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Representation of adaptation in quantitative climate assessments

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Adaptation is a key societal response to reduce the impacts of climate change, yet it is poorly represented in current modelling frameworks. We identify key research gaps and suggest entry points for adaptation in quantitative assessments of climate change to enhance policy guidance.

Adaptation refers to the process by which societies adjust to existing and expected impacts of climate change[1]. Adaptation on the ground is determined by prevailing regional and contextual conditions, and shaped by diverse societal actors. The positive benefits of adaptation, such as risk reduction, vary greatly depending on enabling or constraining conditions, with effects usually seen at the local or regional level[1]. Unlike for mitigation (reducing greenhouse gas emissions), there is no universal metric to assess the wide range of adaptation outcomes. This makes it hard to gauge how effective adaptation measures are in response to different climate impacts in a quantifiable manner on an aggregate scale[2]. As a result, adaptation is poorly represented in global quantitative models used in climate research. Where adaptation is represented, it is either highly stylized or constrained to specific options in selected sectors[3]. As a consequence, there is limited global evidence on the costs and ability of adaptation to respond to mounting climate risks, which leads to an under-representation of adaptation when evaluating climate policy costs[4,5]. Moreover, there is a clear need to understand how adaptation and mitigation interact — the two policy strategies have mostly been investigated in isolation, including in IPCC reports.

There are two types of modelling approach typically used to assess future scenarios of climate change and its consequences that are relevant in the context of adaptation: climate impact models (CIMs) and integrated assessment models (IAMs). Both quantitative approaches are highly relevant to climate policymaking (Fig. 1). Here we reflect on the state of adaptation modelling, discuss possible improvements, highlight challenges and opportunities, and suggest future research needs.

Adaptation in CIMs

CIMs quantify the biophysical impacts of climate change, such as impacts on global agricultural production[6], using different emission and socioeconomic scenarios. While in reality adaptation plays a key role in reducing exposure and vulnerability to climate impacts, it is often not accounted for in climate impact analyses[1]. Some individual attempts have emerged to evaluate the biophysical potential for adaptation (for example, water potential for irrigation[7]) and efforts are underway to systematically improve the overall representation of adaptation in CIMs. The latest round of the Inter-Sectoral Impact Model Intercomparison Project ISIMIP3b (third simulation round, protocol b) is dedicated to quantifying climate-related risks under different socioeconomic conditions and levels of climate change, in both adaptation and no-adaptation scenarios[8]. However, the representation of adaptation will be limited to selected options, mostly focused on the agricultural sector (for example, fertilizer use), rather than capturing the full range of adaptation opportunities that could reduce climate impacts. A major aspect not accounted for in the analysis is societies' capacity to implement adaptation responses, such as education levels. Nevertheless, it seems inevitable to include adaptation in CIMs to improve understanding of the biophysical as well as the socioeconomic potential of adaptation.

Adaptation in IAMs

IAMs construct pathways to achieve different policy goals given varying constraints, such as emission reduction targets, and related economic implications[9]. There are two main groups of IAM: (1) cost–benefit IAMs (CB-IAMs) identify optimal mitigation levels by weighing up the costs and benefits of climate policies in a stylized, purely economic way; and (2) process-based IAMs represent sectors, such as energy and land use, in more detail and typically assess the cost-effectiveness of mitigation pathways (Fig. 1). Both adaptation and biophysical impacts are sparsely included in IAMs, and the challenges and opportunities for including adaptation will vary according to the focus and structure of the model.

Most CB-IAMs do not represent adaptation, as research on the costs and benefits of adaptation is still limited, and because capturing adaptation is generally complex. One of the first exceptions is the Adaptation in Dynamic Integrated model of Climate and the Economy (AD-DICE) model, where optimal adaptation is assumed across all sectors and directly implemented in the damage curve via a protection cost curve[10]. These efforts require a comprehensive aggregated quantification of adaptation costs, which is currently unavailable[11]. More recently, several studies have tried to evaluate adaptation in econometric assessments of climate change by assuming that individuals undertake adaptation investments until the marginal benefits and costs of adaptation are equal[12]. This would be one way to overcome the lack of bottom-up information on adaptation costs. It also increases the realism of aggregate econometric damage estimates, but these approaches are still in their infancy. The strong emphasis on economic optimization in CB-IAMs might make it more challenging to capture non-economic costs and benefits, such as levels of wellbeing, resulting from adaptation decisions and implementation constraints[13]. In addition, the current lack of representation of climate impacts according to different emission and warming scenarios will limit the capability of IAMs to fully represent the impact of adaption on reducing risk and assessing the associated costs.

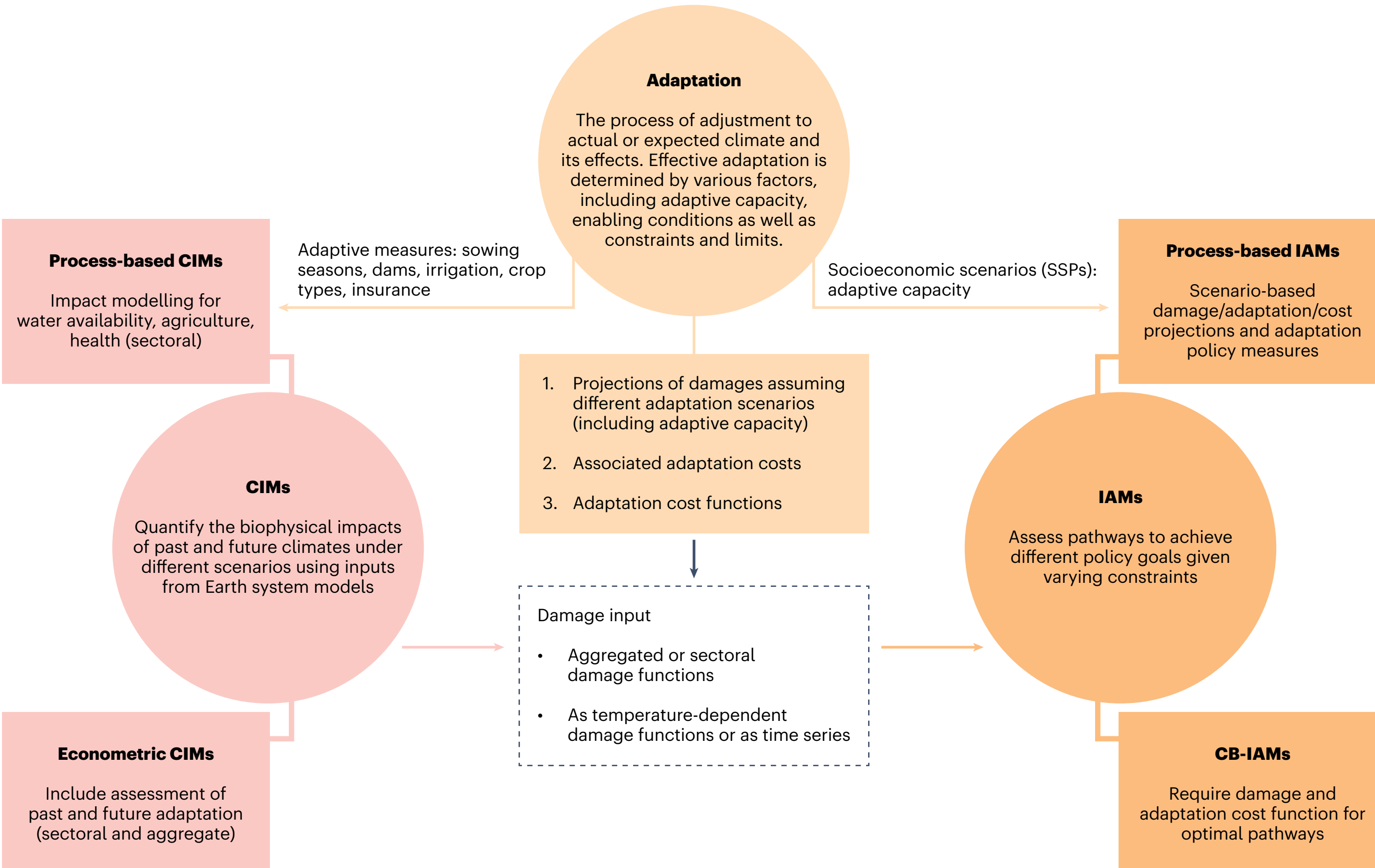

Fig. 1 | Concept of representing adaptation in global quantitative assessment of climate change.

Process-based IAMs, which have a more detailed sector representation, could enable the inclusion of biophysical impacts and adaptation in a more detailed way. This requires impact-specific information on the costs and effects of adaptation, as intended by the ISIMIP3b. Other approaches are emerging to support quantitative assessments of climate change adaptation at different scales[14]. One such approach would be via the Shared Socioeconomic Pathway (SSP) scenario framework, which is already an integral part of IAM work (Fig. 1). This framework can capture socioeconomic dimensions related to adaptive capacity, such as gross domestic product per capita, education and governance (M.A., manuscript in preparation). Representation of adaptive capacity within the SSPs has been demonstrated by developing projections for adaptation options in different sectors, such as air-conditioning[15] and sustainable irrigation[16]. However, sectoral applications are limited and do not provide a comprehensive cross-sectoral assessment of adaptation. There is a risk with the partial representation of impacts and adaptation that scenarios could be used inconsistently (inadvertently as either no-impact or full-impact/adaptation scenarios) by researchers and policymakers. It could also be difficult to show the urgency of local adaptation needs, as IAMs generally have a coarse spatial resolution. Nevertheless, process-based IAMs provide a unique and largely underexplored opportunity to investigate trade-offs and synergies between adaptation and mitigation (such as water-intensive mitigation efforts in water-scarce locations[17]) in a dynamic, intersectoral way.

Discussion and conclusions

Adaptation is a key factor in determining how detrimental climate change impacts will be for different population groups, sectors and regions. The IPCC's latest assessment report[1] finds that limits to adaptation will be reached with increasing warming, further demonstrating that implicit adaptation will not be enough to counter the mounting impacts of climate change. Understanding what adaptation can accomplish and how it interacts with mitigation strategies is key to develop successful climate strategies. Quantitative assessments of adaptation, integrated into projections of impacts and mitigation, will be decisive in building this understanding.

Featuring adaptation in CIMs in a systematic way across all sectors and scales should be a priority. While multiple approaches of including adaptation in quantitative assessments of climate change are possible, it is critically important to represent and understand adaptation in impact research first to enable a systematic inclusion of biophysical impacts and adaptation in IAMs as a second step. While efforts are underway within ISIMIP3b to systematically account for adaptation in different scenarios, it would be necessary to cover an increased number of sectors and adaptation measures closely linked to adaptive capacity to be comprehensive enough for IAMs. Nonetheless, there are steps that can be taken now to better represent adaptation in IAMs, such as the approach that links the socioeconomics of adaptive capacity to the SSP scenarios that the IAMs can process (M.A., manuscript in preparation). This could be one solution to constrain the possible scope of adaptation and avoid overestimating the potential for adaptation. While models might never be able to account for the full complexity that adaptation entails, they should aim for a limited representation that adequately represents the system for inclusion in a modelling context. Quantitative research around adaptation is increasing, yet important questions remain. For example, how do we account for adaptation choices on a global scale that are generally driven by local preference and value systems[18]? Overall, there is a clear need for different research communities to discuss and agree on a common strategy, joint definitions and scenarios, to enable common assessment and integration.

In general, it is important to be transparent about how comprehensive the models are to be certain if questions can be answered or not. The current absence of adaptation in most quantitative assessments of climate change, as well as the lack of a comprehensive representation of impacts in IAMs, limits understanding of the vulnerability of regions, countries and societies, and provides an incomplete picture of the overall scale of the climate challenge.

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References

1. IPCC: Summary for Policymakers. In *Climate Change 2022: Impacts, Adaptation and Vulnerability* (eds Pörtner, H.-O. et al.) (Cambridge Univ. Press, 2022).
2. Michaelowa, A. & Stadelmann, M. in *Adaptation Metrics: Perspectives on Measuring, Aggregating and Comparing Adaptation Results* (eds Christiansen, L. et al.) 63–72 (UNEP DTU Partnership, 2018).
3. Kondrup, C. et al. (eds) *Climate Adaptation Modelling* (Springer, 2022).
4. Holman, I. P. et al. *Reg. Environ. Change* https://doi.org/10.1007/s10113-018-1328-4 (2018).
5. Patt, A. G. et al. *Climatic Change* **99**, 383–402 (2010).
6. Jägermeyr, J. et al. *Nat. Food* **2**, 873–885 (2021).
7. Wang, X. et al. *Nat. Commun.* **12**, 1235 (2021).
8. Lange, S. & Büchner, M. ISIMIP3b bias-adjusted atmospheric climate input data (v1.1). *ISIMIP Repository* https://doi.org/10.48364/ISIMIP.842396.1 (2021).
9. Ackerman, F. et al. *Climatic Change* **95**, 297–315 (2009).
10. De Bruin, K. C. et al. *Climatic Change* **95**, 63–81 (2009).
11. New, M. et al. In *Climate Change 2022: Impacts, Adaptation and Vulnerability* Ch. 17 (eds Pörtner, H.-O. et al.) (IPCC, Cambridge Univ. Press, 2022).
12. Carleton, T. et al. *Q. J. Econ.* https://doi.org/10.1093/qje/qjac020 (2022).
13. Yoo, S. et al. *Econ. Disasters Clim. Change* **6**, 471–494 (2022).
14. Berrang-Ford, L. et al. *Nat. Clim. Change* **11**, 989–1000 (2021).
15. Andrijevic, M. et al. *Environ. Res. Lett.* **16**, 094053 (2021).
16. van Maanen, N. et al. *Environ. Res. Lett*. **17**, 075004 (2022).
17. Caretta, M. A. et al. In *Climate Change 2022: Impacts, Adaptation, and Vulnerability* (eds Pörtner, H.-O. et al.) Ch. 4 (IPCC, Cambridge Univ. Press, 2022).
18. Frankhauser, S. *Annu. Rev. Resour. Econ.* **9**, 209–230 (2017).

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Competing interests

The authors declare no competing interests.