database; hence, we were cautious not to even mention the trend of tropical land surface temperature in the context of Ji *et al.*[4] and the accompanying Supplementary Information. ❐

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Additional information
Supplementary information is available in the online version of the paper.

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COMMENTARY:

Practitioners' work and evidence in IPCC reports

David Viner and Candice Howarth

The Intergovernmental Panel on Climate Change reports provide the most reliable and robust assessment of understanding of the climate system. However, they do not include practitioner-based evidence, which is fundamental to make the reports a relevant source of information for decision-making.

The Intergovernmental Panel on Climate Change (IPCC) is increasing efforts to communicate its results more clearly to a wide audience in a way that limits confusion and increases their use. A clear example is offered by the 'headline statements' from the *Summary for Policymakers* of the Working Group I (WGI) contribution to the fifth assessment report (AR5)[1], which summarizes the overarching conclusions. The IPCC WGI report provides the scientific evidence for international negotiations on mitigation targets, from which individual countries drive national policies and their own negotiating positions (Fig. 1). Increasingly, they are used by engineers, policymakers and other practitioners to develop climate change risk frameworks and vulnerability assessments.

The issue of what is currently termed climate change adaptation is becoming increasingly important, as extreme events witnessed across the globe are increasing[2]. The latest Working Group II (WGII) report, on impacts, adaptation and vulnerability, released in March this year, comprised 30 chapters, predominantly split on a sectoral and regional basis. Five of these chapters explicitly mention climate adaptation in their headlines. However, a close look at the content, author lists and references shows that the 'adaptation' chapters lack practitioner experience, evidence and case studies that demonstrate how adaptation is being carried out on the ground. In other words, they provide an observational, top-down account rather than a practitioner-led evidence base. We question the extent to which this approach goes beyond exercises of observation and interpretation and whether it provides practical applications of climate change adaptation knowledge. Where this is not the case, the role of practitioner-based experience and reporting should be carefully considered.

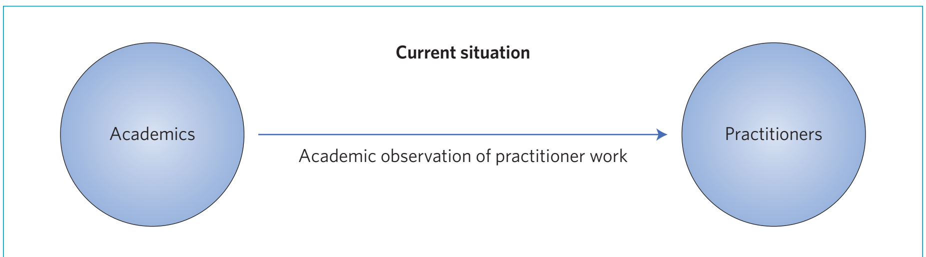

Figure 1 | The academic community merely observes practical actions to address climate change resilience but does not include the practitioner community in the process of systematic review of evidence, such as the IPCC process. This lack of integration hinders a full and realistic assessment of available evidence with the risk of developing potentially less effective policies.

Although increasing efforts are being made to better the science–policy interface, the disconnection between science and practitioners remains a key barrier to progress in the field of climate change adaptation. How practitioners, engineers, ecologists, landscape planners and investors could input into and use the results of the IPCC WGII report in the same way that the WGI report is used in international policy is key to understanding the effectiveness and real impact of climate change in the future. One could argue that the process and flow of information and expertise in the multiplicity of interfaces that exist between science, policy and practitioners are far from well understood for experts to use the information presented in the IPCC reports adequately to assess and refine their models of climate impact. For example, when designing dams, engineers have always attempted to factor climate variability into the design work; however, this methodology is not properly included in IPCC assessments. Given the growing awareness of climate change, planning of infrastructure work is now starting to incorporate future changes in climate. But this approach is informed by the science of WGI and not that of the academic adaptation community.

The IPCC review process is both extensive and robust: over 12,000 scientific references cited, 243 lead authors, 66 review editors from 70 countries, 436 contributing authors from 54 countries, 1,729 expert reviewers from 84 countries, with the final *Summary for Policymakers* approved and accepted by 195 governments[3]. However, this is an exercise conducted primarily by the scientific and political communities, and does not take into account the needs, and the role, of the experts working on the ground. We think that the latest findings from the WGII contribution remain largely inaccessible to practitioners and certainly do not fully incorporate their ongoing work on climate change issues. This is mainly the result of the IPCC process being highly academic-oriented and based on the peer-review mechanism with long lag times, and communication challenges, including different language and cultural interpretations.

Practitioners are active in shaping and guiding policy on the ground. They use pragmatic approaches to deliver solutions — for example, to develop designs that are resilient to climatic extremes — and to include in their work knowledge about the prospects of future climate change. In particular, practitioners face the challenge of turning academic research into practical solutions and thus provide a basis from which to implement policy recommendations. Conway and Mustelin[4] argue that research on adaptation is driving forward negotiation and subsequent implementation of actions. We instead argue that the wealth of actions already implemented by practitioners is driving the agenda and the academic research community is simply reporting and assessing those actions.

One issue the practitioner community faces is how to collate the wealth of evidence they produce to make it accessible to others. Practitioners' reports, blending research with practical evidence, are often produced solely for clients and in confidence. We suggest that key experts able to capture the depth and breadth of this community's work are incorporated not only into the IPCC process, but also into other important review exercises, such as the National Adaptation Programmes of Action (http://go.nature.com/vomqhO).

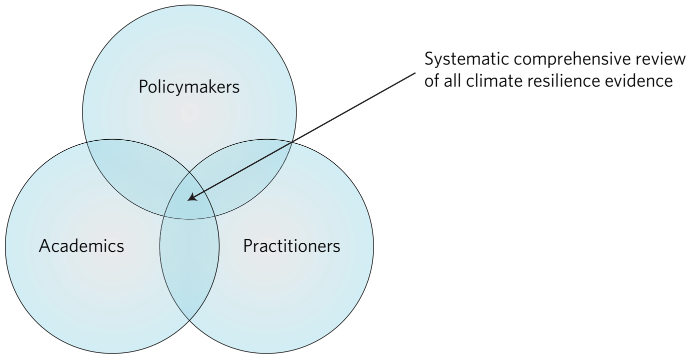

Figure 2 | Integrating policy, practitioner and academic evidence will deliver meaningful comprehensive assessment processes better equipped to inform new policy decisions.

A collaborative approach

The UK government's response to the Somerset flooding in January 2014 demonstrates the need for the academic and practitioner communities to work together to shape policy responses and to deliver solutions on the ground. In that case, the initial rapid response was mainly based on local public (and political) opinion. Engineers and academics with the appropriate expertise in catchment management of flood mitigation design were consulted only later in the process. We think that incorporating a similar proactive and collaborative approach into the formulation of recommendations in the IPCC reports, although at an earlier stage, would better inform the decision-making process (Fig. 2). Rather than being brought in to fix and rebuild, they would have contributed to the construction of climate-resilient infrastructure in the first place.

So what is driving the disconnection between the academic and practitioner communities? Predominantly it is a practical issue. The practitioner communities are driven and limited by fiscal constraints and at times client confidentiality. The academic community has similar fiscal and time constraints. Also, some of the research work of the current and previous IPCC WGII assessments originates from the social sciences, whereas the practitioner communities come from the physical and engineering sciences. Therefore, lack of a common language is often a barrier.

The way forward

If the research produced by the IPCC WGII, and the adaptation community more generally, is to be fully utilized in practice, we strongly recommend that the IPCC and other official assessment processes engage with practitioner communities by integrating them in the design, and writing, of assessments — in this way the language, style and results can meet the needs of the end user.

As a simple example, practitioners from the engineering community understand the term resilience much more than adaptation — engineers strive to build infrastructure and systems that are 'resilient' to various shocks. We recommend that this term takes primacy over the term adaptation.

Practitioners can actively contribute to the participatory approach needed for building climate resilience. Such a participatory process would allow the co-production of knowledge to support decision-makers[5]. Furthermore, as an ongoing process, it would allow the management and adjustment of expectations about how the research undertaken by practitioners can be incorporated through the process, from research design, review and policy information. Incorporating practitioners' experience at the outset of the process would help to understand how to assess, measure and reduce unanticipated costs as well as address contentious issues such as risk and uncertainty. Practitioners are used to working under uncertainty and risk in many different contexts (including cultural, geographical and political), where flexibility through use of cost–benefit analyses is a standard practice. This process would benefit the IPCC WGII by widening the pool of research and practical solutions covered, making the reviews more relevant to decision-makers and by incorporation of more transparent language and terminology (such as climate change resilience) in future assessments.

The IPCC process provides the most compelling account of evidence about climate science through the working group reports and yet, the forthcoming *Synthesis Report* would benefit significantly from incorporation of practitioner experience of climate solutions implementation. Co-production of knowledge, across academic, political and practitioner communities, would frame, structure and deliver climate action. Such a process will ensure that future IPCC reports are more up-to-date, robust and complete in their analysis and that the climate change resilience solutions proposed incorporate the most practically viable research. ❐

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COMMENTARY:

Betting on negative emissions

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Bioenergy with carbon capture and storage could be used to remove carbon dioxide from the atmosphere. However, its credibility as a climate change mitigation option is unproven and its widespread deployment in climate stabilization scenarios might become a dangerous distraction.

Future warming will depend strongly on the cumulative CO_2 emissions released through to the end of this century[1,2]. A finite quota of cumulative CO_2 emissions, no more than 1,200 Gt CO_2, is needed from 2015 onwards to stabilize climate below a global average of 2 °C above pre-industrial conditions by 2100 with a likelihood of 66%. This corresponds to about 30 years at current emissions levels[3]. However, during the past decade, emissions from fossil fuel combustion and cement production have increased substantially to 36.1 ± 1.8 Gt CO_2 yr^{-1} in 2013 (refs 4,5), projected to reach 37.0 ± 1.8 Gt CO_2 yr^{-1} in 2014 (ref. 3), 65% above their 1990 level. Staying within the 2 °C limit in a cost-effective way will require strong mitigation action across all sectors, with greater effort needed the longer mitigation is delayed.

Actions that could stabilize climate as desired include the deliberate removal of CO_2 from the atmosphere by human intervention — called here 'negative emissions'. Along with afforestation, the production of sustainable bioenergy with carbon capture and storage (BECCS) is explicitly being put forth as an important mitigation option by the majority of integrated assessment model (IAM) scenarios aimed at keeping warming below 2 °C in the IPCC's fifth assessment report (AR5)[6]. Indeed, in these scenarios, IAMs often foresee absorption of CO_2 via BECCS up to (and in some cases exceeding) 1,000 Gt CO_2 over the course of the century[7], effectively doubling the available carbon quota.

BECCS is the negative emissions technology most widely selected by IAMs to meet the requirements of temperature limits of 2 °C and below. It is based on assumed carbon-neutral bioenergy (that is, the same amount of CO_2 is sequestered at steady state by biomass feedstock growth as is released during energy generation), combined with capture of CO_2 produced by combustion and its subsequent storage in geological or ocean repositories. In other words, BECCS is a net transfer of CO_2 from the atmosphere, through the biosphere, into geological layers, providing in addition a non-fossil fuel source of energy. Other options include afforestation, direct air capture and increases in soil carbon storage. Afforestation and increased soil carbon storage differ from BECCS in that these land-use and management changes are associated with a saturation of CO_2 removal over time, and in that the sequestration is reversible with terrestrial carbon stocks inherently vulnerable to disturbance[8].

The need for negative emissions

The IPCC's Working Group 3 (WG3) considered in AR5 over 1,000 emission pathways to 2100 (Fig. 1a). Most scenarios (101 of 116) leading to concentration levels of 430–480 ppm CO_2 equivalent (CO_2eq), consistent with limiting warming below 2 °C, require global net negative emissions in the second half of this century, as do many scenarios (235 of 653) that reach between 480 and 720 ppm CO_2eq in 2100 (Fig. 1b, scenarios below zero). About half of the scenarios feature BECCS exceeding 5% of primary energy supply. Many of those (252 of 581) have net positive emissions in 2100 (Fig. 1b). Thus, BECCS does not ensure net negative emissions (that is, its use need not completely offset all positive emissions). BECCS is an important mitigation technology, especially as the stabilization level is lowered, and if near-term mitigation is delayed. By eventually requiring deeper emissions reductions, BECCS can help reconcile higher interim CO_2eq concentrations with low long-term stabilization targets, particularly if overshooting of concentrations is allowed.