nature climate change

Perspective

https://doi.org/10.1038/s41558-025-02354-6

Recommendations for producing knowledge syntheses to inform climate change assessments

Received: 7 August 2024

Accepted: 2 May 2025

Published online: 10 June 2025

Check for updates

James D. Ford[1], Robbert Biesbroek[2], Lea Berrang Ford[1,3], Felix Creutzig[4,5,6], Neal Haddaway[7], Sherilee Harper[8], Jan C. Minx[1,6], Mark New[9,10], Anne J. Sietsma[11], Carol Zavaleta-Cortijo[12] & Max Callaghan[6]

Climate change assessments (CCAs) play a critical role in taking stock of the available science and other forms of knowledge and informing policy processes. As the underlying evidence base increases exponentially, the complexity also increases and challenges CCA author teams to capture all the relevant knowledge. Therefore, CCAs will need to transition from predominantly assessing primary research to focusing on the assessment and critical appraisal of knowledge syntheses of such work, alongside capturing knowledges held outside traditional scientific sources. To support this, a stronger knowledge synthesis culture is needed, and we propose key recommendations and offer guidance for producing robust, transparent, reproducible, inclusive and timely syntheses that can inform CCAs across scales.

Climate change assessments (CCAs) are designed to identify, assess and synthesize the state of knowledge and the evidence base on climate change. They seek to assess uncertainties in the underlying science, make large and diverse evidence bases digestible, critically examine policy-relevant questions, make scientific judgements on key debates and identify gaps in understanding[1–4]. As such, CCAs develop new, accessible and authoritative understanding of the available knowledge base that is crucial for informing action on climate change[5,6].

The IPCC convenes what is probably the best-known CCA process, and in 2023 commenced its seventh assessment cycle (the Seventh Assessment Report, AR7). It is by no means the only CCA, as the assessment space is increasingly crowded. Many nations, for example, now conduct national assessments (for example Austrian Panel on Climate Change, US National Climate Assessment) alongside regional bodies (for example, the European Environment Agency), multilateral agencies (for example World Bank) and science organizations and networks (for example, the Lancet Commission, the Urban Climate Change Research Network and the National Science Academies). There are also other global environmental assessments that relate to climate change more broadly, including the UN Environment Program's Global Environmental Outlook (GEO) and assessments undertaken by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

Since the publication of the earliest CCAs in the 1980s and 1990s, assessment processes have evolved considerably, developing granular and nuanced understanding of multiple aspects of climate change. There is a well-developed literature examining the processes through which assessments have taken place, along with their effectiveness and evolution over time[7–10]. The task of conducting CCAs, however, has arguably never been more challenging, with the volume of literature

[1]Priestley Centre for Climate Futures, University of Leeds, Leeds, UK. [2]Public Administration and Policy, Wageningen University & Research, Wageningen, the Netherlands. [3]Centre for Climate & Health Security, UK Health Security Agency, London, UK. [4]Technische Universität Berlin, Berlin, Germany. [5]Science Policy Research Unit (SPRU), University of Sussex Business School, University of Sussex, Brighton, UK. [6]Department of Environmental Economics and Policy, Potsdam Institute for Climate Impact Research, Potsdam, Germany. [7]Bangor, UK. [8]School of Public Health, University of Alberta, Edmonton, Alberta, Canada. [9]Department of Environmental and Geographical Science, University of Cape Town, Cape Town, South Africa. [10]African Climate and Development Initiative, University of Cape Town, Cape Town, South Africa. [11]Climate Policy Radar, London, UK. [12]Intercultural Citizenship and Indigenous Health Unit (UCISI), Universidad Peruana Cayetano Heredia, Lima, Peru. e-mail: j.ford2@leeds.ac.uk

 https://doi.org/10.1038/s41558-025-02354-6

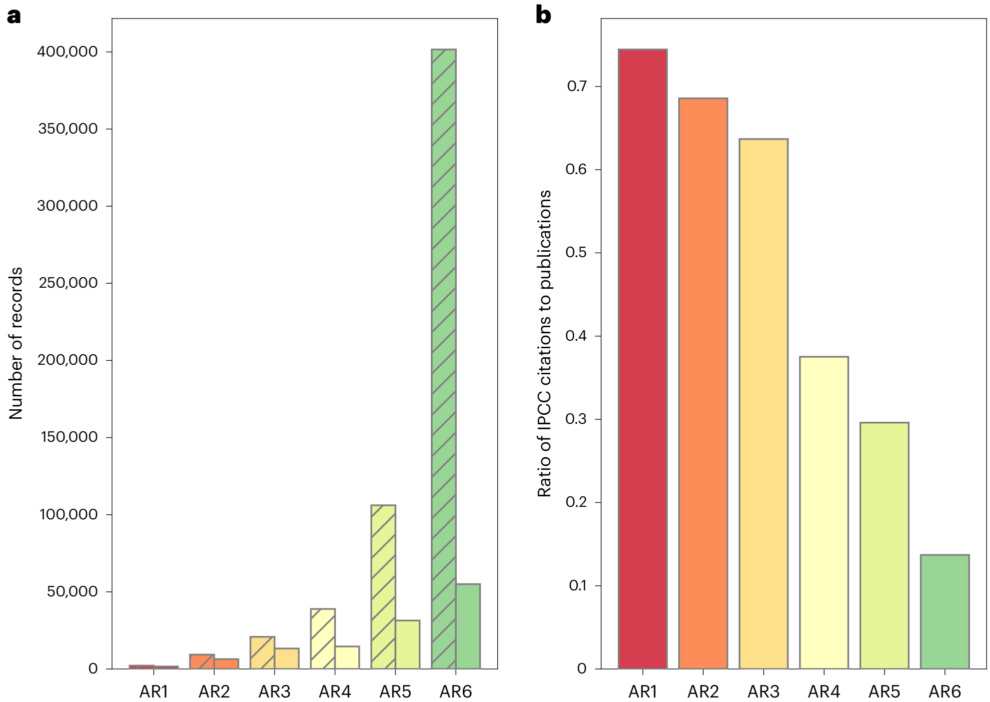

Fig. 1 | Proportion of climate literature cited by the IPCC. a, The number of publications in the Web of Science that mention climate change (solid bars) and the number of unique IPCC citations referencing this work (hatched bars) during each assessment period are shown. **b**, The ratio of IPCC citations to Web of Science publications.

on climate change growing exponentially[8,11,12]; extracting what is 'new' and/or 'relevant' from this exponential growth is therefore getting ever harder. Over the period 1990–2023 the peer-reviewed literature on climate change alone grew at 14.7% yr^{-1}, doubling every 5.1 years (Fig. 1). With digitization and growing interest in climate change, the so-called grey literature is also becoming widely available, containing an important, yet underused, knowledge base that assessments are increasingly seeking to draw upon[13]. The concern is that if this growth cannot be managed, credibility in the assessment process will be undermined—particularly in cases where there is a large or varied knowledge base, or where existing studies show controversy and disagreement[14–16]. To manage this challenge, CCAs and other environmental assessments will need to transition to focus on the assessment and critical appraisal of knowledge syntheses that are derived from primary research and other forms of knowledge.

The term 'knowledge synthesis' can be thought of as a process through which knowledge is systematically and transparently collected, analysed and integrated to draw comprehensive and robust conclusions on specific topics and questions[17]. It is related to the term 'evidence synthesis' but is broader in scope, encompassing a wider range of methodologies (for example, from systematic reviews to dialogues) and forms of knowledge (empirical, scientific, Indigenous, local, practitioner and so on)[17]. It is worth noting that literature review and knowledge synthesis are terms that are sometimes used interchangeably and, while similar, differ in key aspects. Literature reviews typically focus on identifying and characterizing what has been studied and how, whereas knowledge syntheses have a broader aim of generating new and comprehensive understanding by systematically integrating knowledge from multiple studies and other sources (as such, a literature review is a subset of knowledge syntheses). Knowledge syntheses can take a variety of forms, from more traditional papers and reports to online data portals, tools and synthesis figures[18].

Knowledge syntheses are under-represented in the climate change field at present[1,19,20], despite becoming more common in recent years. This goes along with a more general underappreciation of synthesis-focused work in academic reward structures, which is often viewed as second-class research outside of the health and medical sciences (where such syntheses are often considered the highest form of evidence), due in part to limited understanding of methods and approaches for conducting knowledge syntheses[5,21,22].

This Perspective outlines key recommendations for producing knowledge syntheses that are specifically designed to inform CCAs. It deals with topics ranging from epistemological issues around synthesis methodologies to guidance on how and where to start, covering a range of methodologies from those rooted in using the peer-reviewed literature to those focused on the knowledges held by actors embodying and representing knowledge systems. While this Perspective is directed at the producers of knowledge syntheses (which we refer to as synthesis teams), the recommendations can also help author teams in CCAs judge the quality of the underlying syntheses upon which they are drawing. The recommendations are mostly illustrated with IPCC examples (from Working Group II (WGII) in particular), and while they are not exhaustive, they capture what we think are some of the main areas where guidance is needed (Fig. 2). As such, the Perspective is based on our own collective experiences as authors on—and advisors to—multiple IPCC and other climate change/environmental change assessments, and leverages our longstanding background in knowledge synthesis.

Focus on a topic that is a priority for assessment

Priority topics and questions for CCAs are relatively easy to track down. The approved report outlines of many assessments (which contain lists of key topics) are publicly available, published in advance of the assessment process itself, and are often approved by governments, which supports the policy relevance of the topics. Some governments and other policy bodies also identify research gaps (for example, ref. 23). This creates an opportunity to identify and undertake synthesis research with direct relevance to assessment and policy needs. The outline for the IPCC *Special Report on Climate Change and Cities*, for example,

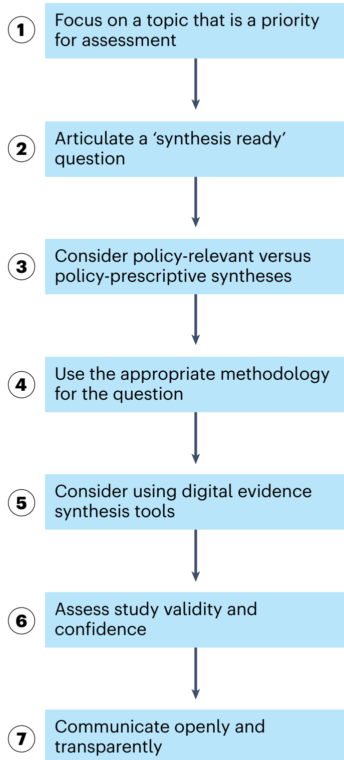

Fig. 2 | Recommendations for writing knowledge syntheses to inform climate change assessments. In this Perspective, we outline seven key recommendations for producing knowledge syntheses.

was approved by governments and released in early August 2024[24]. The UK's Climate Change Risk Assessment process, meanwhile, has a more general 'call for evidence', with two calls targeting evidence gaps to be opened in 2024/2025 as part of the fourth Climate Change Risk Assessment. Approved outlines, topics and evidence gaps provide potential boundaries to help define the sectoral, regional or topical scope and focus of knowledge syntheses.

Synthesis teams should also not be limited by such 'top-down' processes when selecting potential topics and questions. Other sources include existing literature mapping and bibliometric analyses, reports by non-governmental organizations and UN bodies, calls for proposals from research foundations, state-of-the-art discussions at conferences and information in policy documents, among others. Synthesis teams can also conduct their own stakeholder engagement exercises to generate knowledge needs, which is standard practice in many evidence synthesis organizations. Consider engaging early on with lead authors to see if there are 'hot' or debated topics that would be useful to address. Working with decision makers and other stakeholders to co-produce topics and questions should be integral to knowledge synthesis—and built into pre-synthesis activities—particularly where they have direct policy relevance given the growing 'climate action' focus of CCAs and can increase the quality of research and acceptance of the work for decision-making[25–27]. For topics that are often overlooked or only superficially addressed in CCAs, knowledge syntheses can increase the visibility of such topics and the likelihood of being assessed by CCA author teams and help to ensure that key knowledge is incorporated in executive- and high-level summaries (for example, the IPCC *Summary for Policymakers*).

Articulate a 'synthesis ready' question

CCAs need knowledge syntheses that place primacy on the importance of the synthesis question, regardless of the epistemological and methodological challenges of integrating across diverse disciplines, literature bases and knowledge sources. Many existing syntheses are limited to 'low-hanging fruit': summaries of homogeneous literature bases that are readily comparable and use similar epistemologies. In contrast, CCAs typically seek synthesis of insights across disciplines and traditional research boundaries, including engaging with Indigenous knowledge and local knowledge.

To be synthesis ready, there needs to be a comprehensive knowledge base of relevant information, evidence and perspectives to address the synthesis question to ensure that synthesis insights are robust, inclusive and reliable:

- For aggregative (that is, hypothesis testing) quantitative approaches, comprehensiveness is vital to minimize bias, capture effect size, enhance statistical power and understand heterogeneity. An example of a question of interest for IPCC assessments could be: at what level of sea-level rise do barriers and limits to adaptation exist in coastal megacities in southeast Asia? The question is synthesis ready because sea-level projections have been developed for different emissions scenarios at global to regional (and in some cases local) scales, including characterizing uncertainty, which can be combined with historic data on flooding and socioeconomic factors that will affect vulnerability as captured in published literature (for example, population density and infrastructure)[28,29]; it clearly defines the affected population; establishes comparative scenarios (such as different emissions and vulnerability futures); and focuses on measurable outcomes.
- For configurative (that is, hypothesis generating) qualitative approaches, diversity of evidence is an important component of comprehensiveness given the focus on understanding experiences, meanings and perspectives as opposed to measuring outcomes, and this includes having a knowledge base with contributions from authors/representatives from the country/region/location of focus[30,31]. For example, a question of interest for an Arctic Council CCA could be: how are changing ice conditions affecting the food systems of Indigenous communities in the Arctic? This question is synthesis ready because there is documented evidence from Indigenous knowledge holders and within the peer-reviewed literature on how ice conditions are changing and their associated impacts, with perspectives from multiple Arctic regions and settlement types gathered using different methods[32,33]. The question clearly defines the population of focus and makes it clear that the question is examining the impacts of changing ice conditions on specific aspects of Indigenous livelihoods. The question could be further refined to target specific geographical regions if desired (for example Alaska, Greenland and so on), focus on a specific time frame (for example, the past decade) or narrow down food systems to particular aspects such as traditional foods.

Before commencing knowledge synthesis, it is often worthwhile to do a quick scoping search to check the nature of knowledge sources, along with their geographical distribution. And while comprehensiveness may be challenging to delineate in advance, its key components can be delineated a priori.

If the question is ready for synthesis, it is important to clearly define its key components, establishing the system boundaries and making it easier to search for and assess relevant knowledge. This is particularly important for systematic reviews, which require close-framed questions; if the question is more broad and open-framed it is more suitable to systematic mapping, scoping review or other more narrative approaches (Box 1). Consultation with relevant stakeholders can help define the question and its components[34], while tools such as the Population, Exposure, Comparison, Outcome (PECO), Population, Intervention, Comparison, Outcome (PICO), and Sample, Phenomenon of Interest, Design, Evaluation, Research type (SPIDER) frameworks can help formulate and structure precise and clear research questions (for example, see refs. 27,35,36).

 https://doi.org/10.1038/s41558-025-02354-6

BOX 1

Examples of knowledge synthesis methodologies

The landscape of knowledge synthesis is diverse and sometimes difficult to navigate. Below are examples of knowledge synthesis methodologies, which may combine or mix approaches to create a method tailored to the question. We include examples of 'mainstream' methodologies, along with those that emphasize the importance of working with diverse knowledges.

Systematic review. This involves systematically reviewing the literature to identify and appraise evidence for a specific and clearly articulated research question using predefined eligibility criteria for documents and explicitly outlined and reproducible methods[21]. This approach should be explicitly guided by a research question and assess the nature of the evidence, bias and confidence in the evidence when presenting findings. Systematic reviews are particularly useful within CCAs to provide an evidence base to inform climate policy and guide decision-making. For example: to what extent do livestock livelihood interventions reduce climate vulnerability among the ultra-poor?

Evidence map. This approach captures a group of methods (sometimes called a systematic map or scoping review) that are used to answer questions about the state of the knowledge on a particular topic and highlight knowledge clusters and gaps. Evidence maps do not seek to answer a specific research question, but rather to describe and characterize a knowledge base. Such reviews are particularly useful in providing CCAs with an overview of evidence and identifying knowledge gaps within a particular topic. For example: what is the nature of the evidence base on livestock transitions as an adaptation pathway?

Meta-analysis. Meta-analysis is a specific type of review that aims to answer a specific review question but uses statistical techniques to collectively analyse quantitative data across multiple studies[22]. Using particular techniques, meta-analysis pools data across several studies that are relatively homogeneous in terms of methods and data type. For example: does access to green space reduce mortality during heatwaves?

Meta-synthesis. This is a generalized term that reflects a range of qualitative approaches that can be used to synthesize insights from multiple qualitative studies to generate new insights and a deeper understanding of a particular topic or question (for example, case survey meta-analysis[78] and meta-ethnography[89,91]). For example: what are the main factors creating vulnerability to climate change among smallholder farmers?

Rapid review. This type of review integrates key components of a systematic review but involves a simplification of the review process to allow for a more efficient and rapid review process. They involve simplifying review processes in areas with known likely impacts on the risk of bias, which should be clearly stated as caveats, and are suited to cases where the literature is rapidly evolving, decision makers need urgent advice and there are short policy windows and/or resource constraints[25,37]. For example: what is the effectiveness of carbon dioxide removal technologies for meeting emissions goals?

Realist review. This type of review seeks to understand why and how a policy/practice works, for whom and in what context it is effective or ineffective[21]. It focuses on systematically identifying the underlying mechanisms of an intervention, the contexts in which these mechanisms are activated and the outcomes produced[2,92]. Realist reviews use a theory-driven approach to explain the relationships between context, mechanism and outcome. For example: what factors underpin the effectiveness of early warning systems in reducing vulnerability to tropical storms?

Multi-evidence-base approach. This is a structured process that emphasizes the importance of bringing together diverse knowledges (Indigenous, local, scientific) on a particular topic or question, where a joint assessment of knowledge provides a starting point for further knowledge generation[44,52]. It has been used within used within the context of IPBES assessments. For example: how are changing ice conditions affecting the food systems of Indigenous communities in the Arctic?

Structured expert judgement. This is one approach to systematically aggregating expert opinions based on a set of metrics or questions, often using a scoring system, involving individuals with relevant knowledge or expertise on the topic and incorporating a broad range of information types and sources[93]. This approach has been used for issues where there is significant complexity, uncertainty and/or data gaps[28,29,94,95], and can include a diversity of experts including scientists, Indigenous knowledge holders, community representatives and decision makers. For example: what is the state of progress on climate change adaptation in coastal regions?

Oxford Martin Restatements. This is a structured process that aims to assess the scientific evidence base underlying key policy issues[96]. The Restatement process convenes an author group chosen to represent different scientific points of view on a contested topic. A first draft evidence summary is then prepared for the topic in question, which is then debated via correspondence until a consensus is achieved. A near final draft is then sent to diverse stakeholders for comment. Results comprise a series of evidence statements that are categorized according to the nature of the underlying information (for example, uncontentious, strongly supported and so on)[97]. For example: to what extent can economic development offset the impacts of climate change on malaria transmission in sub-Saharan Africa?

Knowledge dialogues. These platforms or forums seek to exchange knowledge and synthesize understanding on a particular topic or question through the process of communication and exchange between people, groups or communities that come from different backgrounds or cultures[48,49]. For example: can Indigenous peoples' agricultural knowledge and practices build resilience to climate change impacts?

Circle of experts. This involves bringing together a diverse group of specialists, practitioners and rights- and stakeholders to collaboratively synthesize knowledge on a particular topic or question; insights are shared and debated and areas of consensus and disagreement are identified. It is particularly well suited to bringing together Indigenous knowledge holders and representatives in an ethical space for authentic dialogue guided by traditional and ceremonial protocols (for example, refs. 50,51,98) with synthesized knowledge shared via videos, stories and reports. For example: what aspects of biodiversity in a specific location are most at risk from climate change?

There will be cases where a question is synthesis ready in the sense that there is extensive knowledge but there are still considerable barriers to accessing this knowledge: for example, knowledge held by local communities, practitioners, Indigenous peoples, policymakers, in hard-to-access grey literature, stored behind paywalls, in different languages or in private sector reports that are not publicly available. In these cases, feasibility will depend on the ability of synthesis teams to collaborate with diverse knowledge holders and/or work with experts specializing in literature retrieval, requiring customized approaches relevant to the context. While this will probably be time consuming, they represent some of the most interesting and needed topic areas for knowledge synthesis. Consulting with a librarian and or knowledge synthesis 'expert' at the outset is important, especially for cases where knowledge is difficult to reach, while organizations such as Cochrane, the Campbell Collaboration and the Collaboration for Environmental Evidence, among others (for example, refs. 2,37), provide resources and guidance (Supplementary Table 1). Such experts include actors embodying and representing knowledge systems where the knowledge base is outside the traditional scientific domain[30].

Consider policy-relevant versus policy-prescriptive syntheses

CCAs are typically designed to inform policy and provide input to support decision-making, but vary in how they do this. The IPCC reports, for example, are expected to be "neutral with respect to policy" and are mandated to be policy relevant but not policy prescriptive[38], whereas national or sector-specific CCAs may make specific recommendations for action, rooted in evidence but taking a more proactive stance on particular policies. Authors conducting knowledge syntheses need to be aware of such guidelines, and—especially if seeking to inform IPCC assessments—it is important to consider and distinguish between policy-relevant and policy-prescriptive syntheses.

The distinction between assessment and prescription of policy response options is subtle but important[39]. Generally speaking, a policy-prescriptive approach would identify and justify one or more policy options that emerge as superior or more desirable from a process of critical appraisal. In contrast, an assessment (or policy-relevant) approach might systematically outline the ways in which multiple policy response options can be compared across a range of criteria (such as feasibility, acceptability, efficacy, impacts on equity), allowing the reader to infer the most appropriate choice[40] (that is, what is/could be); assess what policies work, in what context, for whom and why[13]; with results and conclusions linked to the underlying knowledge base (that is, line of sight), presenting the full breadth of evidence and not just consensus trends. Even where the initial analysis might be similar in both approaches, the presentation of results in a non-policy-prescriptive manner requires a greater degree of methodological transparency and systematic summary of a range of options and assessment criteria, rather than a judgement of the results.

Use the appropriate methodology for the question

There is a well-established corpus of tried and tested knowledge synthesis methodologies that can provide the basis for systematic, transparent, reproducible and defensible assessments of climate-relevant questions[2,22,41] (see Box 1 for some examples). The challenge is to find the most appropriate methodology for the focus[2]. Few of these methodologies in Box 1 have been widely used in a climate change context, underscoring the importance of capacity building and training around knowledge synthesis methodologies (Box 1 and 'Way forward').

It is important to be aware of the epistemological history of a particular methodology, how it has evolved and been applied for different questions, and be cognizant of established standards and protocols around terminology and if/how they may vary by discipline. Failure to do so can create confusion: for instance, outside the health sciences, some reviews may label themselves as 'systematic reviews' without adhering to established standardized protocols[22]. Yet, there is also a tension here across disciplines regarding the advantages and disadvantages of strict expectations of standardized methods and labelling of synthesis methods. On the one hand, the strict protocols expected within the health sciences establish standards and guidance that promote methodological rigour and minimize bias, setting a methodological bar for gold-standard knowledge synthesis. On the other hand, we have seen that systematic review/scoping/mapping standards can create a significant barrier to entry for teams seeking to engage in systematic synthesis approaches for climate change questions, with 'perfect' often the enemy of 'incremental' methodological progress. What is most important is the critical need for transparency around methodology, allowing readers and reviewers to assess the rigour and application of systematic approaches.

Each methodology will have its own general set of steps and procedures. At one end of the spectrum, systematized methodologies primarily use scientific documents (often, but not restricted to, peer-reviewed and scientific grey literature) as their knowledge base. This includes systematic reviews, evidence maps and meta-synthesis, among others, and typically follows key process steps including: (1) developing a systematic and transparent plan for how to identify, select, analyse and synthesize knowledge; (2) conducting a systematic and replicable search for chosen knowledge sources; (3) transparently selecting documents that are relevant to the synthesis question by applying clearly articulated criteria for which documents and other evidence sources are eligible for inclusion and exclusion; (4) critically appraising the quality of knowledge available; (5) systematically extracting key information (for example, by applying a questionnaire or survey); and (6) synthesizing information to identify novel insights using a transparent synthesis methodology. Again, transparency is critical in articulating how knowledge synthesis has (or has not) been implemented systematically and/or aligned with internationally accepted guidelines (for example, refs. 42,43), along with being clear about the caveats and risk of bias inherent in the chosen methods.

At the other end of the spectrum are methodologies that focus on the knowledges held by actors embodying and representing knowledge systems[30,44]. These methodologies respond to the need for increased emphasis on the inclusion of more diverse forms of knowledge (for example Indigenous knowledge, local knowledge), and the consideration of under-represented regions and groups in CCAs[7,45–47]. Such knowledges are frequently held by practitioners or within institutional/social memory and diverse formats (for example, grey literature, oral history) and are thus typically less accessible to CCAs, which tend to rely primarily on publicly available documents. However, overlooking them introduces a high risk of bias. Herein, being more inclusive of diverse forms of knowledge in CCAs is an increasing priority and methodologies including knowledge dialogues[48,49] (Box 2), circle of experts[50,51] and the multi-evidence-base approach[44,52], among others, have been developed to document and synthesize knowledges in a culturally respectful, robust and transparent manner. While these methodologies are not typically considered part of the conventional knowledge synthesis toolbox, they have been successfully applied to inform environmental change-focused assessments, providing access to the observations, testimonies, experiences and understandings of change, its impacts and responses that would otherwise be excluded. For instance, by focusing on the importance of cultural values, knowledge dialogues have identified how mainstream climate policies (for example, limiting meat consumption, promoting community relocation) may have repercussions for Indigenous peoples who depend on animals for their livelihoods, facilitating a more equitable and inclusive assessment of policy options.

The methodologies identified in Box 1 and considered so far are primarily relevant to questions around climate change impacts, adaptation, vulnerability and mitigation; that is, topics relevant to IPCC

https://doi.org/10.1038/s41558-025-02354-6

BOX 2

The use of dialogue methodologies in knowledge synthesis

Indigenous peoples are uniquely sensitive to climate change impacts and their accumulated knowledges and wisdom can help us better understand the challenges posed by climate change and how to respond[47,99]. The importance of including Indigenous knowledges and practices within CCAs has been long recognized, with early attempts to incorporate such knowledge including the Government of Canada's *Mackenzie Basin Impact Study*[100] and the *Arctic Climate Impact Assessment*[101]. For the IPCC, the importance of considering different knowledge systems was emphasized in AR5, with AR6 WGII explicitly capturing Indigenous understanding and voices and recognizing the importance of Indigenous knowledges for adaptation. Despite these developments, CCAs have been critiqued for only capturing Indigenous knowledges documented in the peer-reviewed literature; overlooking other sources of knowledge, including those captured in oral histories, traditions and testimonies; and adopting a predominantly science-driven worldview[102,103].

Responding to these challenges, global environment assessments—including IPBES and most recently the UN Environment Programme's GEO-7 assessment—have used dialogue approaches to mobilize, translate, negotiate, synthesize and apply Indigenous knowledges and perspectives within their reports[44,48,104]. Dialogues are a type of conversation based on trust that create opportunities to exchange different experiences and knowledges in a culturally appropriate environment, conducted according to principles of free prior and informed consent[49]. Within the IPBES and GEO-7 assessments, multiple dialogue sessions brought together participants from diverse Indigenous nations to share stories, knowledge, perspectives, actions, worldviews and concerns on environmental change, both with each other and with participating non-Indigenous researchers. Activities to structure these processes included small and larger group discussion sessions, visioning and storytelling, and participatory scenario planning, with emphasis on building mutual trust and confidence. In some instances, these dialogues were convened within Indigenous territories.

To facilitate mobilizing such knowledge into the assessment process, written records of the dialogue workshops were produced and published online (see refs. 105,106)—after approval by Indigenous people who participated—including documenting the oral testimony of participants, providing the necessary line of sight to the underlying knowledge base. While the IPBES and GEO-7 examples are not explicitly climate focused, and are not without their challenges[44,48,104], they nevertheless provide insights into how knowledge syntheses could more effectively engage diverse knowledge systems to inform CCAs.

WGII and WGIII. WGI also faces challenges in evidence synthesis to bring together heterogeneous data, including climate feedbacks and climate sensitivity; for example, synthesizing alternative approaches to information about the various drivers of sea-level change to produce integrated sea-level projections[53–55]. A key distinction is that WGI approaches are largely grounded in quantitative data sources and physically informed models, and are underpinned by quantitative, probabilistic approaches to synthesis. These include quasi- and Bayesian synthesis, forms of advanced meta-analysis and structurally informed quantitative syntheses that consider not only confidence but also likelihood. Diverging from this primarily quantitative epistemological basis, our focus on WGII and WGIII in this Perspective reflects recognition that relevant evidence, methods and epistemologies are frequently even more heterogeneous, and often cannot be synthesized in a robust manner using primarily quantitative approaches. In many ways, the topics relevant to WGII and WGIII are perhaps the most challenging for knowledge synthesis because of the dependence on multiple disciplines with different understandings of what counts as 'knowledge,' along with different disciplinary standards. The methodologies in Box 1 are also applicable, although potentially more tangentially so, for some questions related to the physical basis of climate change (that is, IPCC WGI)[28,53–55].

Consider using digital synthesis tools

There are various digital tools that can be used to collect, analyse and synthesize knowledge, with review management software, bibliographic databases and open meta-analysis software widely employed and considered standard practice[56,57]. More advanced applications of such tools include the use of machine learning and natural language processing (NLP) techniques, which are increasingly being employed in a climate change context[58,59] (Supplementary Table 2). Their popularity stems from their ability to rapidly locate, screen, classify and synthesize potentially hundreds of thousands of articles—although in practice, the largest-scale analyses use only titles and abstracts, not full texts, and can be prone to hallucinations. Even so, given the aforementioned rapid increase in the volume of literature, such tools are essential to enable the full breadth and diversity of a literature base to be considered in a transparent manner[58,59]. Digital synthesis tools are rarely a replacement for systematic knowledge synthesis, however, as the types of question that can be answered rely on patterns and trends that can be gleaned without assessment of full texts and without human review and interpretation of all documents. Digital technologies are advancing but are likely to provide a complement to, rather than a replacement for, traditional synthesis approaches[60].

Some of these machine learning and NLP tools are single purpose, helping to develop a search query or testing for the risk of bias, but there are a number of more general synthesis platforms too. More than 200 exist[56], but given the great variation in the goals of knowledge synthesis, as well as the lack of a unified metric for performance, it is difficult to say categorically which tool is best for any given context[61,62]. Commonly used platforms offer variety of functions, including 'priority screening' where once the user has provided a number of examples of the records to be included, artificial intelligence (AI) is used to place other records that are likely to be relevant at the front of the screening queue[63] (Supplementary Table 3). Priority screening in some cases can greatly reduce the time required for such 'needle in a haystack' problems and digital synthesis platforms are increasingly becoming more accessible to non-specialist users[64]. Other uses of machine learning and NLP include text classification, where documents or pieces of text can be classified according to a specific category using supervised and unsupervised machine learning approaches. Such classification approaches are also a core element of more recent approaches towards living evidence[19]. Living evidence maps and platforms, for example, have already shown considerable promise (for example, during the COVID pandemic[19]): a machine learning model is trained to identify and categorize relevant articles, which are then used to create an evidence map; when new articles are published, this is (automatically) fed to the same model, after which the map is updated. This means that the evidence map stays up to date and policy relevant for much longer, particularly for fast-moving fields of research such as climate change, although there are often trade-offs in terms of data quality and misclassification.

 https://doi.org/10.1038/s41558-025-02354-6

Not all applications will benefit equally from using such tools. Indeed, experience of applying machine learning and NLP has been mixed: while time savings are possible with digital synthesis tools, they are not always realized; some degree of technical literacy is needed alongside topical expertise to operationalize effectively; and while models are good at creating general overviews, critical assessment still remains extremely difficult and automated data extraction is mostly limited to specific fields and use cases[59]. The rapid advancements in AI will probably further reshape the knowledge synthesis landscape over the coming years, with some platforms using AI to automatically extract data (for example, Laser AI) and write summaries (for example, Consensus). Nevertheless, human–machine collaboration will still be key, as many of these applications have not yet been validated sufficiently[65]. Moreover, there is a need to build literacy within the climate research community in using such technologies, without which their power and pitfalls will be overlooked[59,66], along with the potential for creating "unjust disparities" in terms of who is involved in knowledge syntheses and what knowledges are considered[67].

Lastly, digital synthesis tools and the wider advances in AI could also increase the kinds of evidence considered, for example by making it much easier to incorporate non-English language records, oral evidence or unstructured data from sources such as municipalities or community organizations. Crucially, however, injudicious use of such tools risks worsening existing inequalities: in particular, the latest generation of AI models have large carbon footprints and many digital platforms require strong internet connections.

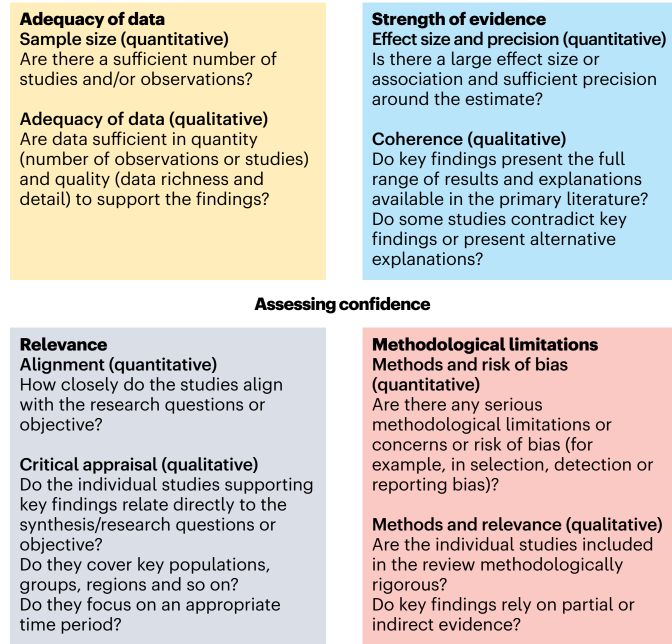

Fig. 3 | Key components for assessing confidence in evidence. Confidence can be assessed by drawing upon tools including GRADE-CERQual, the AACODS checklist (Authority, Accuracy, Coverage, Objectivity, Date, Significance) for grey literature and the mixed methods appraisal tool, among others.

Assess study validity and confidence

A shortcoming of many knowledge syntheses is a failure to consider the variability in study validity across the included knowledge base[41]. Research studies vary considerably in their risk of bias (internal validity due to (for example) issues with blinding and randomization in experimental research[68], a lack of baselines[69,70], emphasis on type I versus type II errors[71] or marginalization of non-Western knowledge systems[30]. There may also be misalignment in external validity (that is, generalizability) where a knowledge synthesis combines multiple types of research (for example plot-scale and landscape-scale studies). It is crucial that knowledge syntheses consider the internal (and often also the external) validity in accordance with the context in which they are generated. This may include, for example, making use of predefined and tested 'critical appraisal' tools to ensure construct validity and maximize procedural objectivity and repeatability[72,73] or assessing the processes through which diverse knowledges have been recognized, included and valued[30,74]. Importantly, syntheses must also do something with the outputs of this validity assessment. Studies can be excluded where the risk to the synthesis is unacceptable, and sensitivity analysis can be used in to examine the impact of excluding high risk or bias/low validity studies on the robustness of the synthesis findings[73].

More generally, an important but often neglected aspect of knowledge synthesis is the consideration of confidence in the underlying knowledge being synthesized—referring to the degree of certainty in the validity of a given finding(s) or conclusion(s). Some individual studies are less reliable due to methodological issues that can lead to inaccurate, biased and/or misleading findings if not accounted for[41,70], and can be problematic for topics and questions where the literature has limited methodological diversity or where important voices are not documented. For example, in their review of the impact of roads on sub-Saharan African ecosystems, Perumal et al.[75] found that the literature primarily reported simulation model results not based on actual field data, while Rebelo et al.[76] in their assessment of water-related ecological infrastructure investments to support sustainable land use found that most reported 'results' in the literature were not based on any empirical data but were propositional. In both cases, clear reporting on the methodological underpinning of the underlying knowledge base allows the reader to judge confidence. It should be noted that assessment of confidence is conducted after synthesis and key findings have been identified, and assesses the confidence in the individual findings emerging from the body of knowledge, not only individual papers or documents.

A diversity of frameworks and tools can be used or adapted for assessing confidence[77–79]. The IPCC, for example, uses guidance on the treatment of uncertainties[80] whereby calibrated language is used to qualitatively assess confidence based on the type, amount, quality and consistency of evidence and the degree of agreement among experts, and has been adopted for use in some published studies (for example, ref. 29), or quantitatively assesses the likelihood or uncertainty in a finding expressed probabilistically (based on statistical analysis). However, the IPCC assessment process fails to transparently justify or document line of sight for how individual confidence and likelihood statements are generated, and we argue would benefit from updating its guidance and protocols for calibrated language. For an evidence base with quantitative and homogeneous measures, there are relatively standard methodological approaches for assessing confidence in quantitative reviews, such as meta-analyses, which can provide estimates of precision, variance and confidence, as well as an assessment of the risk of bias. Assessments of confidence for qualitative or mixed and heterogeneous knowledge bases, however, are frequently overlooked despite well-documented tools and approaches such as GRADE-Cerqual[70].

We recognize that not all authors will have the time to undertake a formal assessment of confidence using a standardized protocol. Nevertheless, there is substantial added value if synthesis teams can provide an assessment of confidence or at minimum provide sufficient and traceable information underpinning their findings to assist CCAs in determining confidence. We encourage authors to become familiar with key aspects of confidence assessment (Fig. 3), including assessing and reporting on: the strength of the evidence, which relates to the extent that a synthesis finding is supported by the underlying knowledge base; methodological limitations, which refer to the constraints and potential weaknesses in the underlying knowledge base being evaluated that can affect the robustness of the findings;

relevance, which relates to how closely the knowledge base aligns with the synthesis question, capturing the extent to which the findings are directly applicable and meaningful to the topic under investigation; and data adequacy, which concerns not only how much evidence there is to support a particular finding, but also how much evidence varies or is consistent.

An additional challenge is that some CCA confidence statements can be interpreted quite differently depending on framing. For example, AR7 WGI concluded that "Considering only processes for which projections can be made with at least medium confidence, relative to the period 1995–2014, GMSL will rise ... by 2100 between 0.38 [0.28 to 0.55, likely range] m (SSP1 1.9) and 0.77 [0.63 to 1.01, likely range] m (SSP5 8.5)"[81]. However, WGI could also have concluded, with high confidence, that global mean sea level (GMSL) by 2100 will be less than 2.5 m. The former cited statement could be misinterpreted as excluding the possibility of GMSL rise in excess of 1.0 m (an interpretation that would be a false negative). The latter statement could also be misinterpreted as indicating that the GMSL rise of 2 m is as likely as GMSL rise of 1 m (an interpretation that would be a false positive). Both statements are consistent with the underlying evidence base; however, the interpretation varies depending on how the confidence statement is framed.

Communicate openly and transparently

It is important that synthesis teams follow principles of open science to promote integrity, reproducibility, transparency and trust across all aspects of knowledge synthesis[82,83]. Results and conclusions need to be linked to the underlying knowledge base, presenting the full breadth of evidence and not just consensus trends. Key components of open science in the context of knowledge synthesis[82] include:

- **Open methodology**: the methods used are fully reported so that the study can be understood and repeated where relevant, and readers can understand what was included (and what was not), how, when and where[84]. To assist in such transparency, we suggest that synthesis teams make relevant protocols accessible and consider publishing them before the research commences in online platforms and/or some journals that specialize in this (for example, *Campbell Systematic Reviews*, Protocol Exchange, PROSPERO, Joanna Briggs Institute)[78].
- **Open data**: all data and metadata are made available (for example, in annexes or supplementary information), including documentation of included and excluded documents (for example, European Open Science Cloud) or search tools (such as Google Dataset; https://datasetsearch.research.google.com/) to facilitate the search and reuse of existing data and transcripts and testimonials (with permission) where more qualitative methodologies are used.
- **Open source**: the code for tools used to synthesize information is provided in full.
- **Open access**: synthesized knowledge is freely available in open-access formats. Synthesis teams should also consider producing summaries that capture key results, as the technical language often used in peer-reviewed publications can limit uptake in decision-making. For example, the International Initiative for Impact Evaluation produces short and plain-language evidence impact summaries to demonstrate and encourage the use of evidence to inform programming and policy-making (for example, ref. 85), underpinned by a publication in a peer-reviewed journal. Similarly, the Priestley Centre for Climate Future's Climate Evidence Unit at the University of Leeds produces short evidence summaries on diverse climate-related topics and questions targeted at decision makers. Academic journals are also increasingly seeking to increase the accessibility of research by requiring non-technical summary statements (such as the 'Science for Society' summaries in *One Earth* or 'Research in Context' panels in *Lancet Planetary Health*).

Using visuals to present findings is also important. Assessments of large volumes of knowledge cannot be easily synthesized in text and still be accessible and understandable for diverse audiences. Communicating information and ideas using symbols and imagery is therefore increasingly important[86–88]. Considering visualizations at the start of knowledge synthesis will help guide the structuring of the assessment procedure and coding protocols to allow a more balanced representation of visuals. As different target audiences are sensitive to different types of visualization, careful and early consideration of what kind of visuals are best suited for the targeted audience, and potentially co-creating them, is required. Online tools such as EviAtlas[89] or the *IPCC WGI Interactive Atlas*[18,90] offer a new way for users to explore the results of knowledge synthesis.

Way forward

The explosion of the scientific literature on climate change and recognition of the importance of including diverse forms of knowledge has placed increasing pressure on those involved in CCAs. While challenges facing the IPCC are the best documented, assessments focusing on local to national scales, along with sectoral assessments, face similar challenges. Existing practices of conducting CCAs are no longer sustainable, even for many subcomponents of climate change, as the volume of literature continues to grow.

We argue that there is an important role for the scientific community in ensuring that credible, transparent, systematic and comprehensive assessments take place by conducting topical and regional knowledge synthesis that can feed into such assessments. Many of our recommendations here are about what researchers can do (and how), but advancing knowledge synthesis ultimately requires a much wider community effort. Scientific journals and their editors, for example, can adopt more rigorous standards and a deeper understanding of what constitutes knowledge synthesis, along with valuing the inclusion of more diverse forms of knowledge. Traditional literature reviews remain the norm, which can lead to misleading conclusions that can hinder effective policy-making and scientific progress. Setting clear criteria of what constitutes a high-quality knowledge synthesis, requiring registered protocols and including required methodological transparency in journal guidelines could be important steps.

Furthermore, reviewers could be more critical about whether the study meets the criteria set for knowledge synthesis, or reviewers with specific methodological skills such as information specialists could be a requirement for any knowledge synthesis paper. Similarly, funders of research should make placing the results of a study in an evidence repository a condition of receiving funding to enhance transparency and avoid duplication of research, and incentivize knowledge synthesis by providing dedicated funding There are several global and regional science synthesis centres that support teams of scientists to undertake knowledge synthesis work and can help support teams to bring together existing but disparate data, methods, theories and tools in new and unexpected ways. Examples include the African Synthesis Centre for Climate Change, Environment and Development in South Africa, the National Center for Ecological Analysis & Synthesis in the United States, Biodiversity and Ecosystem Services in Brazil and the Synthesis Centre for Biodiversity Sciences in Germany.

Robust primary studies are the backbone of meaningful knowledge syntheses but so far, the culture of knowledge synthesis is only slowly emerging. This needs to develop more quickly to keep informing governments, businesses and civil society about the best available knowledge on pressing sustainability challenges and possible response options. We hope that these recommendations are useful to start building such a culture and provide these actors with the best available knowledge to act.

References

1. Berrang-Ford, L. et al. Editorial: Evidence synthesis for accelerated learning on climate solutions. *Campbell System. Rev.* **16**, e1128 (2020).

2. Haddaway, N. R., Lotfi, T. & Mbuagbaw, L. Systematic reviews: a glossary for public health. *Scand. J. Public Health* **51**, 1–10 (2023).
   This paper develops a typology for choosing and naming review methods used with a focus on application in a public health context.
3. Haddaway, N. R. & Macura, B. The role of reporting standards in producing robust literature reviews comment. *Nat. Clim. Change* **8**, 444–447 (2018).
4. Surkovic, E. & Vigar, D. Scientific advice for policymakers on climate change: the role of evidence synthesis. *Phil. Trans. R. Soc. A* **380**, 20210147 (2022).
5. Donnelly, C. A. et al. Four principles for synthesizing evidence. *Nature* **558**, 361–364 (2018).
6. Nalau, J., Gilmore, E. & Howden, M. Improving adaptation assessment in the IPCC. *npj Clim. Action* **3**, 76 (2024).
7. Hughes, H. Actors, activities, and forms of authority in the IPCC. *Rev. Int. Stud.* **50**, 333–353 (2024).
8. Slade, R. et al. Back to basics for the IPCC: applying lessons from AR6 to the Seventh Assessment Cycle. *npj Clim. Action* **3**, 48 (2024).
9. Asayama, S. et al. Three institutional pathways to envision the future of the IPCC. *Nat. Clim. Change* https://doi.org/10.1038/s41558-023-01780-8 (2023).
10. Oppenheimer, M. et al. *Discerning Experts—The Practices of Scientific Assessment for Environmental Policy* (Univ. Chicago Press, 2019).
   The authors examine how environmental assessments are shaped by expert judgement, institutional norms and political contexts.
11. Callaghan, M. W., Minx, J. C. & Forster, P. M. A topography of climate change research. *Nat. Clim. Change* **10**, 118–123 (2020).
   This paper documents the massive expansion of scientific literature on climate change and the nature of the challenge facing global environmental assessments.
12. Khojasteh, D. et al. Climate change science is evolving toward adaptation and mitigation solutions. *Wiley Interdiscip. Rev. Clim. Change* https://doi.org/10.1002/wcc.884 (2024).
13. Sietsma, A. J. et al. Machine learning evidence map reveals global differences in adaptation action. *One Earth* **7**, 280–292 (2024).
14. Lamb, W. F., Creutzig, F., Callaghan, M. W. & Minx, J. C. Learning about urban climate solutions from case studies. *Nat. Clim. Change* **9**, 279–287 (2019).
15. Haddaway, N. R. et al. On the use of computer-assistance to facilitate systematic mapping. *Campbell System. Rev.* **16**, e1129 (2020).
16. Minx, J. C., Callaghan, M., Lamb, W. F., Garard, J. & Edenhofer, O. Learning about climate change solutions in the IPCC and beyond. *Environ. Sci. Policy* **77**, 252–259 (2017).
17. Dicks, L. V. et al. *Knowledge Synthesis for Environmental Decisions: An Evaluation of Existing Methods, and Guidance for their Selection, Use and Development* (EKLIPSE, 2017); https://researchportal.port.ac.uk/en/publications/knowledge-synthesis-for-environmental-decisions-an-evaluation-of-
18. Alegria, A. et al. Towards an IPCC Atlas for comprehensive climate change risk assessments. *npj Clim. Action* **3**, 108 (2024).
19. Elliott, J. et al. Decision makers need 'living' evidence synthesis. *Nature* **600**, 383–385 (2021).
20. Pearson, H. Scientists are building giant 'evidence banks' to create policies that actually work. *Nature* **634**, 16–17 (2024).
21. Berrang-Ford, L., Pearce, T. & Ford, J. D. Systematic review approaches for climate change adaptation research. *Reg. Environ. Change* **15**, 755–769 (2015).
   This study examines and illustrates how to conduct systematic reviews for adaptation-relevant questions.
22. Chigbu, U. E., Atiku, S. O. & Du Plessis, C. C. The science of literature reviews: searching, identifying, selecting, and synthesising. *Publications* **11**, 2 (2023).
   The authors focus in detail on the steps involved in literature reviews.
23. Bednar-Friedl, B. et al. *The Next Frontier for Climate Change Science: Insights from the Authors of the IPCC 6th Assessment Report on Knowledge Gaps and Priorities for Research* (eds Drabicka, K. et al.) (European Comission Directorate-General for Research and Innovation, Publications Office of the European Union, 202); https://data.europa.eu/doi/10.2777/34601
24. *Sixty-first Session of the IPCC 27 July–2 August 2024, Sofia, Bulgaria: Decisions Adopted by the Panel* (IPCC, 2024); https://www.ipcc.ch/site/assets/uploads/2024/08/IPCC-61_decisions-adopted-by-the-Panel.pdf
25. Collins, A., Coughlin, D. & Randall, N. Engaging environmental policy-makers with systematic reviews: challenges, solutions and lessons learned. *Environ. Evid.* **8**, 2 (2019).
26. Haddaway, N. & Crowe, S. Experiences and lessons in stakeholder engagement in environmental evidence synthesis: a truly special series. *Environ. Evid.* **7**, 11 (2018).
27. Pullin, A. S., Frampton, G. K., Livoreil, B. & Petrokofsky, G. (eds) *Guidelines and Standards for Evidence Synthesis in Environmental Management* Version 5.1 (Collaboration for Environmental Evidence, 2022); https://environmentalevidence.org/information-for-authors/
28. Kopp, R. et al. Communicating future sea-level rise uncertainty and ambiguity to assessment users. *Nat. Clim. Change* **13**, 648–660 (2023).
29. Magnan, A. K. et al. Sea level rise risks and societal adaptation benefits in low-lying coastal areas. *Sci. Rep.* **12**, 10677 (2022).
30. Milbank, C. et al. Rethinking hierarchies of evidence for sustainable food systems. *Nat. Food* **2**, 843–845 (2021).
31. Vijayan, D. et al. Indigenous knowledge in food system transformations. *Commun. Earth Environ.* **3**, 213 (2022).
32. Ford, J., Pearce, T., Canosa, I. & Harper, S. The rapidly changing Arctic and its societal implications. *Wiley Interdiscip. Rev. Clim. Change* **12**, e735 (2021).
33. *Alaskan Inuit Food Security Conceptual Framework: How to Assess the Arctic from an Inuit Perspective* (Inuit Circumpolar Council-Alaska, 2015).
34. Haddaway, N. et al. A framework for stakeholder engagement during systematic reviews and maps in environmental management. *Environ. Evid.* **6**, 11 (2017).
35. Methley, A., Campbell, S., Chew-Graham, C., McNally, R. & Cheraghi-Sohi, S. PICO, PICOS and SPIDER: a comparison study of specificity and sensitivity in three search tools for qualitative systematic reviews. *BMC Health Serv. Res.* **14**, 579 (2014).
36. Cooke, A., Smith, D. & Booth, A. Beyond PICO: the SPIDER tool for qualitative evidence synthesis. *Qual. Health Res.* **22**, 1435–1443 (2012).
37. *Evidence Synthesis for Policy: Statement of Principles* (Royal Society & Academy of Medical Sciences, 2018).
38. *Principles Governing IPCC Work* (IPCC, 2013).
39. Büntgen, U. The importance of distinguishing climate science from climate activism. *npj Clim. Action* **3**, 36 (2024).
40. Singh, C., Ford, J., Ley, D., Bazaz, A. & Revi, A. Assessing the feasibility of adaptation options: methodological advancements and directions for climate adaptation research and practice. *Climatic Change* **162**, 255–277 (2020).
41. Haddaway, N. R. et al. Eight problems with literature reviews and how to fix them. *Nat. Ecol. Evol.* **4**, 1582–1589 (2020).
   This study identifies and characterizes major pitfalls that should be avoided when conducting and reporting systematic reviews.

42. *Preferred Reporting Items for Systematic Reviews and Meta Analyses* (PRISMA, 2020); https://www.prisma-statement.org/
43. *RepOrting standards for Systematic Evidence Syntheses* (ROSES, 2024); https://www.roses-reporting.com/
44. Tengo, M. et al. Weaving knowledge systems in IPBES, CBD and beyond-lessons learned for sustainability. *Curr. Opin. Environ. Sustain.* **26–27**, 17–25 (2017).
45. Smith, H. A. & Sharp, K. Indigenous climate knowledges. *Wiley Interdiscip. Rev. Clim. Change* **3**, 467–476 (2012).
46. Mahony, M. & Hulme, M. Epistemic geographies of climate change: Science, space and politics. *Prog. Hum. Geogr.* **42**, 395–424 (2018).
47. Ford, J. D. et al. Including Indigenous knowledge and experience in IPCC assessment reports. *Nat. Clim. Change* **6**, 349–353 (2016).
48. McElwee, P. et al. Working with Indigenous and local knowledge (ILK) in large-scale ecological assessments: reviewing the experience of the IPBES Global Assessment. *J. Appl. Ecol.* **57**, 1666–1676 (2020).
49. *The Knowledge Dialogues Methodology* (Pan American Health Organization, 2022); https://doi.org/10.37774/9789275124703
50. McDowell, G. et al. *The Canadian Mountain Assessment* (Univ. Calgary Press, 2023).
This book is an example of a climate change assessment where Indigenous knowledge was incorporated from the beginning of the assessment process.
51. *We Rise Together: Achieving Pathway to Canada Target 1 Through the Creation of Indigenous Protected and Conserved Areas in the Spirit and Practice of Reconciliation: Indigenous Circle of Experts Report and Recommendations* (Government of Canada, 2018); https://publications.gc.ca/pub?id=9.852966&sl=0
52. Tengö, M., Brondizio, E., Elmqvist, T., Malmer, P. & Spierenburg, M. Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach. *AMBIO* **43**, 579–591 (2014).
The authors present an approach for connecting multiple forms of knowledge in environmental assessments.
53. Sherwood, S. et al. An assessment of Earth's climate sensitivity using multiple lines of evidence. *Rev. Geophys.* **58**, e2019RG000678 (2020).
54. Xu, B. & He, X. A physics-informed Bayesian storyline approach to assess sediment transport in the Mekong. *Wat. Resour. Res.* **58**, e2022WR032681 (2022).
55. Kopp, R. et al. The Framework for Assessing Changes To Sea-level (FACTS) v1.0: a platform for characterizing parametric and structural uncertainty in future global, relative, and extreme sea-level change. *Geosci. Model Dev.* **16**, 7461–7489 (2023).
56. Johnson, E., O'Keefe, H., Sutton, A. & Marshall, C. The systematic review toolbox: keeping up to date with tools to support evidence synthesis. *Syst. Rev.* **11**, 258 (2022).
57. Tsafnat, G. et al. Systematic review automation technologies. *Syst. Rev.* **9**, 74 (2014).
58. Debernardi, C., Seeber, M. & Cattaneo, M. Thirty years of climate change research:a fine-grained analysis of geographical specialization. *Environ. Sci. Policy* **152**, 103663 (2024).
59. Sietsma, A., Ford, J. & Minx, J. The next generation of machine learning for tracking adaptation texts. *Nat. Clim. Change* **14**, 31–39 (2024).
This Perspective offers an in-depth examination of how machine learning can be used to track adaptation progress, along with pitfalls and opportunities.
60. Binz, M. et al. How should the advent of large language models affect the practice of science? Preprint at https://arxiv.org/pdf/2312.03759 (2025).
61. Khalil, H. et al. Automation tools to support undertaking scoping reviews. *Res. Synth. Methods* https://doi.org/10.1002/jrsm.1731 (2024).
62. Affengruber, L. et al. Rapid review methods series: guidance on the use of supportive software. *BMJ Evid. Based Med.* **29**, 264–271 (2024).
63. Jimenez, R. et al. Machine learning computational tools to assist the performance of systematic reviews: a mapping review. *BMC Med. Res. Methodol.* **22**, 322 (2022).
64. Callaghan, M. & Müller-Hansen, F. Statistical stopping criteria for automated screening in systematic reviews. *Syst. Rev.* **9**, 273 (2020).
65. Muccione, V. et al. Integrating artificial intelligence with expert knowledge in global environmental assessments: opportunities, challenges and the way ahead. *Reg. Environ. Change* **24**, 121 (2024).
This study explores how AI can be used within global environmental assessments, illustrating how some processes can be automated and streamlined.
66. Debnath, R., Creutzig, F., Sovacool, B. K. & Shuckburgh, E. Harnessing human and machine intelligence for planetary-level climate action. *npj Clim. Action* **2**, 20 (2024).
67. Wells, S. Ready or not, AI is coming to science education—and students have opinions. *Nature* **628**, 459–461 (2024).
68. Schulz, K. & Grimes, D. Blinding in randomised trials: hiding who got what. *Lancet* **359**, 696–700 (2002).
69. McClenachan, L., Ferretti, F. & Baum, J. From archives to conservation: why historical data are needed to set baselines for marine animals and ecosystems. *Conserv. Lett.* **5**, 349–359 (2012).
70. Ford, J. D. Increasing trust in climate vulnerability projections. *Earths Future* **2**, e2023EF003655 (2024).
71. Lloyd, E. & Oreskes, N. Climate Change attribution: when is it appropriate to accept new methods. *Earths Future* **6**, 311–325 (2018).
72. Shea, B. et al. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. *BMJ* **358**, j4008 (2017).
73. Frampton, G. et al. Principles and framework for assessing the risk of bias for studies included in comparative quantitative environmental systematic reviews. *Environ. Evid.* **11**, 12 (2022).
74. David-Chavez, D. M. & Gavin, M. C. A global assessment of Indigenous community engagement in climate research. *Environ. Res. Lett.* **13**, 123005 (2018).
75. Perumal, L., New, M., Jonas, M. & Liu, W. The impact of roads on sub-Saharan African ecosystems: a systematic review. *Environ. Res. Lett.* **16**, 113001 (2021).
76. Rebelo, A., Holden, P., Esler, K. & New, M. Benefits of water-related ecological infrastructure investments to support sustainable land-use: a review of evidence from critically water-stressed catchments in South Africa. *R. Soc. Open Sci.* **8**, 201402 (2021).
77. Sprague, N. L. et al. The CHANGE (Climate Health ANalysis Grading Evaluation) tool for weight of evidence reviews on climate change and health research. *Environ. Health* **23**, 7 (2024).
78. Jager, N. W., Newig, J., Challies, E., Kochskämper, E. & von Wehrden, H. Case study meta-analysis in the social sciences. Insights on data quality and reliability from a large-N case survey. *Res. Synth. Methods* **13**, 12–27 (2022).
79. Eick, S. M., Goin, D. E., Chartres, N., Lam, J. & Woodruff, T. J. Assessing risk of bias in human environmental epidemiology studies using three tools: different conclusions from different tools. *Syst. Rev.* **9**, 249 (2020).
80. Mastrandrea, M. D. et al. *Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties* (IPCC, 2010).

81. Fox-Kemper, B. et al. in *Climate Change 2021: The Physical Science Basis* (eds Masson-Delmotte, V. et al.) 1211–1362 (IPCC, Cambridge Univ. Press, 2023).
82. Haddaway, N. Open synthesis: on the need for evidence synthesis to embrace Open Science. *Environ. Evid.* **7**, 26 (2018).
The author explores key principles needed to underpin open science in the context of evidence synthesis.
83. Nosek, B. et al. Promoting an open research culture. *Science* **348**, 1422–1425 (2015).
84. Chin, J., Growns, B., Sebastian, J., Page, M. & Nakagawa, S. The transparency and reproducibility of systematic reviews in forensic science. *Forensic Sci. Int.* **340**, 111472 (2022).
85. *Informing Rainfall Risk Insurance for Farmers in Gujarat, India*: *Evidence Impact Summaries* (3ie, 2021); https://www.3ieimpact.org/evidence-hub/Evidence-impact-summaries/strengthening-rule-law-and-justice-programming-usaid
86. de Bruin, W. et al. Improving figures for climate change communications: insights from interviews with international policymakers and practitioners. *Climatic Change* **177**, 57 (2024).
87. Harold, J., Lorenzoni, I., Shipley, T. & Coventry, K. Communication of IPCC visuals: IPCC authors' views and assessments of visual complexity. *Climatic Change* **158**, 255–270 (2020).
88. Haddaway, N. et al. EviAtlas: a tool for visualising evidence synthesis databases. *Environ. Evid.* **8**, 22 (2019).
89. Yoeli, H., Dhital, R., Hermaszewska, S. & Sin, J. A meta-ethnography of participatory health research and co-production in Nepal. *Social Sci. Med.* **301**, 114955 (2022).
90. *IPCC WGI Interactive Atlas* (IPCC, 2024); https://interactive-atlas.ipcc.ch/
91. Campbell, R. et al. Evaluating meta-ethnography: systematic analysis and synthesis of qualitative research. *Health Technol. Assess.* https://doi.org/10.3310/hta15430 (2011).
92. Pawson, R., Greenhalgh, T., Harvey, G. & Walshe, K. Realist review: a new method of systematic review designed for complex policy interventions. *J. Health Serv. Res. Policy* **10**, 21–34 (2005).
93. Magnan, A. K. et al. The value of structured expert judgment to help assess climate adaptation. *Clim. Risk Manage.* **47**, 100692 (2025).
94. Magnan, A. K. et al. Status of global coastal adaptation. *Nat. Clim. Change* https://doi.org/10.1038/s41558-023-01834-x (2023).
95. Mitchell, D. et al. Expert judgement reveals current and emerging UK climate- mortality burden. *Lancet Planet. Health* **8**, e684–e694 (2024).
96. *Oxford Martin Restatements* (Oxford Martin School, 2024); https://www.oxfordmartin.ox.ac.uk/publications/restatements
97. Jordon, M. W. et al. A restatement of the natural science evidence base concerning grassland management, grazing livestock and soil carbon storage. *Proc. R. Soc. B* **291**, (2024). https://doi.org/10.1098/rspb.2023.2669
98. *The White/Wiphala Paper on Indigenous Peoples' Food Systems* (FAO, 2021); https://doi.org/10.4060/cb4932eN
99. Petzold, J., Andrews, N., Ford, J. D., Hedemann, C. & Postigo, J. C. Indigenous knowledge on climate change adaptation: a global evidence map of academic literature. *Environ. Res. Lett.* **15**, 113007 (2020).
100. Cohen, S. *Mackenzie Basin Impact Study* 327 (Atmospheric Environment Services, Environment Canada, 1997).
101. *Arctic Climate Impact Assessment* (Cambridge Univ. Press, 2005).
102. Rashidi, P. & Lyons, K. Democratizing global climate governance? The case of Indigenous representation in the Intergovernmental Panel on Climate Change (IPCC). *Globalizations* **20**, 1312–1327 (2023).
103. van Bavel, B., Petrasek Macdonald, J. & Sambo Dorough, D. in *A Critical Assessment of the Intergovernmental Panel on Climate Change* (eds De Pryck, K. & Hulme, M.) Ch. 13 (Cambridge Univ. Press, 2022).
104. Hill, R. et al. Working with Indigenous, local and scientific knowledge in assessments of nature and nature's linkages with people. *Curr. Opin. Environ. Sustain.* **43**, 8–20 (2020).
105. *First Indigenous Knowledge and Local Knowledge Dialogue to Support the Preparation of the GEO-7 Assessment* (UNEP, 2024); https://www.unep.org/events/online-event/first-indigenous-knowledge-and-local-knowledge-dialogue-support-preparation-geo
106. *Indigenous and Local Knowledge Dialogue Reports* (IPBES, 2024); https://www.ipbes.net/ilk-dialogue-reports

Acknowledgements

We thank B. van den Hurk who commented on earlier versions of the paper. The work of J.D.F. was supported by UK Economic and Social Research Council (grant number ES/Z000114/1) and an ERC Advanced Grant (via the UKRI Horizon Europe guarantee scheme, EPSRC grant number EP/Z533385/1). The work of R.B. was supported through the Dutch Research Council (NWO grant number VI.Vidi.211.132). The work of J.C.M. and M.C. was supported by the European Research Council (ERC) under the European Union's Horizon 2020 Framework Programme as part of the project 'GeoEngineering and NegatIve Emissions pathways in Europe' (GENIE) (grant agreement number 951542) as well as the project 'Pathfinder 2: accelerating climate action for health' funded by the Wellcome Trust (project-ID 227165/Z/23/Z).

Author contributions

J.D.F., R.B., L.B.F., F.C., N.H., S.H., J.C.M., M.N., A.J.S., C.Z.-C. and M.C. conceptualized the Perspective. J.D.F. R.B. and L.B.F. wrote the original and final draft of the paper. J.C.M. and M.C. conducted analysis for Fig. 1. All authors provided input on the text.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41558-025-02354-6.

Correspondence should be addressed to James D. Ford.

Peer review information *Nature Climate Change* thanks Robert Kopp and Debora Ley for their contribution to the peer review of this work.