 November 2017).
Barkemeyer, R., Dessai, S., Monge-Sanz, B., Renzi, B.G., Napolitano, G., 2016. Linguistic analysis of IPCC summaries for policymakers and associated coverage. Nat. Clim. Change 6http://dx.doi.org/10.1038/NCLIMATE2824. (311 +).
Beck, S., Borie, M., Chilvers, J., Esguerra, A., Heubach, K., Hulme, M., Lidskog, R., Lövbrand, E., Marquard, E., Miller, C., Nadim, T., Neßhöver, C., Settele, J., Turnhout, E., Vasileiadou, E., Görg, C., 2014. owards a Reflexive Turn in the Governance of Global Environmental Expertise. The Cases of the IPCC and the IPBES. GAIA – Ecol. Perspect. Sci. Soc. 23, 80–87. http://dx.doi.org/10.14512/gaia.23.2.4.
Beck, S., 2010. Moving beyond the linear model of expertise? IPCC and the test of adaptation. Reg. Environ. Change 11, 297–306. http://dx.doi.org/10.1007/s10113-010-0136-2.
Beck, S., 2011. The challenges of building cosmopolitan climate expertise: the case of Germany. Wiley Interdiscip. Rev. Clim. Change 3http://dx.doi.org/10.1002/wcc.151. n/a–n/a.
Bengtsson-Palme, J., Larsson, D.G.J., 2015. Antibiotic resistance genes in the environment: prioritizing risks. Nat. Rev. Microbiol. 13http://dx.doi.org/10.1038/nrmicro3399-c1. (396-396).
Biermann, F., 2001. Big science, small impacts—in the South? The influence of global environmental assessments on expert communities in India. Glob. Environ. Change 11, 297–309. http://dx.doi.org/10.1016/S0959-3780(01)00008-5.
Bjurstrom, A., Polk, M., 2011. Physical and economic bias in climate change research: a scientometric study of IPCC Third Assessment Report. Clim. Change 108, 1–22. http://dx.doi.org/10.1007/s10584-011-0018-8.
Boerlin, P., Reid-Smith, R.J., 2008. Antimicrobial resistance: its emergence and transmission. Anim. Health Res. Rev. 9, 115–126.
Borie, M., Hulme, M., 2015. Framing global biodiversity: IPBES between mother earth and ecosystem services. Environ. Sci. Policy. 54, 487–496. http://dx.doi.org/10.1016/j.envsci.2015.05.009.
Bowerman, N., 2014. Good Policy Ideas That Won't Happen (yet). The Future of Humanity Institute.
Budescu, D.V., Por, H.-H., Broomell, S.B., Smithson, M., 2014. The interpretation of IPCC probabilistic statements around the world. Nat. Clim. Change 4, 508–512. http://dx.

doi.org/10.1038/nclimate2194.
Davies, S.C., Gibbens, N., 2013. UK Five Year Antimicrobial Resistance Strategy 2013 to 2018. Lond. Dep. Health.
Demeritt, D., 2001. The construction of global warming and the politics of science. Ann. Assoc. Am. Geogr. 91, 307–337.
Edwards, P.N., 2010. A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming. MIT Press, Cambridge, MA.
Esguerra, A., Beck, S., Lidskog, R., 2017. Stakeholder engagement in the making: IPBES legitimization in politics. Glob. Environ. Politics 17, 59–76. http://dx.doi.org/10.1162/GLEP.
Fogel, C., 2005. Biotic carbon sequestration and the Kyoto protocol: the construction of global knowledge by the intergovernmental panel on climate change. Int. Environ. Agreem. Polit. Law Econ. 5, 191–210. http://dx.doi.org/10.1007/s10784-005-1749-7.
Ford, J.D., Cameron, L., Rubis, J., Maillet, M., Nakashima, D., Willox, A.C., Pearce, T., 2016. Including indigenous knowledge and experience in IPCC assessment reports. Nat. Clim. Change 6, 349–353. http://dx.doi.org/10.1038/nclimate2954.
Geden, O., 2015. Policy: climate advisers must maintain integrity. Nature 521, 27–28. http://dx.doi.org/10.1038/521027a.
Grace, D., 2015. Review of Evidence on Antimicrobial Resistance and Animal Agriculture in Developing Countries.
Grace, D., 2016. Sustainable Agricultural Development for Food Security and Nutrition: What Roles for Livestock? A Report by the CFS High Level Panel of Experts on Food Security and Nutrition.
Guston, D.H., 2001. Boundary organizations in environmental policy and science: an introduction. Sci. Technol. Hum. Values 26, 399–408.
Haas, P.M., Stevens, C., 2011. Organized science, usable knowledge, and multilateral environmental governance. In: Lidskog, R., Sundqvist, G. (Eds.), Governing the Air: The Dynamics of Science, Policy, and Citizen Interaction. MIT Press, Cambridge, MA, pp. 125–162.
Hansen, J.E., 2007. Scientific reticence and sea level rise. Environ. Res. Lett. 2, 024002.
Ho-Lem, C., Zerriffi, H., Kandlikar, M., 2011. Who participates in the Intergovernmental Panel on Climate Change and why: a quantitative assessment of the national representation of authors in the Intergovernmental Panel on Climate Change. Glob. Environ. Change 21, 1308–1317. http://dx.doi.org/10.1016/j.gloenvcha.2011.05.007.
Hoppe, R., Wesselink, A., Cairns, R., 2013. Lost in the problem: the role of boundary organizations in the governance of climate change: Role of boundary organizations in the governance of climate change. Wiley Interdiscip. Rev. Clim. Change 4, 283–300. http://dx.doi.org/10.1002/wcc.225.
Hughes, H., 2015. Bourdieu and the IPCC's symbolic power. Glob. Environ. Polit. 15, 85–104. http://dx.doi.org/10.1162/GLEP_a_00323.
Hulme, M., Neill, S.J.O., Dessai, S., 2011. Is weather event attribution necessary for adaptation funding? Science 334, 764–765.
Hulme, M., 2011. Reducing the future to climate: a story of climate determinism and reductionism. Osiris 26, 245–266.
IPCC, 2011. Summary for policymakers. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., von Stec, C. (Eds.), IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Cambridge University Press, Cambridge.
IPCC, 2012. In: Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.-K., Allen, S.K., Tignor, M., Midgley, P.M. (Eds.), 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. Cambridge University Press, Cambridge.
IPCC, 2016. Scoping Meeting for the IPCC Special Report on the Impacts of Global Warming of 1.5 °C Above Pre-industrial Levels and Related Global Greenhouse Gas Emission in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty.
Jabbour, J., Flachsland, C., 2017. 40 years of global environmental assessments: a retrospective analysis. Environ. Sci. Policyand Policy 77, 193–202. http://dx.doi.org/10.1016/j.envsci.2017.05.001.
Jasanoff, S., 1990. The Fifth Branch: Science Advisers as Policymakers. Harvard University Press, Cambridge, MA.
Jasanoff, S., 2003. Breaking the waves in science studies: comment on HM Collins and Robert Evans,The third wave of science studies. Soc. Stud. Sci. 33, 389–400.
Jasanoff, S., 2005. Designs on Nature: Science and Democracy in Europe and the United States. Princeton University Press.
Jasanoff, S., 2011. Cosmopolitan Knowledge: climate science and global civic epistemology. In: Dryzek, J., Norgaard, R.B., Schlosberg, D. (Eds.), Oxford Handbook of Climate Change and Society. Oxford University Press, Oxford, pp. 129–143.
Jasovský, D., Littmann, J., Zorzet, A., Cars, O., 2016. Antimicrobial resistance-a threat to the worldýs sustainable development. Upsala J. Med. Sci. 121, 159–164. http://dx.doi.org/10.1080/03009734.2016.1195900.
Kümmerer, K., 2009. Antibiotics in the aquatic environment – a review – part I. Chemosphere 75, 417–434. http://dx.doi.org/10.1016/j.chemosphere.2008.11.086.
Kowarsch, M., Jabbour, J., 2017. Solution-oriented Global Environmental Assessments: Opportunities and Challenges. http://dx.doi.org/10.1016/j.envsci.2017.08.013.
Kowarsch, M., Flachsland, C., Garard, J., Jabbour, J., Riousset, P., 2017. The treatment of divergent viewpoints in global environmental assessments. Environ. Sci. Policy 77, 225–234. http://dx.doi.org/10.1016/j.envsci.2017.04.001.
Lahsen, M., 2007. Trust through participation? problems of knowledge in climate decision making. In: Pettenger, M.E. (Ed.), The Social Construction of Climate Change. Ashgate, Farnham, pp. 173–196.
Lahsen, M., 2009. A science–policy interface in the global south: the politics of carbon sinks and science in Brazil. Clim. Change 97, 339–372. http://dx.doi.org/10.1007/s10584-009-9610-6.
Mahony, M., 2013. Boundary spaces: science, politics and the epistemic geographies of climate change in Copenhagen, 2009. Geoforum 49, 29–39. http://dx.doi.org/10.1016/j.geoforum.2013.05.005.
Mahony, M., 2014. The predictive state: science, territory and the future of the Indian climate. Soc. Stud. Sci. 44, 109–133. http://dx.doi.org/10.1177/0306312713501407.
Mahony, M., 2015. Climate change and the geographies of objectivity: the case of the IPCC's burning embers diagram. Trans. Inst. Br. Geogr. 40, 153–167. http://dx.doi.org/10.1111/tran.12064.
Martinez, J.L., 2009. Environmental pollution by antibiotics and by antibiotic resistance determinants. Environ. Pollut. 157, 2893–2902. http://dx.doi.org/10.1016/j.envpol.2009.05.051.
Martínez, J.L., Coque, T.M., Baquero, F., 2015. What is a resistance gene? Ranking risk in resistomes. Nat. Rev. Microbiol. 13, 116–123. http://dx.doi.org/10.1038/nrmicro3399.
Masood, E., 1995. Developing countries dispute use of figures on climate change impacts. Nature 376http://dx.doi.org/10.1038/376374b0. (374-374).
Maxwell, S., 2015. Towards Next Generation Food Policy Research. Simon Maxwell: Research & Policy in International Development.
Miller, T.R., Wiek, A., Sarewitz, D., Robinson, J., Olsson, L., Kriebel, D., Loorbach, D., 2014. The future of sustainability science: a solutions-oriented research agenda. Sustain. Sci. 9, 239–246. http://dx.doi.org/10.1007/s11625-013-0224-6.
Miller, C.A., 2004. Climate science and the making of a global political order. In: Jasanoff, S. (Ed.), States of Knowledge: The Co-Production of Science and Social Order. Routledge, London, pp. 46–66.
Miller, C.A., 2009. Epistemic constitutionalism in international governance: the case of climate change. In: Heazle, M., Griffiths, M., Conley, T. (Eds.), Foreign Policy Challenges in the 21 st Century. Edward Elgar, Cheltenham, pp. 141–163.
Minx, J.C., Callaghan, M., Lamb, W.F., Garard, J., Edenhofer, O., 2017. Learning about climate change solutions in the IPCC and beyond. Environ. Sci. Policy 77, 252–259. http://dx.doi.org/10.1016/j.envsci.2017.05.014.
Mitchell, R.B., Clark, W.C., Cash, D.W., Dickson, N.M., 2006. Global Environmental Assessments: Information and Influence. MIT Press, Cambridge, MA.
Montana, J., 2017. Accommodating consensus and diversity in environmental knowledge production: achieving closure through typologies in IPBES. Environ. Sci. Policy 68, 20–27. http://dx.doi.org/10.1016/j.envsci.2016.11.011.
Morris, C., Helliwell, R., Raman, S., 2016. Framing the agricultural use of antibiotics and antimicrobial resistance in UK national newspapers and the farming press. J. Rural Stud. 45, 43–53. http://dx.doi.org/10.1016/j.jrurstud.2016.03.003.
O'Neill, B.C., Oppenheimer, M., Warren, R., Hallegatte, S., Kopp, R.E., Pörtner, H.O., Scholes, R., Birkmann, J., Foden, W., Licker, R., Mach, K.J., Marbaix, P., Mastrandrea, M.D., Price, J., Takahashi, K., van Ypersele, J.-P., Yohe, G., 2017. IPCC reasons for concern regarding climate change risks. Nat. Clim Change 7, 28–37. http://dx.doi.org/10.1038/nclimate3179.
O'Reilly, J., Oreskes, N., Oppenheimer, M., 2012. The rapid disintegration of projections: the west antarctic ice sheet and the intergovernmental panel on climate change. Soc. Stud. Sci. 42, 709–731.
Oppenheimer, M., O'Neill, B.C., Webster, M., Agrawala, S., 2007. Climate change: the limits of consensus. Science 317, 1505–1506.
Orlove, B., Lazrus, H., Hovelsrud, G.K., Giannini, A., 2014. Recognitions and Responsibilities: on the origins and consequences of the uneven attention to climate change around the world. Curr. Anthropol. 55, 249–275. http://dx.doi.org/10.1086/676298.
Pearce, W., 2014. Scientific data and its limits: rethinking the use of evidence in local climate change policy. Evid. Policy: J. Res. Debate Pract. 10, 187–203. http://dx.doi.org/10.1332/174426514X13990326347801.
Pearce, W., Brown, B., Nerlich, B., Koteyko, N., 2015. Communicating climate change: conduits, content, and consensus. Wiley Interdiscip. Rev. Clim. Change 6, 613–626. http://dx.doi.org/10.1002/wcc.366.
Pearce, W., Grundmann, R., Hulme, M., Raman, S., Kershaw, E.H., Tsouvalis, J., 2017. Beyond counting climate consensus. Environ. Commun. 0, 1–8. http://dx.doi.org/10.1080/17524032.2017.1333965.
Review on Antimicrobial Resistance, 2015. Antimicrobials in Agriculture and the Environment: Reducing Unnecessary Use and Waste. Review on Antimicrobial Resistance, London. https://amr-review.org/sites/default/files/Antimicrobials%20in%20agriculture%20and%20the%20environment%20-%20Reducing%20unnecessary%20use%20and%20waste.pdf.
Russill, C., 2016. The climate of communication: from detection to danger. In: O'Lear, S., Dalby, S. (Eds.), Reframing Climate Change: Constructing Ecological Geopolitics. Routledge, London, pp. 31–51.
Sörlin, S., 2013. Reconfiguring environmental expertise. Environ. Sci. Policy 1–11. http://dx.doi.org/10.1016/j.envsci.2012.11.006.
Salyers, A.A., Amábile-Cuevas, C.F., 1997. Why are antibiotic resistance genes so resistant to elimination? Antimicrob. Agents Chemother. 41, 2321–2325.
Scoones, I., 2009. The politics of global assessments: the case of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). J. Peasant Stud. 36, 547–571. http://dx.doi.org/10.1080/03066150903155008.
Singer, A., 2017. Antimicrobial resistance: more than just overusing antibiotics. Pharm. J. 298. http://dx.doi.org/10.1211/PJ.2017.20202286.
Stirling, A., 2008. Opening up and closing down power, participation, and pluralism in the social appraisal of technology. Sci. Technol. Hum. Values 33, 262–294. http://dx.doi.org/10.1177/0162243907311265.
Stirling, A., 2010. Keep it complex. Nature 468, 1029–1031.

Tollefson, J., 2015. Is the 2 °C world a fantasy? Nat. News 527, 436. http://dx.doi.org/10.1038/527436a.
United Nations, 2016. Draft Political Declaration of the High-Level Meeting of the General Assembly on Antimicrobial Resistance.
World Health Organization, 2015. Global Action Plan on Antimicrobial Resistance. World Health Organization, Geneva.
World Health Organization, 2017. WHO Guidelines on Use of Medically Important Antimicrobials in Food-Producing Animals. World Health Organization, Geneva.
Wesselink, A., Buchanan, K.S., Georgiadou, Y., Turnhout, E., 2013. Technical knowledge, discursive spaces and politics at the science–policy interface. Environ. Sci. Policy 30, 1–9. http://dx.doi.org/10.1016/j.envsci.2012.12.008.
Wellington, E.M., Boxall, A.B., Cross, P., Feil, E.J., Gaze, W.H., Hawkey, P.M., Johnson-Rollings, A.S., Jones, D.L., Lee, N.M., Otten, W., Thomas, C.M., Williams, A.P., 2013. The role of the natural environment in the emergence of antibiotic resistance in Gram-negative bacteria. Lancet Infect. Dis. 13, 155–165. http://dx.doi.org/10.1016/S1473-3099(12)70317-1.
Woolhouse, M., Farrar, J., 2014. Policy: an intergovernmental panel on antimicrobial resistance. Nature 509, 555–557. http://dx.doi.org/10.1038/509555a.
Yamineva, Y., 2017. Lessons from the Intergovernmental Panel on Climate Change on inclusiveness across geographies and stakeholders. Environ. Sci. Policy 1–8. http://dx.doi.org/10.1016/j.envsci.2017.04.005.