Environmental Science and Policy 139 (2023) 118–129

Contents lists available at ScienceDirect

Environmental Science and Policy

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

Enhancing the review process in global environmental assessments: The case of the IPCC☆

Jean P. Palutikof[a,o,*], Sarah L. Boulter[a], Christopher B. Field[b], Katharine J. Mach[c,d], Martin R. Manning[e], Michael D. Mastrandrea[f], Leo Meyer[g], Jan C. Minx[h,i], Joy J. Pereira[j], Gian-Kasper Plattner[k], Suzana Kahn Ribeiro[l], Youba Sokona[m], Frank Stadler[a], Rob Swart[n]

[a] National Climate Change Adaptation Research Facility, Griffith University, Queensland 4222, Australia
[b] Stanford Woods Institute for the Environment and Department of Earth System Science, Stanford University, Stanford, CA 94305, USA
[c] Department of Environmental Science and Policy, Rosenstiel School of Marine, Atmospheric, and Earth Science, University of Miami, Miami, FL 33149, USA
[d] Leonard and Jayne Abess Center for Ecosystem Science and Policy, University of Miami, Coral Gables, FL 33124, USA
[e] Climate Change Research Institute, Victoria University of Wellington, Wellington 6140, New Zealand
[f] Woods Institute for the Environment, Stanford University, Stanford, CA 94305, USA
[g] ClimateContact Consultancy, Utrecht, the Netherlands
[h] Mercator Research Institute on Global Commons & Climate Change, Torgauer Str. 19, 10829 Berlin, Germany
[i] Priestley International Centre for Climate, University of Leeds, LS2 9JT, UK
[j] SEADPRI-Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor D.E., Malaysia
[k] Swiss Federal Research Institute WSL, 8903 Birmensdorf, Switzerland
[l] Univ Fed Rio de Janeiro, COPPE, 21941–615 Rio de Janeiro, Brazil
[m] Department of Science, Technology, Engineering, and Public Policy, University College London, London WC1E 6JA, UK
[n] Wageningen Environmental Research (WENR), Droevendaalsesteeg 3–3A, 6708 PB Wageningen, the Netherlands
[o] Cities Research Institute, Griffith University, Queensland 4222, Australia

ARTICLE INFO

Keywords:
Global environmental assessments
IPCC
Review process

ABSTRACT

External review is a fundamental component of Global Environmental Assessments, ensuring their processes are comprehensive, objective, open and transparent, and are perceived as such. Here, we focus on review of Intergovernmental Panel on Climate Change (IPCC) Assessment Reports. The review process has received little scrutiny, although review comments and author responses are public. Here we analyse review documents from the Fourth and Fifth Assessments, focusing primarily on Working Group II. We address three questions: Is the review representative? Is it comprehensive? Is it insightful? Overall we found the review process to be fit for purpose, although there are outstanding issues. First, the overwhelming majority of reviewers are from developed countries, although evidence suggests participation by developing country reviewers increased between the Fourth and Fifth Assessments. Second, earlier sections of chapters are more densely reviewed than later ones. This is true even when executive summaries are removed from analysis. In consequence, some sections on specialised topics may escape in-depth review. Thirdly, those review comments which are received make a valid and valuable contribution to the scientific development of chapters. We suggest how outstanding issues could be addressed, including through enhanced reviewer recognition, a wider role for review editors, adherence to mandated page lengths from early in the process, reviewer training, and consistency in reporting to allow systematic evaluation. Making such changes will result in more transparent, consistent and representative processes delivering reviews which effectively contribute to the credibility and legitimacy of future Global Environmental Assessments and, ultimately, their recognition and contribution.

☆ This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.
* Correspondence to: National Climate Change Adaptation Research Facility, Griffith University, Parklands Drive, Gold Coast 4222, Australia.
E-mail address: j.palutikof@griffith.edu.au (J.P. Palutikof).

https://doi.org/10.1016/j.envsci.2022.10.012
Received 16 November 2021; Received in revised form 2 May 2022; Accepted 18 October 2022
Available online 7 November 2022

1. Introduction

Since the late 1970s, over 140 Global Environmental Assessments (GEAs) have been performed (Castree et al., 2020). Many papers have been written evaluating their successes and limitations as boundary work delivering useful and authoritative knowledge for policy development. These include for UNEP's Global Environmental Outlook (Riousset et al., 2017), the Millenium Ecosystem Assessment (Reid and Mooney, 2016), the Consultative Group of International Agricultural Research (Clark et al., 2016), and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Gustafsson and Lidskog, 2018; Beck et al., 2014; Hughes and Vadrot, 2019). However, in part because of its longevity and critical role in the development of international policy around the existential threat of climate change, the focus of many analyses of GEAs and their effectiveness is the Intergovernmental Panel on Climate Change (IPCC), which released its first report in 1990 and has recently completed its Sixth Assessment (Vardy et al., 2017; De Pryck, 2021).

The procedures and purpose of the IPCC have been carefully examined and sometimes criticised over time (Beck and Mahony, 2017, 2018; Hughes and Paterson, 2019; Beck and Oomen, 2021; De Pryck, 2021). Scrutiny of *procedures* has included overarching recommendations to make the process more fit for purpose (InterAcademy Council, 2010; Stocker and Plattner, 2014), the challenge of dealing with a vastly expanding literature (Minx et al., 2017; Callaghan et al., 2020; Berrang-Ford et al., 2021), the difficulties of recruiting an authorship representative of topic, geography and gender (Ho-Lem et al., 2011; Corbera et al., 2015; Hughes and Paterson, 2017; Yamineva, 2017) and maintaining relevance (Livingston et al., 2018; Beck et al., 2014), the approach to treating uncertainties (and calibrated language) (Swart et al., 2009; Mastrandrea and Mach, 2011; Mach et al., 2017), and the role of the approval process (Edenhofer and Minx, 2014; Mach et al., 2016).

Originally, the *purpose* of IPCC Assessment Reports was to inform international policy development and, since its establishment in 1992, negotiations of the United Nations Framework Convention on Climate Change (UNFCCC). This role has evolved over time and the influence of IPCC reports has expanded into the mainstream of popular thinking around climate change (Mach and Field, 2017). The Paris Agreement of December 2015 is seen as a pivotal point at which the role of the IPCC shifted from assessing the scientific evidence for climate change to a focus on solutions (Beck and Mahony, 2017). It has been suggested that fundamental change is required if the needs of bodies such as the UNFCCC are to continue to be properly served by the IPCC in particular and GEAs in general (Beck et al., 2014; Kowarsch et al., 2017).

A thread running through IPCC history, and common to the majority of GEAs, is some form of external review. A central precept of the IPCC is that assessments should be 'comprehensive, objective, open and transparent' (IPCC, 2013a). Fundamental to achievement of these goals is the quality control provided by external review (Edwards and Schneider, 1997; Castree et al., 2020). Despite the detailed scrutiny of the IPCC, as outlined above, only rarely has the role and contribution of external review been examined (InterAcademy Council, 2010; Kosolosky, 2015). The InterAcademy Council (2010) carried out an extensive independent review of IPCC governance, management and processes following the Fourth Assessment Report. It made recommendations regarding how review comments should be treated by authors, and how the process should be overseen by Review Editors. These have been influential in how subsequent assessments have been managed.

In this paper, we explore the review process as it was undertaken in the IPCC Fourth and Fifth Assessments (AR4 and AR5 respectively). The analysis is based largely on publicly-accessible chapter drafts, review comments and author responses, which are not yet available for the Sixth Assessment (AR6) although the Assessment itself is largely complete (at the time of writing, only the Synthesis Report is outstanding). Here, we aim to inform the subsequent debate about likely post-2022 assessments. Many of the recommendations we make in Section 6.2 apply not only to the IPCC, but to the wider body of GEAs. In particular, we address three questions:

- Is the review representative? Do reviewers bring to the process the full breadth of knowledge around climate change? Is, for example, the review balanced in terms of the distribution of experts between the global north and south?
- Is the review comprehensive? Are all sections of every chapter considered and fully reviewed?
- Is the review insightful? Do review comments add value to the preparation of the next chapter draft, with respect to both scientific quality and policy relevance?

Our analysis is primarily with respect to Working Group II (WG2), while also drawing on evidence from Working Groups I (WG1) and III (WG3). Although they have changed over time, for the AR4 and AR5 considered here the titles for the working groups have remained the same: Working Group I (WG1) *The Physical Science Basis*; Working Group II (WG2) *Impacts, Adaptation and Vulnerability*; and Working Group III (WG3) *Mitigation of Climate Change*.

2. The IPCC review process

The assessment process itself and steps of the review are set out in the *Principles Governing IPCC Work* Appendix A (IPCC, 2013a). Each report starts with a structure developed by government-nominated experts, leading to a chapter outline which then becomes formally approved by governments. Over a period of around six years and through three formal review cycles (two for the chapters and a third devoted to the Summary for Policymakers), a global community of many thousands of scientists and government representatives creates the three WG volumes, together with a Synthesis Report.

There are two formal reviews of each chapter: expert review of the first-order draft (FOD) and expert and government review of the second-order draft (SOD). The final chapter drafts that are developed following the expert and government review then underpin the final government review of the Summary for Policymakers (SPM), which is carried forward to a plenary meeting at which the SPM is 'approved' and the full report 'accepted' (IPCC, 2013a). Also, it has become expected that there will be a preliminary informal review of a zero-order draft by experts selected by, and including, participants in the current and previous assessments. These steps were followed in the AR4 and AR5 and, more recently, in the AR6.

Today, the process of recruitment for expert reviewers in both review rounds is very open, with potential reviewers asked to self-declare their expertise, including publications. Co-Chairs and WG Bureau members have some latitude in determining how the review will be conducted, mainly around the extent to which they proactively recruit reviewers, and the degree to which they define and screen for expertise. (Clearly the potential for gatekeeping exists, and could exclude valuable perspectives, for example from practitioners. We are not aware of any examples of individuals being excluded on the basis of their publication record). The degree of involvement of governments in the SOD review varies widely. Some governments are pro-active in recruiting reviewers from public sectors and universities and collating their comments (van der Veer et al., 2014), while many do not participate at all.

At the start of each assessment, at least two review editors for each chapter are recruited at the same time as the author team. Their role is to 'assist the Working Group… Bureaux in identifying reviewers for the expert review process, ensure that all substantive expert and government review comments are afforded appropriate consideration, advise lead authors on how to handle contentious/controversial issues and ensure genuine controversies are reflected adequately in the text of the Report' (IPCC, 2013a).

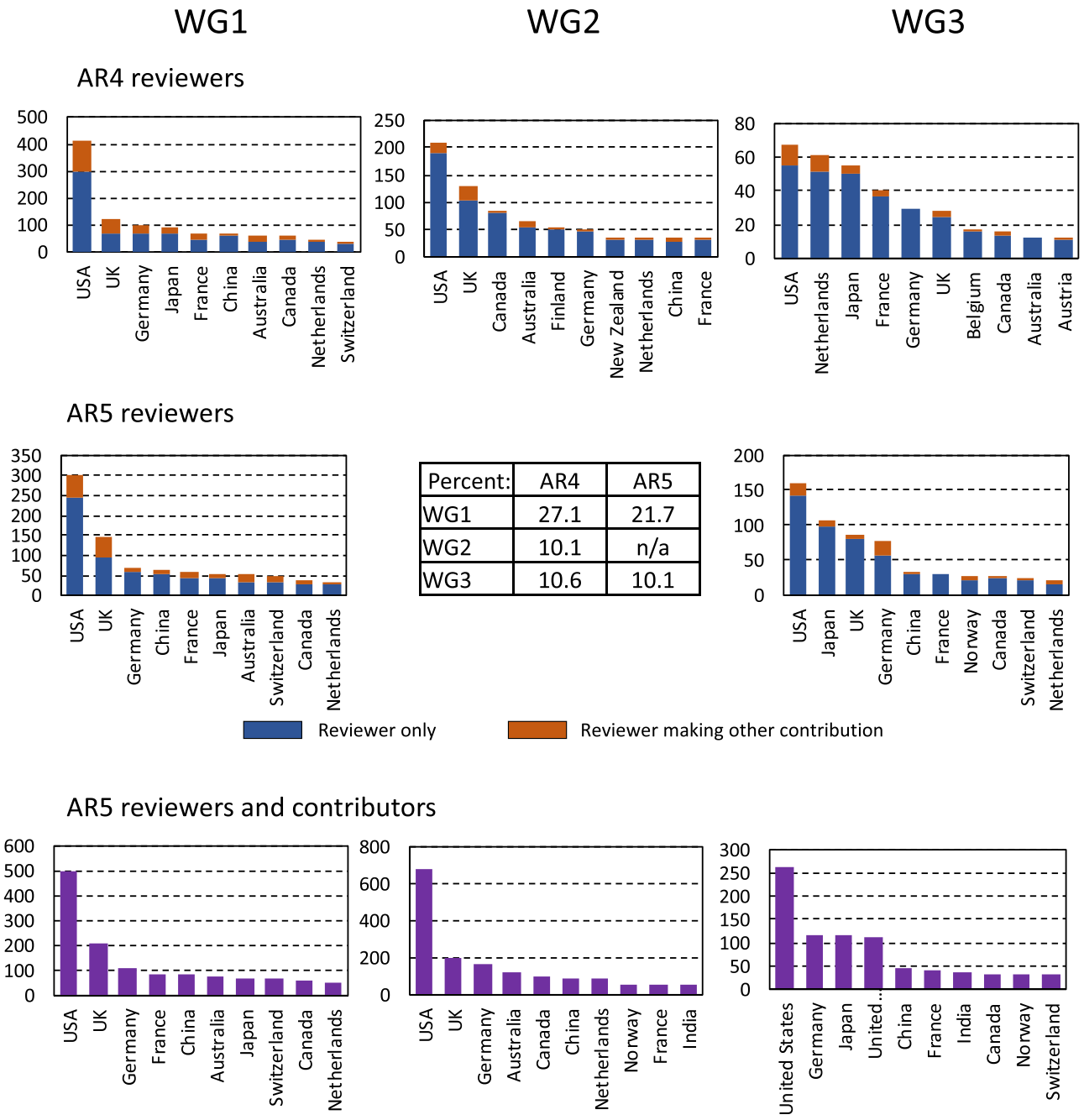
Review comments are collated into tables by the team managing the

assessment, generally termed the Technical Support Unit (TSU). Chapter authors are expected to respond to each comment, explaining the action taken, or why no action was deemed necessary. Once the Assessment is published, comments and author responses for the formal reviews are made public. To demonstrate the scale of the review, in the AR5, WG2 received 19,598 comments on the FOD from 563 expert reviewers, and 28,544 comments on the SOD from 452 expert reviewers and 33 governments (IPCC, 2015).

3. Is the review representative?

We define representativeness as being the state in which 'participants bring to the process the full breadth of knowledge around climate change'. This definition, although narrow, is appropriate in the context of the IPCC, whose role is defined as being '… to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation.' (IPCC, 2013a).

Representativeness has many dimensions, characterised by, amongst others, gender identity, ethnicity, culture, country background and socio-economic status (Forrester, 2020; Amano et al., 2021). Published information in the assessment reports does not permit exploration of the vast majority of these: report annexes and appendices list contributors



Percent:	AR4	AR5
WG1	27.1	21.7
WG2	10.1	n/a
WG3	10.6	10.1

Fig. 1. Number of reviewers and contributors in the three IPCC WG assessments of the AR4 and AR5, as set out in the Assessment Report Annexes. Each graph shows the number for the ten countries contributing the largest number of reviewers/contributors for that assessment and WG. In the upper two rows, blue bars are the number of expert reviewers who did not contribute to the Assessment in other roles (e.g., as Lead Author), orange bars are reviewers who did have an additional role. In the bottom row, duplicates (i.e., where individuals are listed as both reviewers and contributors) have been removed. The central table shows, across all expert reviewers, the proportion with an additional role. Data sources: IPCC (2007a, b, c; 2013c; 2014b, c).

by country. This is the information we have available to assess representativeness.

In the AR4, all WGs list contributors and reviewers separately, so that a consistent between-WG comparison of the origin of reviewers can be made (IPCC, 2007a, 2007b, 2007c). In the AR5, however, although WG1 and WG3 repeat this pattern (IPCC, 2013b, 2013c,), WG2 has a single annex listing contributors and reviewers without distinction (IPCC, 2014c). Hence, we look at reviewers plus contributors for all three WGs, and reviewers alone for WG1 and WG3. Hopefully this issue will not recur in the AR6 as the Panel-approved outlines for all three WGs specify separate annexes for listing contributors and reviewers. Finally (and excluding the WG2 AR5), we separated out reviewers who only undertook that role from reviewers who had another role, such as Lead Authorship.

The annexes provide the potential to track reasonably consistently the geographical representation of reviewers participating in the AR4 and AR5 (see Figs. 1 and 2, Table 1). We found that:

- The developed world is overwhelmingly dominant: 80% or more of reviewers are from developed countries in all AR4 WGs and in at least WG1 and WG3 of the AR5. WG2 and WG3 generally have more developing country reviewers. This pattern has also been noted among authors (Vardy et al., 2017; Hughes and Paterson, 2019).
- The number of reviewers from each developing country is small, on average fewer than four (despite relatively large numbers of participants from some countries, notably China). This compares with the average number from each developed country, generally around 30 (see Table 1).
- The United States is a clear leader in all WGs for both reviewers alone, and reviewers and contributors together. Together, four Anglophone developed countries, the United States, United Kingdom, Australia and Canada, contribute around half of reviewers for WG1 and WG2, and around a third for WG3.
- Expert reviewers in WG2 and WG3 generally undertake the role without additional participation in the assessment: only around 10% have an additional role. However, for WG1 this figure rises to around one fifth (see Fig. 1).
- There is growth in reviewer participation between the AR4 and AR5, in terms of number of reviewers and number of countries involved overall, and the scale of reviewer participation from developing countries. In WG3, for example, no developing country contributed more than 15 reviewers in the AR4, but in the AR5 China had 30 reviewers and India 20. It is more difficult to make a comparison for WG2 because there are no separate figures for reviewers, but five developing countries contributed more than fifteen reviewers and authors/review editors to the AR5: China (92), India (53), South Africa (30), Mexico (23) and Brazil (19). Similar growth patterns are seen among authors (Hughes and Paterson, 2019; Standring and Lidskog, 2021).

To explore more deeply, we focused on WG2 and categorised FOD and SOD review comments for four chapters representative of the sectoral, adaptation, regional and synthesis components of each WG2 assessment, and present in both the AR4 and AR5 albeit under slightly different titles (see Table 2). WG2 review comments are available for the AR4 at https://archive.ipcc.ch/report/ar4/wg2/ and for the AR5 at https://archive.ipcc.ch/report/ar5/wg2/ (accessed 10 May 2021).

There is considerable variation in the number of review comments in the four chapters analysed from the WG2 AR5 (Fig. 3). For example, in the SOD review, regional Chapter 27 has only half the number of comments of the other three chapters. Across all four chapters assessed, TSU staff play an important role, their comments accounting on average for 25% of comments across the four chapters in the two reviews. For Chapter 27, it is unlikely the FOD review would have been adequate without TSU participation, with only 391 comments of which almost half were from TSU staff. (Note that the TSU does not participate in the scientific review in all WGs and/or all assessments – this is a matter for individual Co-Chairs and Bureaux to decide).

The analysis could not be exactly replicated for the AR4 because TSU comments were frequently blocked into a single cell in the review comment spreadsheet. We could explore the relative contributions from

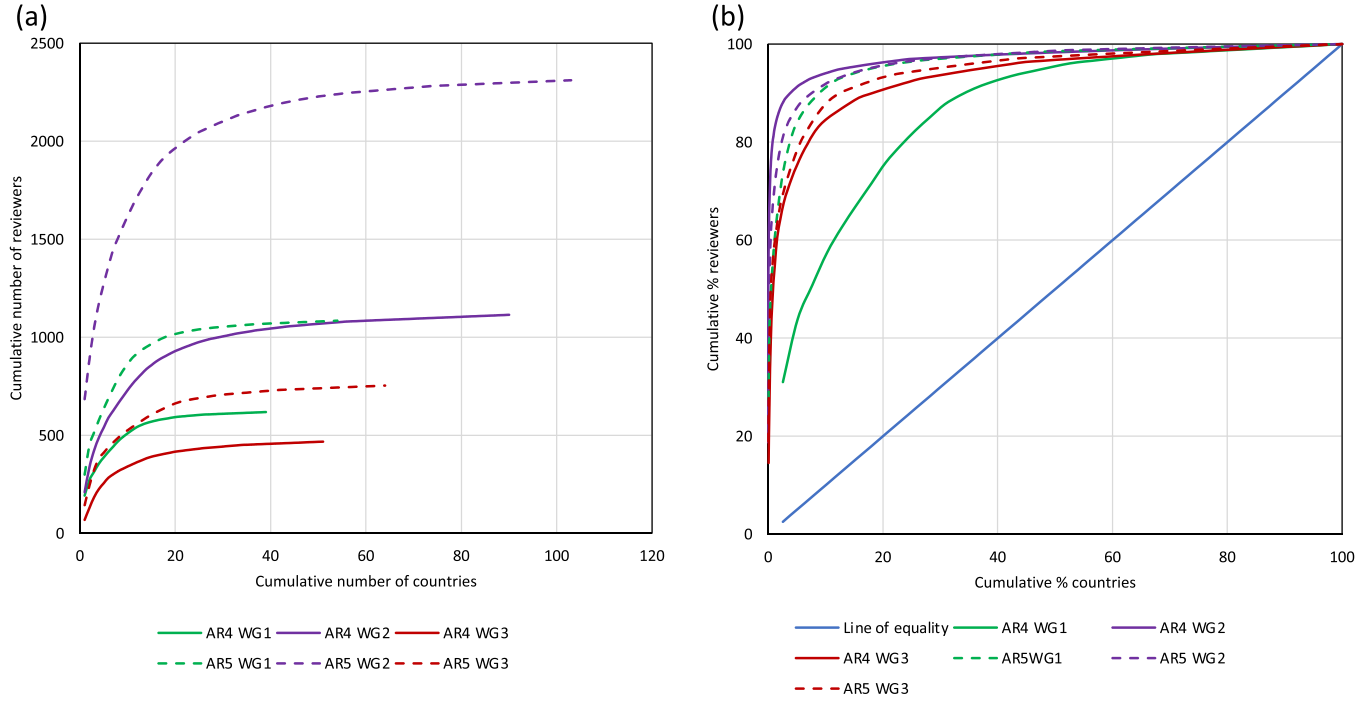


Fig. 2. (a) Cumulative number of expert reviewers against country of nationality as recorded in annexes to the AR4 and AR5; (b) as (a) but shown as a percentage of the total for each assessment report. Note that for AR5 WG2 the data are for reviewers and contributors (as discussed in the text). Data sources: IPCC (2007a, b, c; 2013c; 2014b, c).

Table 1
Individuals and countries participating in the AR4 and AR5 review process. Cells for 'Individuals' and 'Countries' show the number in the review for that category, with the percentage of the total in parentheses. R/C = average number of reviewers per country. Aus = Australia; Can = Canada; EinT = Economies in Transition. Members of TSU are listed in the Assessment Report Annexes by their country of origin. Classification into developed/developing/EinT is based on UN (2014). This closely follows the UNFCCC classification into Annex I (developed) and non-Annex I (developing) nations, except that in UN (2014) Turkey is classed as developing and EinT countries are listed separately, whereas these are included in the UNFCCC Annex I. For the compilation of 'Reviewers+contributors', duplicates (i.e., where individuals are listed as both reviewer and contributor) have been removed. Data sources: IPCC (2007a, b, c; 2013a; 2014b, c).

AR4						
Reviewers		TOTAL	Developed	Aus; Can; UK; USA	Developing	EinT
WG1	Individuals	619	578 (93.4)	330 (53.3)	40 (6.5)	1 (0.2)
	Countries	40	23	n/a	16	1
	R/C	15.5	25.1		2.5	1.0
WG2	Individuals	1126	911 (80.9)	488 (43.3)	203 (18.0)	12 (1.1)
	Countries	93	29	n/a	61	3
	R/C	12.1	31.4		3.3	4.0
WG3	Individuals	468	408 (87.2)	124 (26.5)	59 (12.6)	1 (0.2)
	Countries	52	24	n/a	27	1
	R/C	9.0	17.0		2.2	1.0
AR5						
Reviewers		TOTAL	Developed	Aus; Can; UK; USA	Developing	EinT
WG1	Individuals	1090	949 (87.1)	538 (55.6)	135 (12.4)	6 (0.6)
	Countries	56	27	n/a	27	2
	R/C	19.5	35.1		5.0	3.0
WG3	Individuals	836	692 (82.8)	286 (34.2)	141 (16.9)	3 (0.4)
	Countries	66	25	n/a	39	2
	R/C	12.7	27.7		3.6	1.5
Contributors		TOTAL	Developed	Aus; Can; UK; USA	Developing	EinT
WG1	Individuals	553	477 (86.3)	298 (53.9)	67 (12.1)	9 (1.6)
	Countries	43	23	n/a	19	1
	R/C	12.9	20.7		3.5	9.0
WG3	Individuals	398	286 (71.9)	145 (36.4)	110 (27.6)	2 (0.5)
	Countries	56	24	n/a	31	1
	R/C	7.1	11.9		3.6	2.0
Reviewers+ contributors		TOTAL	Developed	Aus; Can; UK; USA	Developing	EinT
WG1	Individuals	1643	1426 (86.8)	836 (50.9)	202 (12.3)	15 (0.9)
	Countries	68	28	n/a	38	2
	R/C	24.2	50.9		5.3	7.5
WG2	Individuals	2311	1856 (80.3)	1107 (47.9)	432 (18.7)	23 (1.0)
	Countries	103	31	n/a	67	5
	R/C	22.4	59.9		6.5	4.6
WG3	Individuals	1234	978 (79.3)	431 (34.9)	251 (20.3)	5 (0.4)
	Countries	78	28	n/a	48	2
	R/C	15.8	34.9		5.23	2.5

developed and developing country reviewers. The same contrasts observed in the AR5 occur in the AR4. On average across the FODs and SODs of the four chapters, 65% of comments are from developed countries and 35% from developing. The contribution from developed countries reaches a maximum of 94% for the Chapter 19 SOD and a minimum of 24% for the regional Chapter 13 FOD.

Overall, the AR4 and AR5 assessment report reviews are dominated by a small number of developed countries and, in the WG2 AR5 at least, the TSU. For at least one chapter (WG2 AR5 Chapter 27 FOD), the participation of TSU staff was essential to ensure a proper review. There is a considerable improvement in developing country participation between the AR4 and AR5 (see Table 1) – a trend which hopefully will continue into the AR6.

Table 2
Representative chapters from the WG2 AR4 and AR5 used in analyses as specified in the text.

Fourth Assessment		Fifth Assessment		
No:	*Title:*	*No:*	*Title:*	*Chapter 'type' (see text for explanation)*
5	Food, fibre, and forest products	7	Food security and food production systems	Sectoral
13	Latin America	27	Central and South America	Regional
17	Assessment of adaptation practices, options, constraints and capacity	15	Adaptation planning and implementation	Adaptation
19	Assessing key vulnerabilities and the risk from climate change	19	Emergent risks and key vulnerabilities	Synthesis

4. Is the review comprehensive?

To address this, we analysed how review comments are distributed throughout individual chapters, to understand whether all sections had been equally considered by reviewers.

The analysis was carried out for all chapters in the WG2 AR4 and AR5 FOD and SOD review, using the WG2 chapter drafts and comments files from the IPCC website (available for the AR4 at https://archive.ipcc.ch/report/ar4/wg2/ and for the AR5 at https://archive.ipcc.ch/report/ar5/wg2/ (accessed 10 May 2021)). The process is as follows:

- Pages in the main text of each chapter (excluding the title, table of contents and reference pages) were numbered and the numbers expressed as percentages of the total. The pages were then assembled into 5% blocks.
- For each 5% block (which generally includes more than one actual page) the number of comments was counted. Where a comment referred to text spanning more than one block, it was attributed to the first.
- The number of comments per 5% block was summed across all chapters in a particular WG, assessment and review. This provided 20 datapoints for each of the WG2 AR4 FOD, WG2 AR4 SOD Expert, WG2 AR4 SOD Government, WG2 AR5 FOD, and WG2 AR5 SOD review (in the AR5, WG2 did not produce separate government and expert review comments files for the SOD).

The chapter draft pdfs are arranged in different ways in the two assessments. In the AR4, tables and figures are embedded in the text close to the point at which they are first referenced. In the AR5, the tables and figures follow the reference list, and the text flows continuously. This arrangement meant that tables and figures could not be considered in the comment counts for the AR5. It is therefore not possible to make a direct comparison between results for the two assessments.

This approach allows understanding, at the WG level for each assessment, of the extent to which the review is a comprehensive exploration. Fig. 4a shows a clear downward trend in the number of review comments throughout chapters, suggesting that reviewers look in detail at the executive summaries and the opening pages, but tend to fall away as the chapter progresses. The analysis was repeated with executive summaries removed (Fig. 4b) on the hypothesis that the downward trend could be largely explained by reviewers focusing

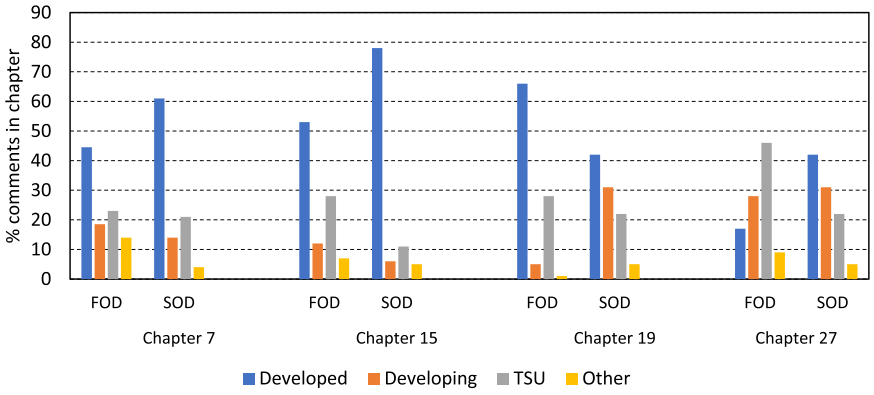


Fig. 3. Origin of review comments on four chapters (see Table 2) of the IPCC WG2 AR5. Bar length represents percentage of comments in that chapter. Comments are categorised according to whether they were submitted from a developed or developing country, by a member of the TSU, or other. 'Other' contains comments from international organisations or where a country affiliation could not be assigned because no country affiliation is provided for reviewers in the review spreadsheets, only their institution. Consequently, where a reviewer identified as, for example, 'Independent' or 'Consultant', no country affiliation could be assigned, and the comment was classified as 'Other'. (The 'Other'category is small: on average 6.3% of comments across four chapters and two reviews, rising to a maximum of 14% for the Chapter 7 FOD). In the SOD review spreadsheets, government review comments were assigned to a country, expert review comments were treated as in the FOD. For data source see text.

attention there. As Fig. 4b shows, even when executive summaries are removed, the downward trends persist.

To quantify the extent of the trends, we averaged the percentages across the AR4 and AR5 FODs and SODs, and accumulated these averages. The results show that, on average, 35% of comments relate to the first quarter of each chapter, 61% of comments to the first half, and 82% to the first three-quarters (Fig. 4c). When executive summaries are excluded these figures reduce slightly but the bias towards early sections of chapters is still present.

To explore further, we examined the distribution of comments by page for the eight chapters in Table 2. For each chapter, we began with the four highest- and four lowest-commented pages, each category representing about 10% of the total chapter length (excluding references and, for the AR5, tables and figures): across the AR4 and AR5 FODs and SODs for these four chapters, the average page length is 44. Where there was a tie we included the tied pages bringing the total of scrutinised pages to 75.

Many pages with low comment counts are not of concern because, for example, they are context-setting or provide an overview of chapter content (in the eight chapters, 13% of lowest-commented pages in the AR4, 22% in the AR5) or are, in the case of the AR4 where tables are embedded, part of large multi-page tables where comments have been made on earlier pages (42% of lowest-commented pages). However, there are cases where relevant text has received few comments. Often, these cover topics which are highly specialised or tangential to the main topic of the chapter. For example, they may be boxes or case studies on specific issues or locales within a regional chapter (15% of lowest-commented pages in the AR4, 8% in the AR5). The remainder are main text, representing 30% of lowest-commented pages in the AR4 and 70% in the AR5).

Conversely, contentious issues may receive a very high number of comments, going beyond their significance or relevance to the chapter, and potentially creating a disproportionate effort for authors. A example is the topic of geo-engineering in the AR5 Chapter 19 which, while not a major focus of the chapter, received many comments (53 comments on 1.5 pages of text in the FOD and 42 comments on one page in the SOD, compared to 10 comments/page average for the FOD text of Chapter 19 and 16 comments/page average for the SOD text).

Overall, there is a tendency for the number of review comments to drop away over the length of chapters. (Note there is no similar trend across chapters). Review Editors are well-positioned to check on this tendency and on whether all sections of the chapter have been adequately reviewed. In fact, for the AR6, a WG1 guidance note for Review Editors asks them to report on 'areas or sections of chapters that appear to be under-reviewed' (WG1 TSU undated). Similar guidance was provided to WG2 authors (Pereira, personal communication).

5. Is the review insightful?

Even where a chapter receives many well-distributed review comments, these may still not support the authors to improve their chapter. Useful comments range from constructive criticism of structure, content and/or interpretation through to recommendations of relevant literature overlooked by authors, and suggestions for improving policy relevance. Less useful comments include those correcting spelling and punctuation errors, recommending inclusion of policy prescriptive commentary (a fundamental mantra of the IPCC is that assessments should be policy relevant but not policy prescriptive), or expressing personal opinions insufficiently supported by scientific evidence.

For the four chapters in Table 2, we analysed the AR5 FOD and SOD comments to understand their content. We selected the AR5 because the structure of the review comment files is very straightforward, with one comment per table cell (in the AR4, and particularly for the TSU review, many separate comments are held in a single cell).

After initial appraisal of the comments, and drawing on the typology developed by Mach et al. (2016), we devised a classification system based on 10 categories (left-hand column, Table 3). However, using this classification, the extent of the agreement between the two people performing the analsis was deemed unacceptably low. When the categories were merged into five (right-hand column, Table 3), the classification became much more straightforward and in consequence the level of agreement reached a satisfactory level.

The five categories are: *minor* comments which include typographic corrections and statements of approval or disapproval requiring no action, but also requests for policy recommendations which fall outside the IPCC's mandate and therefore cannot be acted on; *style* comments suggesting changes to improve structure and/or clarity; comments relating to *references*, e.g., missing, too old; *policy*-related comments; comments focusing on the *science*, e.g., related to the balance and currency of the discussion.

Minor comments may be useful but do not contribute to the substance of the chapter. *Style* comments, although important for readability and hence potentially influential for relevance and usability, do not contribute to scientific content. The remaining three categories can potentially improve the chapter in terms of its scientific assessment of the literature, although there will be varying levels of insight and relevance (not considered here). The *reference* category should improve the scope of the literature assessed and ensure its relevance (although reviewers' desire to promote their own publications may negate the latter point). *Policy* comments should impose proper use of IPCC uncertainty language. They may support policy relevance while ensuring the chapter avoids being policy prescriptive (although we recognise the ultimate impossibility of maintaining this balance and the complications that ensue in its pursuit (Beck and Mahony, 2018; Oppenheimer et al., 2019)). The *science* category should speak directly to scientific content –

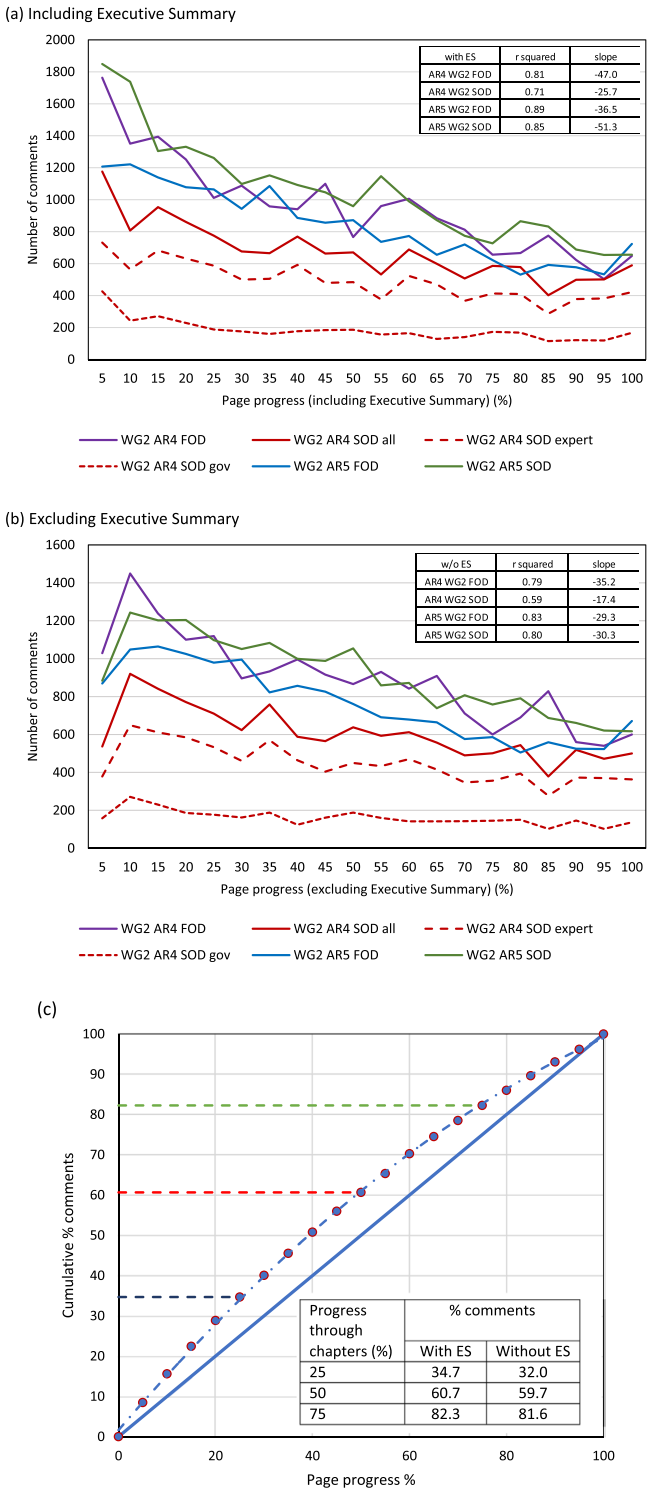


Fig. 4. Number of comments against progress through all chapters in the WG2 AR4 and AR5 FOD and SOD. **(a) and (b)** see text for construction method. The r-squared value for the regression of number of comments against 5% block is shown in the tables top right, together with the slope (comments/5% block) of the (linear) best-fit line. **(c)** the blue dot-dash line shows the number of comments across all chapters in all WGs for both assessments, expressed as a percentage of the total in each 5% block and accumulated. The Executive Summary is included (the line for chapters without their executive summaries would be indistinguishable). The solid line represents the equal distribution of comments throughout all chapters. Dashed lines show percentage of comments at 25% of chapter length (blue), 50% (red) and 75% (green). The table (bottom right) shows percentage of total comments against averaged progress through chapters. ES = Executive Summary. For data sources see text.

Table 3
Classification of review comments on four WG2 AR5 FOD and SOD chapters.

Description/example	Final classification
No action: • Positive (praise)/negative (critical) comment without any concrete suggestion for change • Policy prescriptive comment e.g. request for authors to make a policy recommendation • A long reflective comment lacking any suggestion for action Typographic adjustment: • Correcting typo/grammatical error/typographic repetition (e.g. and and) • Requesting italicisation of IPCC uncertainty terminology • Correcting cross reference (e.g. traceability reference) • Commenting that reference cited in text is not present in reference list	Minor
Scientific rigour: • Questioning a statement in the chapter on scientific grounds • Requesting additional discussion/addition of an alternative perspective • Questioning accuracy of definitions Balance and agreement: • Request to o adjust balance of examples from developing vs developed countries o maintain balance between this chapter and other chapters/ other WGs o check on agreement between the chapter and Executive Summary • Comment on failure to stress importance of some drivers etc./ exaggeration of drivers, impacts etc. (i.e. scientific balance) Content: • Suggesting the addition or subtraction of specific material • Providing a specific example or figure with a request to include • Requesting an example (but does not offer one)	Science
Reference: • Pointing to a specific reference with request to include • Request to include a reference (but does not suggest one) • Commenting that there are too many references/references are too old/references are inappropriate	Reference
Clarity: • Suggesting text change/rewording to increase readability or improve understanding • Commenting on clarity of definitions (the definition is unclear) with or without suggestion for change Structure: • Request to move material between sections • Request to remove repetition between sections • Comment that there are large gaps e.g. add a whole section (comments on small gaps are classified under Content)	Style
Policy relevance: • Request to include discussion of policy-relevant implications or dimensions • Comment on use of non-objective language e.g. 'alarming' IPCC-related: • Request to add IPCC uncertainty language • Comment on lack of agreement between definitions used and IPCC definitions • Request to use conditional language (e.g. climate change may, not climate change will) • Request to avoid ad hoc use of words associated with IPCC uncertainty language where not used in that context	Policy

that the chapter presents a balanced, informed, up-to-date assessment of the state-of-play of research and scientific debate around the chapter topic.

Fig. 5 shows the results of the review comment classification. Across the four chapters, 48% of WG2 AR5 FOD comments and 54% of SOD comments fall into the *science* category, while just 13% of FOD comments and 10% of SOD comments are classified as *minor*. The percentages are broadly the same between the FOD and SOD, with slightly more

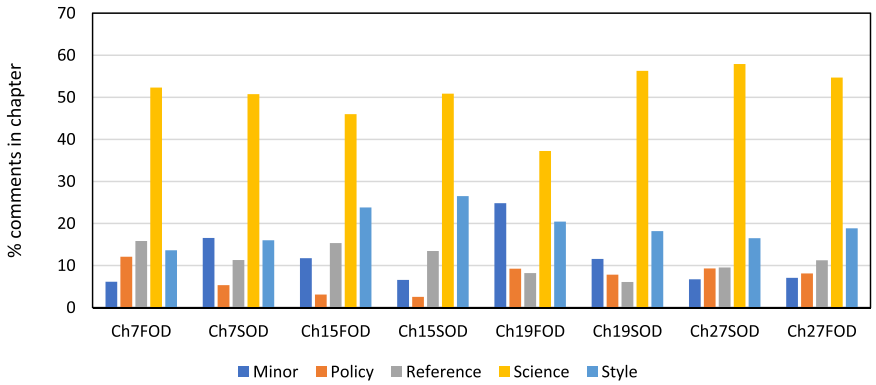


Fig. 5. Categorisation of review comments on the FODs and SODs of four chapters of the WG2 AR5. For explanation of categories see Table 3 and text. For data sources see text.

minor comments and slightly fewer *science* comments in the FOD compared to the SOD - possibly reflecting the respective levels of chapter development. Chapter 19 is something of an outlier, with 25% *minor* comments and 37% *science* comments in the FOD, but this changes in the SOD with 12% and 56% comments respectively – again possibly a function of chapter development. Overall, for the four sample chapters considered, *minor* and *style* comments combined contribute 30% to the total, while the remaining 70% are in the *science*, *reference* and *policy* categories: we can reasonably infer that the content of the review comments is useful to the scientific development of chapter drafts.

6. Discussion

6.1. Analysis results

Clark et al. (2002) stated 'The most influential assessments are those … perceived by a broad array of actors to possess … saliency, credibility and legitimacy.' A review process which is effective, and seen to be such, is fundamental to the achievement of these attributes: to ensure the scientific quality of the assessment, review should be comprehensive, in-depth and performed by experts representative of the global science community. In this paper we have explored the extent to which the AR4 and AR5 FOD and SOD reviews fulfilled these expectations.

We find, *first*, that the bulk of reviewers come from a few developed countries. Developing countries were underrepresented, and many only contribute one or two reviewers. For example, in the WG2 AR5, 67 developing countries contributed expert reviewers but, of these, 37 contributed only one or two individuals. Of course, some developing countries have very small populations (e.g., some Pacific Island nations) so that the potential pool of experts is small. These patterns match earlier findings around representativeness of authors (Corbera et al., 2015). The writing and review of IPCC reports is carried out in the English language, which can create barriers for potential expert reviewers (Amano et al., 2021). There is evidence that the contribution of reviewers from developing countries, especially those that have invested substantially in climate science research such as China and India, grew substantially between the AR4 and AR5. *Second*, there is a clear tendency for the earlier sections of chapters to be more heavily reviewed. Although absence of comments does not necessarily imply inadequate review, there is the possibility that some topics receiving relatively few comments (such as focused case studies requiring specialist reviewers) were not adequately reviewed. *Third*, we inspected the content of review comments and found that the majority contribute to the scientific development of chapters. In passing, we note that there is a paper to be written about the responses of authors to review comments, since the quality of those responses is a further indicator of the comprehensiveness and contribution of the review process, but this is not that paper.

Overall, then, those review comments which are received make an effective contribution to chapter development. They are key to the univocality of the assessment – the degree to which it can speak in a single voice in representing current scientific understanding (Oppenheimer et al., 2019). In terms of the saliency, credibility and legitimacy of the assessment, the review contributes to saliency through the involvement of governments in the SOD review, to credibility because the bulk of comments contribute to the scientific development of chapters, and to legitimacy because the process is defined, transparent and approved.

6.2. Recommendations

There is work to be done to strengthen the positive attributes of the review process and counter any negatives, ensuring on one hand that chapters are fully reviewed from beginning to end, and reviewers are drawn from a wider constituency, while on the other that the process does not become excessively expensive and cumbersome (De Pryck, 2021). What practical end-to-end changes can be made to the review process to achieve these goals?

6.2.1. Recruiting diverse reviewers

How can the IPCC in particular, and GEAs more widely, broaden participation in their reviews? Here, we have focused on contrasts between developed and developing world participation, but there are many aspects to representativeness including gender, the voices of local and Indigenous knowledge (Beck et al., 2014) as well as participation by non-governmental organisations, business, and industry (Howarth et al., 2017). The issue has been touched on tangentially by the IPCC's own 'Task Force on the Future of the IPCC' in its Decision IPCC/XLI-4 (https://archive.ipcc.ch/meetings/session41/p41_decisions_future.pdf accessed 24 April 2022). The challenge for GEAs is to incentivise participation when potential reviewers may have little time to engage in review and may receive little or no recognition for, or benefit from, their efforts. The IPCC makes much of the fact that participation in assessments is voluntary and unpaid. This is only true to an extent. Academic staff in western universities will have time in their working week for research and service, which they can juggle to make space, for example, to act as assessment reviewers. Academics in developing countries as well as private sector employees will likely have to devote leisure time if they wish to participate as reviewers.

To overcome these barriers, word-of-mouth' and 'open call' approaches are clearly insufficient. GEAs need to mobilise their myriad stakeholders. IPCC WGs already ask participants for names of potential reviewers, but simply sending an email to names on lists is insufficient. There is clear evidence that Co-Chairs' nationality influences reviewer participation. In WG3, one of the AR4 Co-Chairs was from The Netherlands, which had 61 expert reviewers, a figure which dropped to 21 in the AR5. Conversely, in the AR5, with a Co-Chair from Germany,

WG3 had 77 German expert reviewers, but only 30 in the AR4 (IPCC, 2007c, 2014b). This suggests efforts at local levels to communicate about the on-going assessment and personal contacts through authors and Bureaux members are important in recruiting reviewers. Such efforts need to be intensified. National Focal Points could be a valuable resource, but historically these are often based in national meteorological departments with weak connections into the communities with potential interest in reviewing WG2 and WG3 chapters. Regional science organisations and intergovernmental bodies such as the Asia-Pacific Network for Global Change Research and the World Academy of Sciences, as well as global efforts through organisations such as ICSU and WCRP, can be asked to use their networks to recruit expert reviewers and provide follow-up and support to transition initial contacts into active participation as a reviewer. At the local level, we have noted that universities play an important role in developed countries by enabling and valuing the contribution of academic staff to IPCC reports, and the same level of awareness needs to be built among developing world institutions. It may be that international science organisations such as the InterAcademy Partnership and the International Science Council could play a role in building this awareness.

Other relatively straightforward incentives which might encourage reviewers to participate include cash or in-kind (e.g. access to journals) payment (see van der Veer et al., 2014 for experience with such approaches).

There are, of course, indirect factors at work in reviewer recruitment, beyond the direct influence of GEAs. We have observed, for example, that developing countries with large research investments, such as China and Brazil, increased their participation in review substantially between the AR4 and AR5.

6.2.2. *Training and review workshops*

Training and review workshops have shown promise in the AR6 in recruiting reviewers, and we outline two examples below. Workshops offer networking opportunities which may be seen as an attraction by potential participants.

First, in 2018 and 2019 effort was directed towards increasing the number of reviewers from Africa and Latin America by holding two free online training courses in how to provide effective review comments. In an evaluation of the first course, focused on the review of the Special Report on Climate Change and Land (IPCC, 2019) SOD, Meyer (2018) reported that 16% of all expert reviewers of the Report registered under an African country, of which he estimates about half could be attributed to the e-learning course. The second course, delivered online in Spanish and focused on Latin America, was directed at the review of the WG2 AR6 FOD. Although Barclay (2021) shows that hosting these training workshops has helped to increase participation from the Global South to a certain degree, he notes the challenge of transitioning participants in training workshops to the active reviewer (or author) role, and the need for more effort.

Second, there have been efforts to build capacity in the Asia-Pacific region. A workshop held in 2018 linked authors working on the IPCC AR6 to senior and early-career scientists in Asia, particularly those working in regions poorly represented in the AR5, specifically Central Asia, West Asia, Southeast Asia and the Hindu Kush region (Pereira and Hunt, 2019). The workshop highlighted the need to build capacity to take up the roles of authors and reviewers of IPCC reports, for example through training sessions. One such training session took place in Suva, Fiji, focused on reviewing the WG2 AR6 Chapter 15 (Small Islands) FOD, which led to submission of review comments as a group (Pereira and Muhamad, 2019). It is worth noting that a major challenge in the Pacific is poor internet access, making it difficult for scientists to download chapter drafts and upload review comments.

The opportunity to meet face to face either to train to be a reviewer, or to develop a suite of review comments addressing a particular chapter, is potentially a powerful mechanism to recruit reviewers, although it comes with an additional cost. Review of regional chapters in WG2 could be substantially strengthened by regional review workshops. Cross-fertilisation of insights could be achieved by inviting out-of-region disciplinary experts in, say, adaptation to attend workshops.

6.2.3. *Reviewers' role and recognition*

Reviewers need to be properly recognised for their contribution. Currently, their names are listed in a report annex, and that recognition remains the same if they make one comment or many. Some reviewers, especially where they have provided insightful comments on a specialist topic, may be co-opted as contributing authors, which affords them greater recognition but removes them from subsequent reviews of that chapter. One possibility would be to recruit, potentially compensate and coordinate (through the TSU) a small cohort of reviewers for each chapter at the start of the process who undertake to comprehensively review each draft and who are named on the chapter title page (as in, for example, reports from the U.S. National Academies of Sciences, Engineering and Medicine). The cohort could meet with the writing team (remotely or face-to-face if finances permit) in a meeting chaired by the Review Editor to discuss chapter progress and any substantial points of difference. Subject specialists could be assigned to review particular sections related to their expertise.

6.2.4. *The writing process*

Chapters should be 'reviewable' in terms of length and accessibility. Although indicative page lengths are provided by WG Bureaux or TSU, drafts can frequently run close to a hundred pages, making review a formidable undertaking and one that many will baulk at entirely, or give up midway leaving only a partial review. Authors need to be mindful of page length from an early point in the process, rather than having to edit for length once the review process is largely complete. Accessibility can be improved, for example by using comprehensive hyperlinked tables of content to direct reviewers to those sections where their expertise is most relevant and required. These strategies would benefit the comprehensiveness and insightfulness of the review process (not to mention chapter quality) and allow reviewers to play a more direct and meaningful role in commenting on what is and is not included in chapter text.

6.2.5. *The role of review editors*

We see an expanded role for review editors. Currently, review editors only become fully active once review comments on the FOD have been addressed by authors (prior to that, they may be asked to provide lists of potential reviewers). We suggest a more active role, for example, to recruit and mentor the cohort of reviewers suggested in Section 6.2.2, including reviewers from traditionally under-represented countries. They can, without a large increase in workload, advise authors on making drafts more concise and reviewable, check to ensure all parts of the chapter draft have been properly reviewed and report to authors and Co-Chairs any concerns they might have in that respect.

6.2.6. *Assessment report structure*

At present the main IPCC outputs are the three WG assessment reports and associated special reports. It may be, given the exponential growth in publications dealing with climate change (Burkett et al., 2014; Callaghan et al., 2021), that there needs to be a shift in emphasis away from all-encompassing assessments with their long production cycles towards more targeted reports with shorter delivery times. This may even require a move away from the rigid three WG structure towards a more fluid arrangement which could change and evolve for each assessment cycle. Tailoring assessment reports to specific audiences such as the finance and reinsurance sector, land use managers or local government would benefit the review process. It would incentivise relevant reviewers, and might have the added advantage of reducing the total number of review comments while increasingly their relevance – an important consideration given the very large number of comments authors have to deal with.

6.2.7. Reporting and monitoring the review process

Reporting of the review needs to achieve greater *prominence*, *accessibility* and *consistency*. Giving greater *prominence* to the review process and outcomes would contribute to reviewer recognition, and could be achieved by changing the position of review comment and author response files on the IPCC website, even to the extent of placing the record of review alongside each chapter, as is done by journals such as eLife. Improved *accessibility* would open the review to more diverse scrutiny, and could be achieved using searchable database-style formats to present the record of review. For example, comments of individual reviewers could be made traceable through each writing stage, together with the author response, so that reviewers could see how their comments influenced chapter development. *Consistency* of reporting between WGs and assessments is essential to support monitoring of the review process. Indeed, we have noted in this paper how the lack of consistent reporting has affected our analyses (see Section 6). How the record of review is presented in the final published assessment needs to be agreed at Panel (not WG) level. Ideally, and in recognition of the importance of review to the credibility and legitimacy of its assessments, the IPCC should build on consistent reporting to publish an evaluation of the review process for each assessment: how many reviewers, from which world regions, contributing how many comments – not dissimilar to the analyses presented here. This would support a monitoring initiative to track progress in (hopefully) increasing participation by reviewers from non-academic institutions, non-Anglophone countries and the developing world.

6.2.8. Reviewer anonymity

Currently, IPCC reviews are open: each comment has a name (or government in the case of the government review) attached at the time the TSU returns the reviews to authors for consideration. Draft chapters can be reviewed by anyone with demonstrable scientific credentials. This is important for the credibility of assessment reports and should be maintained. However, it is open to abuse, such as campaigns by denier communities. To guard against this, and as a contribution to report legitimacy, it is important that reviewers continue to be named.

It is possible to envisage at least one alternative approach to the current system. Some journals, such as *Atmospheric Chemistry and Physics*, the *PLOS* journals and the *European Scientific Journal* are moving away from blind review to explore more open models, in which review comments are made available online at the time the paper is published. Reviewers can reveal their names at the review stage, or at the time of publication or can remain anonymous. Following these approaches, the IPCC could move to alternative systems, for example in which reviewers remain anonymous during the process, but their names are revealed at the end of the assessment (Fresco-Santalla and Hernández-Pérez, 2014; Papanas and Mikhailidis, 2022). However, and unlike the situation with the journals named above, IPCC reviewers would be made aware when registering that their names will ultimately be made public.

7. Conclusions

7.1. What constitutes a sufficient review?

In the evaluations of the IPCC review process presented above, we have concentrated on reviewer numbers, their country of origin, where their review comments clustered within chapters, and, to an extent, the content of their comments. We have not attempted to establish more broadly a reference point for a sufficient review of a GEA.

The issue of what constitutes a sufficient review has many aspects (Edwards and Schneider, 2001; Papanas and Mikhailidis, 2022). For example, to what extent should the relevant expertise of the reviewer count, and how should that be measured? Is it the case with all peer-reviewed material that the number of comments per page drops as one moves through the text? How do we think about the fact that quality doesn't have a simple relationship to quantity? The best, most mature material doesn't need a lot of comments and, from an author's perspective, it is generally more useful to receive two or three deeply insightful comments than dozens of specific suggestions.

The categorisation of comments as carried out in Section 5 is a first step towards addressing this, but it is only a first step. There is another paper to be written that attempts to define a sufficient review, and that uses this definition as a baseline against which to explore the sufficiency of reviews in GEAs.

7.2. Analysis of AR6 review comments

As noted in Section 1, although IPCC assessment reports have been subject to extensive post-publication analysis, this has generally, and despite its significance, excluded the review process. We note that changes to how the review is reported by the IPCC could make it much easier for scholars to pursue analysis, and would support greater insights, for example around diversity. We trust that, once the AR6 review comments and author responses are published, analyses will emerge. Hopefully the tools and questions brought forward here will prove to be useful as a foundation for these analyses, for example Table 3 as a starting point for review comment classification.

7.3. Looking forward

Overall, we found that the review process in IPCC assessments as laid out in Appendix A of the *Principles Governing IPCC Work* (IPCC, 2013a) is fit for purpose. However, the context in which the IPCC operates has changed. Assessments are now widely reported and scrutinised by the media. Solutions-oriented assessments, addressing the needs of state and non-state actors at different levels of decision-making, are increasingly called for following the Paris Agreement (Beck and Mahony, 2017; De Pryck and Wanneau, 2017; Beck and Oomen, 2021). The volume of material to be assessed is increasing exponentially (Burkett et al., 2014). To address these emerging pressures, changes to review implementation are essential. We sought in Section 6 to make recommendations relevant to post-2022 assessments. These, together, offer a blueprint to enhance the processes and outcomes of review in GEAs more widely.

Our recommendations are practical, taking into account financial constraints under which GEAs generally operate. If we imagine more generous financial support, many things might be done differently. Training workshops for reviewers could be delivered face-to-face with dedicated follow-up to strengthen the likelihood that training translates into review participation. Round tables between authors and key reviewers could take place during author meetings so that review becomes a true dialogue. Management teams such as IPCC TSUs could continue beyond delivery of the final report and general 'tidying up' to monitor and evaluate the assessment process (and, inter alia, the review) and make recommendations for procedures in subsequent assessments – a process of growth.

GEAs in general are subject to the same external pressures and shifting contexts affecting the IPCC. They have the same requirements to be comprehensive, objective, open and transparent, and to be perceived as such. Effective review is an important contributor in meeting these requirements. GEAs have vital roles in providing governments with the evidence base for decision making, and in building capacity among policy-makers and the wider community to support action. A robust, transparent and trustworthy review process provides strong support to the fulfillment of this role.

CRediT authorship contribution statement

Jean P. Palutikof: Conceptualisation, methodology, writing – original draft, writing - review and editing; **Sarah L. Boulter**: Data curation, formal analysis, writing – review and editing; **Christopher B. Field**: Writing – review and editing; **Katharine J. Mach**: Writing – review and editing; **Martin R. Manning**: Writing – review and editing; **Michael D.**

Mastrandrea: Writing – review and editing; **Leo Meyer**: Writing – review and editing; **Jan C. Minx**: Writing – review and editing; **Joy J. Pereira**: Writing – review and editing; **Gian-Kasper Plattner**: Writing – review and editing; **Suzana Kahn Ribeiro**: Writing – review and editing; **Youba Sokona**: Writing – review and editing; **Frank Stadler**: Writing – review and editing; **Rob Swart**: Writing – review and editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Amano, T., Berdejo-Espinola, V., Christie, A.P., Willott, K., Akasaka, M., Báldi, A., et al., 2021. Tapping into non-English-language science for the conservation of global biodiversity. PLoS Biol. 19, e3001296 https://doi.org/10.1371/journal.pbio.3001296.

Barclay, D., 2021. Understanding and Addressing the Barriers to Entry of Global South Researchers to Becoming Expert Reviewers of the IPCC Assessment Reports. Future Climate for Africa,, Cape Town. ⟨https://futureclimateafrica.org/wp-content/uploads/2021/07/Impact-case-study-design-CCKE-IPCC-final.pdf⟩.

Beck, S., Mahony, M., 2017. The IPCC and the politics of anticipation. Nat. Clim. Change 7, 311–313. https://doi.org/10.1038/nclimate3264.

Beck, S., Mahony, M., 2018. The IPCC and the new map of science and politics. WIREs Clim. Change 9, e547. https://doi.org/10.1002/wcc.547.

Beck, S., Oomen, J., 2021. Imagining the corridor of climate mitigation – What is at stake in IPCC's politics of anticipation? Environ. Sci. Policy 123, 169–178. https://doi.org/10.1016/j.envsci.2021.05.011.

Beck, S., Borie, M., Chilvers, J., Esguerra, A., Hebach, K., et al., 2014. Towards a reflexive turn in the governance of global environmental expertise. GAIA 23, 80–87. https://doi.org/10.14512/gaia.23.2.4.

Berrang-Ford, L., Sietsma, A.J., Callaghan, M., Minx, J.C., Scheelbeek, P.F.D., Haddaway, N.R., Haines, A., Dangour, A.D., 2021. Systematic mapping of global research on climate and health: a machine learning review. Lancet Planet. Health 5, E514–E525. https://doi.org/10.1016/S2542-5196(21)00179-0.

Burkett, V.R., Suarez, A.G., Bindi, M., Conde, C., Mukerji, R., Prather St., M.J., Clair, A.L., Yohe, G.W., 2014. Point of departure. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 169–194.

Callaghan, M., Schleussner, C.-F., Nath, S., Lejeune, Q., Knutson, T., Reichstein, M., Hansen, G., Theokritoff, E., Andrijevic, M., Brecha, R.J., Hegarty, M., Jones, C., Lee, K., Lucas, A., van Maanen, N., Menke, I., Pfleiderer, P., Yesil, B., Minx, J.C., 2021. Machine-learning-based evidence and attribution mapping of 100,000 climate impact studies. Nat. Clim. Change 11, 966–972. https://doi.org/10.1038/s41558-021-01168-6.

Callaghan, M.W., Minx, J.C., Forster, P.M., 2020. A topography of climate change research. Nat. Clim. Change 10, 118–123. https://doi.org/10.1038/s41558-019-0684-5.

Castree, N., Bellamy, R., Osaka, S., 2020. The future of global environmental assessments: Making a case for fundamental change. Anthr. Rev. 8, 56–82. https://doi.org/10.1177/2053019620971664.

Clark, W., Mitchell, R., Cash, D., Alcock, F., 2002. *Information as Influence: How Institutions Mediate the Impact of Scientific Assessments on Global Environmental Affairs*. KSG Faculty Research Working Papers Series RWP02-044.

Clark, W.C., Tomich, T.P., van Noordwijk, M., et al., 2016. Boundary work for sustainable development: Natural resource management at the Consultative Group on International Agricultural Research (CGIAR). P Natl. Acad. Sci. USA 113, 4615–4622. https://doi.org/10.1073/pnas.0900231108.

Corbera, E., Calvet-Mir, L., Hughes, H., Paterson, M., 2015. Patterns of authorship in the IPCC Working Group III report. Nat. Clim. Change 6, 94–99. https://doi.org/10.1038/nclimate2782.

De Pryck, K., 2021. Controversial practices: Tracing the proceduralization of the IPCC in time and space. Glob. Policy 12 (Suppl.7), 80–89. https://doi.org/10.1111/1758-5899.12910.

De Pryck, K., Wanneau, K., 2017. (Anti) -boundary work in global environmental change research and assessment. Environ. Sci. Policy 77, 203–210. https://doi.org/10.1016/j.envsci.2017.03.012.

Edenhofer, O., Minx, J., 2014. Mapmakers and navigators, facts and values. Science 345 (6192), 37–38. https://doi.org/10.1126/science.1255998.

Edwards, P.N., Schneider, S.H., 1997. The 1995 IPCC report: broad consensus or "scientific cleansing"? Ecofable/Ecoscience 1, 3–9. ⟨http://www.pne.people.si.umich.edu/PDF/ecofables.pdf⟩. (Accessed 16 April 2022).

Edwards, P.N., Schneider, S.H., 2001. Self-Governance and Peer Review in Science-for-Policy: The Case of the IPCC Second Assessment Report. Chapter 7 in C Miller and PN Edwards. *Changing the Atmosphere: Expert Knowledge and Environmental Governance*. MIT Press,, Cambridge, MA.

Forrester, N., 2020. Diversity in science: next steps for research group leaders. Nature 585, s65–s67. https://doi.org/10.1038/d41586-020-02681-y.

Fresco-Santalla, A., Hernández-Pérez, T., 2014. Current and evolving models of peer review. Ser. Libr. 67, 373–398. https://doi.org/10.1080/0361526X.2014.985415.

Gustafsson, K.M., Lidskog, R., 2018. Organizing international experts: IPBES's efforts to gain epistemic authority. Environ. Sociol. 4, 456. https://doi.org/10.1080/23251042.2018.1463488.

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. https://doi.org/10.1016/j.gloenvcha.2011.05.007.

Howarth, C., Viner, D., Dessai, S., Rapley, C., Jones, A., 2017. Enhancing the contribution and role of practitioner knowledge in the Intergovernmental Panel on Climate Change (IPCC) Working Group (WG) II process: Insights from UK workshops. Clim. Serv. 5, 3–10. https://doi.org/10.1016/j.cliser.2017.04.003.

Hughes, H.R., Paterson, M., 2017. Rev. Policy Res. 34, 744–766. https://doi.org/10.1111/ropr.12255.

Hughes, H.R., Vadrot, A.B.M., 2019. Weighting the world: IPBES and the struggle over biocultural diversity. Glob. Environ. Polit. 19, 14–37. https://doi.org/10.1162/glep_a_00503.

IPCC, 2019. In: Shukla, P.R., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., Pörtner, H.-O., Roberts, D.C., Zhai, P., Slade, R., Connors, S., van Diemen, R., Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J., Portugal Pereira, J., Vyas, P., Huntley, E., Kissick, K., Belkacemi, M., Malley, J. (Eds.), Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, Clim. Change Land.: IPCC Spec. Rep. Clim. Change, Desert, Land. Degrad., Sustain. Land. Manag., Food Secur., Greenh. Gas. Fluxes Terr. Ecosyst.. In press (Accessed 4 November 2022). ⟨https://ipcc.ch/srccl/⟩.

InterAcademy Council, 2010. Climate Change Assessments: Review of the Processes and Procedures of the IPCC. InterAcademy Partnership,, Trieste (Available from). ⟨https://archive.ipcc.ch/pdf/IAC_report/IAC%20Report.pdf⟩.

IPCC, 2013a. Appendix A: Procedures for the preparation, review, acceptance, adoption, approval and publication of IPCC reports. In *Principles Governing IPCC Work*. IPCC,, Batumi, Georgia (Accessed 2 May 2022). ⟨https://archive.ipcc.ch/pdf/ipcc-principles/ipcc-principles-appendix-a-final.pdf⟩.

IPCC, 2015. IPCC Factsheet: How Does the IPCC Review Process Work? IPCC Secretariat, Geneva.

Meyer, L., 2018. E-learning Course Reviewing IPCC Assessment Reports. Project Closure Report. ClimateContact Consultancy, Netherlands. ⟨https://climatecontact.nl/media/1030/report-e-learning-ipcc-review-25-9-2018.pdf⟩.

Pereira, J.J., Hunt, J.C.R. (Eds.), 2019. Climate Science and Technology in Asia: Current Status and Future Needs. Report of the Workshop on Status of Climate Science and Technology in Asia, 15-16 November 2018, Kuala Lumpur, Malaysia. LESTARI Publishers, Bangi, Malaysia.

Reid, W.V., Mooney, H.A., 2016. The Millennium Ecosystem Assessment: testing the limits of interdisciplinary and multi-scale science. Curr. Opin. Environ. Sustain. 19, 40–46. https://doi.org/10.1016/j.cosust.2015.11.009.

Riousset, P., Flachsland, C., Kowarsch, M., 2017. Global environmental assessments: Impact mechanisms. Environ. Sci. Policy 77, 260–267. https://doi.org/10.1016/j.envsci.2017.02.006.

Standring, A., Lidskog, R., 2021. (How) Does diversity still matter for the IPCC? Instrumental, substantive and co-productive logics of diversity in global environmental assessments. Climate 9, 99. https://doi.org/10.3390/cli9060099.

IPCC, 2014a. Annex IV: Contributors to the IPCC WGIII Fifth Assessment Report. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., Minx, J.C. (Eds.), *Climate Change 2014: Mitigation of Climate Change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1357–1370.

IPCC, 2007b. Appendix II: Reviewers of the IPCC WGII Fourth Assessment Report. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 899–932.

IPCC, 2007c. Annex IV: Reviewers of the IPCC WGIII Fourth Assessment Report. In: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (Eds.), *Climate Change 2007: Mitigation*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 833–840.

Stocker, T.F., Plattner, G.K., 2014. Climate policy: Rethink IPCC reports. Nature 513, 163–165. https://doi.org/10.1038/513163a.

IPCC, 2013b. Annex V: Contributors to the IPCC WGI Fifth Assessment Report. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1477–1495.

IPCC, 2013c. Annex VI: Expert Reviewers of the IPCC WGI Fifth Assessment Report. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the

Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1497–1522.
IPCC, 2007a. Annex III: Reviewers of the IPCC WGI Fourth Assessment Report. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 969–979.
IPCC, 2014b. Annex V: Expert Reviewers, Government Reviewers and Other Scientific Advisors of the IPCC WGIII Fifth Assessment Report. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., Minx, J.C. (Eds.), *Climate Change 2014: Mitigation of Climate Change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1371–1413.
IPCC, 2014c. Annex I: Authors and Expert Reviewers. In: Barros, V.R., Field, C.B., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1735–1756.
Swart, R., Bernstein, L., Ha-Duong, M., Petersen, A., 2009. Agreeing to disagree: uncertainty management in assessing climate change, impacts and responses by the IPCC. Clim. Change 92, 1–29. https://doi.org/10.1007/s10584-008-9444-7.
UN, 2014. Country Classification. Annex to *World Economic Situation and Prospects 2014*. United Nations, New York. ⟨https://www.un.org/en/development/desa/policy/wesp/wesp_archive/wesp2014.pdf⟩.
Hughes H.R., Paterson M. (2019) The IPCC and key tensions in global climate politics. Samfundsøkonomen. ⟨https://www.djoef-forlag.dk/openaccess/samf/samfdocs/2019/2019_4/Samf_2_4_2019.pdf⟩. (Accessed 15 April 2022).
Kosolosky, L., 2015. Peer review is melting our glaciers: what led the Intergovernmental Panel on Climate Change (IPCC) to go astray? J. Gen. Philos. Sci. 46, 351–366. https://doi.org/10.1007/s10838-015-9303-y.
Kowarsch, M., Jabbour, J., Flachsland, C., et al., 2017. A road map for global environmental assessments. Nat. Clim. Change 7, 379–382. https://doi.org/10.1038/nclimate3307.
Livingston, J.E., Lövbrand, E., Olsson, J.A., 2018. From climates multiple to climate singular: Maintaining policy-relevance in the IPCC synthesis report. Environ. Sci. Policy 90, 83–90. https://doi.org/10.1016/j.envsci.2018.10.003.
Mach, K.J., Field, C.B., 2017. Toward the next generation of assessment. Annu. Rev. Environ. Resour. 42, 569–597. https://doi.org/10.1146/annurev-environ-102016-061007.
Mach, K.J., Freeman, P.T., Mastrandrea, M.D., Field, C.B., 2016. A multistage crucible of revision and approval shapes IPCC policymaker summaries. Sci. Adv. 2, e1600421 https://doi.org/10.1126/sciadv.1600421.
Mach, K.J., Mastrandrea, M.D., Freeman, P.T., Field, C.B., 2017. Unleashing expert judgement in assessment. Glob. Environ. Change 44, 1–14. https://doi.org/10.1016/j.gloenvcha.2017.02.005.
Mastrandrea, M.D., Mach, K.J., 2011. Treatment of uncertainties in IPCC Assessment Reports: past approaches and considerations for the Fifth Assessment Report. Clim. Change 108, 659–673. https://doi.org/10.1007/s10584-011-0177-7.
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. https://doi.org/10.1016/j.envsci.2017.05.014.
Oppenheimer, M., Oreskes, N., Jamieson, D., O'Reilly, J., Brysse, K., Shindell, M., Wazeck, M., 2019. Discerning Experts: The Practices of Scientific Assessment for Environmental Policy. University of Chicago Press,, Chicago IL, p. 281.
Papanas, N., Mikhailidis, D.P., 2022. Alice through the looking glass: Can we improve peer review? The. Int. J. Low. Extrem. Wounds 1–4. https://doi.org/10.1177/15347346221084784.
van der Veer, L., Visser, H., Petersen, A., Janssen, P., 2014. Innovating the IPCC review process – the potential of young talent. Clim. Change 125, 137–148. https://doi.org/10.1007/s10584-014-1145-9.
Vardy, M., Oppenheimer, M., Dubash, N.K., O'Reilly, J., Jamieson, D., 2017. The intergovernmental panel on climate change: challenges and opportunities. Annu. Rev. Environ. Resour. 42, 55–75. https://doi.org/10.1146/annurev-environ-102016-061053.
Pereira J.J., Muhamad N. (2019) Nurturing the Pacific Contribution to IPCC. Buletin SEADPRI 19:10. ⟨http://www.ukm.my/seadpri/wp-content/uploads/2020/01/FINAL_Bul19.pdf⟩. (Accessed 1 October 2021).
WG1 TSU, Undated. *Guidance Note of the Role of Review Editors of the Working Group I Sixth Assessment Report*. Working Group I Technical Support Unit, Paris. ⟨https://www.ipcc.ch/site/assets/uploads/2017/08/AR6_WGI_Guidance_note_Role_REs.pdf⟩. (Accessed 17 March 2021).
Yamineva, Y., 2017. Lessons from the intergovernmental panel on climate change on inclusiveness across geographies and stakeholders. Environ. Sci. Policy 77, 244–251. https://doi.org/10.1016/j.envsci.2017.04.005.