






Towards an open model intercomparison platform for integrated assessment models scenarios

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The majority of scenarios in the IPCC database are generated by integrated assessment models (IAMs) and come from model intercomparison projects. However, the way in which the current model intercomparison projects are organized is not open to all IAM teams worldwide. Here we propose a transparent and inclusive platform that is open to anyone with an IAM regarding protocols development, scenario submissions and results evaluation. We discuss the challenges of this approach, particularly human resources and financial support. We identify diversity in the level of model capability and quality of model output as possibly critical issues. Despite such challenges, the IAM community and its scientific activities can improve and benefit from the proposed platform, ultimately contributing to better climate policymaking.

Long-term climate change mitigation scenarios have played vital roles in many aspects of climate change science. These scenarios are provided by integrated assessment models (IAMs), which are detailed numerical models that simulate anthropogenic components such as energy systems and land-use changes to explore future greenhouse gas emissions and climate outcomes¹. They explore possible quantitative pathways to attain climate goals and indicate possible societal directions and approaches for achieving desirable outcomes, and they assess technological, economic and/or societal implications with respect to

future climate change mitigation actions. In addition to mitigation studies, IAMs are frequently used to assess physical aspects of Earth's systems and climate change impacts and adaptations. Their societal influence has grown in recent decades via outlets such as the Intergovernmental Panel on Climate Change (IPCC; <https://www.ipcc.ch>), Network for Greening the Financial System (<https://www.ngfs.net/en>) and the United Nations Environmental Programme gap report. Climate policies that have already been pledged or implemented are critically investigated in conjunction with potential future outcomes.

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Three sets of scenarios produced by IAMs are used that are also compiled by the IPCC in its Sixth Assessment Report (AR6) database². The first set comprises climate research community scenarios that are used across working groups in the IPCC, including the Shared Socio-economic Pathways, Representative Concentration Pathways³, *Special Report of Emissions Scenarios*⁴ and IPCC scenarios (IS92)⁵. The second set of scenarios is generated under model intercomparison projects (MIPs), in which multiple models participate under common research protocols with specific research focuses^{6–8}. The third set consists of non-MIP-based individual studies, typically published as peer-reviewed research papers or reports. Regardless of the classification, all sets of scenarios are important for the advancement of scientific knowledge as well as IPCC work, including reports. Here we focus on MIP-based scenarios, as the majority of scenarios compiled by IPCC reports, including AR6, originated from MIPs, and they are highly influential in real-world climate-related decision-making. For example, 937 of 1,336 scenarios were submitted from MIPs in AR6⁹. This study reviews MIPs involved in IAM research in the past 40 years and explains the current organization of MIPs and potential issues, with a special focus on global studies. Finally, we propose an MIP platform restructuring of MIPs to improve their openness and transparency, followed by discussions on that platform.

MIPs role in global IAM studies

IAM MIPs compare model outputs and can be used to evaluate IAM outcomes¹⁰. MIPs have several roles and characteristics. First, they can provide robust findings when multimodel results agree on a specific aspect. The scenarios generated by an IAM depend on certain model assumptions, including model structure and basic parameter selections (such as elasticity parameters) and their future assumptions (for example, technoeconomic parameters¹¹). Because these assumptions can lead to bias in results derived from a single model, multimodel results can strengthen the reliability of the findings. Second, MIPs can provide a sense of the model uncertainty associated with multimodels; although not parametric, this information is valuable for determining the degree of certainty of the findings. Third, MIPs can provide an opportunity to improve models. For example, the results of an individual model can be compared with benchmark results from other models as a means of model evaluation. MIPs can highlight model outputs that have not yet been well investigated and/or addressed, which provides opportunities to review model structure and parameter assumptions through comparisons with other models' results. Fourth, MIPs can provide opportunities for individual and community-wide model improvement. Through MIPs, some models can learn from other advanced models and improve. Despite the need for caution when using MIP results, they add great value to the modelling process¹².

MIPs history

MIPs using IAMs have a long history¹³. In this Perspective, we address global MIPs that simulate global-scale analysis rather than that of specific regions or nations (Table 1). The early development of IAMs included World III¹⁴ and similar models in the 1970s, followed by Dynamic Integrated Climate–Economy (DICE)^{15,16} and the Edmonds–Reilly–Barns (ERB)¹⁷ models in the 1980s, which were the first generation of models to address energy systems and climate issues specifically. Around the same time, an energy modelling community began to emerge in the USA under the umbrella of the Stanford Energy Modelling Forum (EMF), whose first study was published in 1977. About 10 years later, the first model comparison study of IAMs was published¹⁸. Since then, the IAM community has been more active in conducting model comparison studies due to a combination of societal needs, growing interest in topics suitable for IAM analysis beyond simple climate-related issues (for example, land-use management), and advances in the academic field.

In the 1990s and 2000s, most MIPs were coordinated by the EMF, including regular global studies. These EMF studies actively continued

for more than 20 years, providing a solid basis for scientific advancement and community development. Since the late 2000s, European Union (EU)-based MIPs have been conducted more frequently, and in the 2010s these were the main drivers of IAM MIPs. Notably, agricultural MIPs have made important contributions in terms of the coordination of multiple IAMs and agricultural economic models from earlier 2010s focusing on agriculture and land use^{19–22} independent from the mainstream. The focus was not global, but there have been attempts to collect national scenarios as well^{23,24}. The details of history are further described (Box 1).

Current state of IAM MIP structure and concerns

The typical approach of the IAM community in conducting MIPs is as follows (Fig. 1). Note that not all past MIPs went through this process, but relatively recent MIPs normally follow this process. First, MIP organizers decide on the research topic, required scenarios and required variables. These are summarized into a scenario experimental protocol that is shared among the participants of the study who will implement the results of the IAM model runs. Then the MIP organizers assess the data and lead the publication of the results. The submitted data are disclosed to the public after the paper publication. The database is additionally made available to the IPCC for its assessments concerned with the IPCC context.

Although this overall process is mostly common among past MIPs conducted within the IAM community, the degree of openness differed slightly among the MIPs. For EMFs, participation of known IAMs was invited through the community network. Some modelling teams were supported by the US government as part of the EMF project, and other modelling teams were able to participate if they could finance their research activities with their own budgets.

Many MIPs organized by EU-funded projects have differed slightly from EMF MIPs. Specifically, teams are involved in the entire modelling process, from designing the protocol and implementing scenarios to analysing and publishing data. Practically, an essential requirement of EU-funded MIPs is that the modelling team, including non-EU partners, should be involved in the project consortium.

The European commitment to support modelling research has led to a concentration of studies with important consequences for the IPCC. In Chapter 3 of the AR6 by Working Group 3, a chart of scenarios contributed by each model in a series of MIPs (Fig. 3.1 in ref. 25) demonstrates that MIPs have been dominated by EU models fuelled by a large community of EU research framework programmes. The origins of various scenarios are mainly the European community (ENGAGE, EMF 36, COMMIT, CD–LINKS and ADVANCE), with minor exceptions (EMF 30 and EMF 33) (Fig. 3.2 in ref. 25). Notably, EMF 36 was led by a European research community and focused on economic aspects that generally did not involve IAMs. Although these findings highlight the great contributions of the EU in advancing MIP studies, they could be interpreted as evidence that specific regions dominate the views of the IPCC, or that the current diversity in international modelling capacity makes it difficult to attain a critical mass of models from non-dominant regions such as China, India and Brazil. Each of these perspectives may hold some truth; it is difficult to deny that there is a risk of bias in some climate change mitigation scenarios. These considerations are not limited to certain scenarios, but apply across climate research fields²⁶. Moreover, the diversification of participation in scenario development was frequently mentioned at the IPCC Workshop on the Use of Scenarios in the Sixth Assessment Report and Subsequent Assessments, held in April 2023 (<https://www.ipcc.ch>). Although the EU now leads the majority of IAM MIPs, current trends imply that the development of more open MIPs will yield a greater diversity of contributions than that shown in the AR6 (Fig. 3.1 in ref. 25).

Special attention should be paid to this opportunity for two reasons. First, the IPCC and its related scenarios have become extremely influential in international and national climate policymaking, which implies that applications of these scenarios are always at risk of bias. The scientific community should try to maintain diversity to the extent

Table 1 | Major global MIPs conducted within the IAM community

Year	Coordinating region	Title	Journal	Number of models	Reference(s)
2021	EU	ENGAGE: Exploring National and Global Actions to Reduce Greenhouse Gas Emissions	<i>Nature Climate Change, Nature Sustainability</i>	9	6–8
2020	EU	COMMIT: Climate Policy Assessment and Mitigation Modelling to Integrate National and Global Transition Pathways	<i>Nature Communications</i>	9	43
2018	EU	CD-LINKS: Linking Climate and Development Policies–Leveraging International Networks and Knowledge Sharing	<i>Nature Energy, Nature Sustainability</i>	6	44,45
2017	USA	EMF 33: Bio-energy and Land Use	<i>Climatic Change</i>	12	46
2017	USA	EMF 30: Short-lived Climate Forcers/Air Quality	<i>Climatic Change</i>	9	47
2017	EU	ADVANCE: Advanced Model Development and Validation for the Improved Analysis of Costs and Impacts of Mitigation Policies	<i>Nature Climate Change, Energy Economics</i>	7	48,49
2016	USA	LAMP: Latin American Model Intercomparison Project	<i>Energy Economics</i>	6	50
2014	EU	AMPERE: Assessment of Climate-Change Mitigation Pathways and Evaluation of the Robustness of Mitigation Cost Estimates	<i>Technological Forecasting and Social Changes</i>	11	51
2014	EU	LIMITS: Low-Climatic-Impact Scenarios and the Implications of Required Tight Emission Control Strategies	<i>Nature Climate Change, Climate Change Economics</i>	6	52,53
2013	USA	EMF 27: Global Model Comparison Exercise	<i>Climatic Change</i>	18	54
2013	EU	ROSE: Roadmaps toward Sustainable Energy Futures	<i>Climatic Change</i>	3	55
2012	EU	RECIPE: Report on Energy and Climate Policy in Europe	<i>Climatic Change</i>	3	56
2012	USA	AME: Asian Modelling Exercise	<i>Energy Economics</i>	19	57
2010	Japan	Marginal Abatement Cost study	<i>Sustainability Science</i>	3	58
2011	USA	EMF 25: Energy Efficiency and Climate-Change Mitigation	(Non-journal article)	10	59
2010	EU	ADAM: Adaptation and Mitigation Strategies Supporting European Climate Policy	<i>Energy Journal</i>	5	60
2009	USA	EMF 22: Climate-Change Control Scenarios	<i>Energy Economics</i>	10	61
2006	EU	IMCP: Innovation Modelling Comparison Project	<i>Energy Journal</i>	11	62
2006	USA	EMF 21: Multi-gas Mitigation and Climate Change	<i>Energy Journal</i>	19	63
2004	USA	EMF 19: Climate Change: Technology Strategies and International Trade	<i>Energy Economics</i>	14	64
1999	USA	EMF 16: Costs of the Kyoto Protocol	<i>Energy Journal</i>	13	65
1996	USA	EMF 14: Integrated Assessment of Climate Change	(Non-journal article)	4	66
1993	USA	EMF 12: Controlling Global Carbon Emissions—Cost and Policy Options	<i>American Economic Review</i>	10	67

possible. Second, future scenarios depend on assumptions made by scenario developers. The peer-review stage in the publication of an academic paper requires the justification of assumptions, but this does not guarantee that a study, or even a set of studies, represents the unbiased exploration of possible futures. Thus, climate change mitigation scenarios and IAM model structures involve and reflect scenario developers’ views or value judgements, which vary across cultures, values and social backgrounds.

IAM MIPs have grown in size and frequency, increasing the capacity of the IAM community and expanding its influence on policymaking. Existing MIPs have substantially contributed to the development of the IAM field over the past decade. Many IAM teams outside the EU and the USA have received direct or indirect benefits from their contributions. The current strategy is to govern MIPs in terms of the efficiency of the study; however, it would be better to reconsider the openness and transparency of IAM MIP structures regarding the IPCC AR7 cycle, which essentially leads inclusiveness of the entire scientific community.

The proposal and its procedures

Given this background, we propose a new approach and structure for the MIP style undertaken by the IAMs, to form a more open, transparent and inclusive research platform. Specifically, MIPs should be open to

anyone worldwide who handles IAMs, and the process from protocol development and scenario provision to scenario assessment should be conducted in consideration of openness and transparency. A good example of coordination in the climate research community is the Earth system model (ESM) community, which regularly conducts MIP work under the open umbrella of the Coupled Model Intercomparison Project (CMIP)²⁷. Although ESMs are more homogeneous than IAMs, many processes could be adopted from the internationally coordinated MIPs of the ESM community, with some customization for specific circumstances. The proposed platform consists of five steps (shown in the bottom of Fig. 1), some of which have been discussed earlier^{28,29}. As described in the following, the proposal is not limited to the data submission system but rather a comprehensive process on how to organize the entire MIP studies.

Make proposal and submit to central organization

An MIP abstract is submitted to the IAM MIP coordinating organization. Then the MIP coordination organization evaluates the MIP abstract on the basis of specified criteria²⁷; if the abstract is deemed valuable, then the organization endorses it. The abstract should include at least the main motivation and objective of the exercise, scenario design, minimum requirement in model representation (for example, land-use and

BOX 1

Detailed history of MIPs in the IAM community

In the 1990s, most IAM MIPs were conducted under the EMF, which regularly coordinated such global studies. EMF 14⁶⁶ was completed in 1996, followed by EMF 16⁶⁵, which was a substantial step forward in that the number of participating models expanded substantially, with participation from Australia, Europe and Japan. Since then, EMF global MIP studies have resulted in the construction of about 10–20 models worldwide. In the 2000s, three EMFs were developed: EMF 19, which focused on carbon constraints and advanced energy technologies⁶⁴, EMF 21, which dealt with climate stabilization scenarios considering non-CO₂ greenhouse gas emissions⁶³, and EMF 22, which examined degrees of participation in climate policy⁶¹. In addition, an MIP initiated by the EU-funded Innovation Modelling Comparison Project⁶⁸ focused on endogenous technological changes.

In the 2010s, MIPs continued under the umbrella of the EMF, including EMF 27, EMF 30 and EMF 33, which investigated the availability of technology⁵⁴ and the impacts of climate responses, focusing on short-lived gases⁴⁷ and the potential of bioenergy⁴⁶. Other MIPs conducted under EMF coordination included economic or non-IAM models such as EMF 36⁶⁹; however, these were not centred around IAMs. In parallel with these EMF activities, the 2010s represented a very different landscape for the IAM field, in which a number of model comparison studies were based on EU-funded projects, including Adaptation and Mitigation Strategies Supporting European Climate Policy in 2010⁶⁰, Report on Energy and Climate Policy in Europe in 2012⁵⁶, and Roadmaps toward Sustainable Energy futures in 2014⁵⁵. Long-term effects of delayed participation in climate mitigation, burden sharing and economic impacts were addressed

by Low-Climax-Impact Scenarios and the Implications of Required Tight Emission Control Strategies in 2014⁵² and the Assessment of Climate Change Mitigation Pathways and Evaluation of the Robustness of Mitigation Cost Estimates in 2014⁵¹. CD-LINKS studies during 2016–2019 and Advanced Model Development and Validation for the Improved Analysis of Costs and Impacts of Mitigation Policies (ADVANCE) projects during 2015–2018 produced the first MIPs under the 1.5°C target^{44,45,48}, focusing on investment, food security and residual emissions. ADVANCE placed special attention on renewable energy⁴⁹. In 2021, Exploring National and Global Actions to Reduce Greenhouse Gas Emissions (ENGAGE) addressed constraints on negative emissions and associated land-use-related impacts, and in 2020, Climate Policy Assessment and Mitigation Modelling to Integrate National and Global Transition Pathways (COMMIT) discussed the effects of nationally determined contributions and good practices⁴³.

During the 2010s, the Asian Modelling Exercise and Latin American Model Intercomparison Project were conducted with the support of the USA^{50,57}, focusing on specific regions within a global context, and the Marginal Abatement Cost comparison was led by Japan⁵⁸; the latter two projects were not supported by either the EMF or the EU.

There are also attempts to collect national scenarios, such as Linking Climate and Development Policies–Leveraging International Networks and Knowledge Sharing (CD-LINKS)^{23,24}, which included individual national scenarios^{70–76}, COMMIT⁷⁷, and the Deep Decarbonization Pathways Project. In addition, specific regions such as the European Union have developed regional MIPs^{78,79}.

energy system should have internal feedback), to judge whether the study is valuable and eligible to use resources of multiple IAM teams.

There should be a central organization that handles the overall IAM MIPs (including endorsement of MIP proposals), which would be equivalent to the World Climate Research Programme for the CMIP. The current Integrated Assessment Modelling Consortium (IAMC; <https://www.iamconsortium.org/>) could be a strong candidate as a corresponding organization in the IAM community, but others may be found to be more suitable. Special attention should be paid to the approval of MIP proposals, which should be inclusive and scientifically relevant. Furthermore, there should be some flexibility in this endorsement because if the standard is too strict, it will delay studies undertaken by IAMs.

Open the protocol and revise

The steering committee for each MIP writes the MIP protocol and makes it publicly available. For example, as CMIP does, IAM could also use a journal such as *Geoscientific Model Development*, but it is not necessarily limited to specific journals. The public review of the MIP protocol before its implementation would offer numerous advantages. First, it would leave room for improvement of the protocol, particularly by non-IAM modellers, who would have different perspectives from conventional IAM modellers. These external views may provide an opportunity to reconsider the proposal and make it more impactful. Second, individual modellers can check whether they can join or not, and if needed, they can request amendments to allow more models to participate. Third, it would enable IAM teams to plan their resource allocation or seek funding for their studies. Eventually, the IAM community would become more open, more transparent and better able to address critiques directed at it.

Implement protocol by IAMs and submit scenarios

Individual IAMs decide whether to join the MIP on the basis of their own criteria, and the model outputs are submitted to an IAM MIP database. There must be a data centre to compile IAM output information, to facilitate the MIPs that will be discussed at the next section.

Model registration is needed. At present, the International Institute for Applied Systems Analysis (IIASA) plays a central role in model registration, in conjunction with the data host. Rather than maintaining the current approach for IAM MIPs, it may be preferable to consider making model registration an independent function.

Another important element for this process is vetting (that is, quality checks). At present, a tripartite vetting procedure is being implemented in a subset of MIPs within the IAM community. One is to ensure consistency with historical records, which is relatively simple when comparing statistics for energy and agriculture. Another is the near-term feasibility of specific projects that are not amenable to drastic changes in the short term. For example, the construction of new nuclear power plants in the short term is strongly constrained by the current plan. The final one is to check the consistency among variables (for example, the additivity of variables between the total and the summation of subcategories). The IAM community can therefore build the vetting system on existing vetting processes. In the meantime, the quality checks would be dependent on MIPs and their primary focus. For example, if an MIP has a special focus on bioenergy, it would be natural to have more requirements for bioenergy-related variables than other focused MIPs. In addition to these vetting procedures, there should be further data checks, bug fixes and refinement of the scenarios, which have been also carried out by current MIPs conventionally. These steps would also play a role to bring opportunity to advance models.

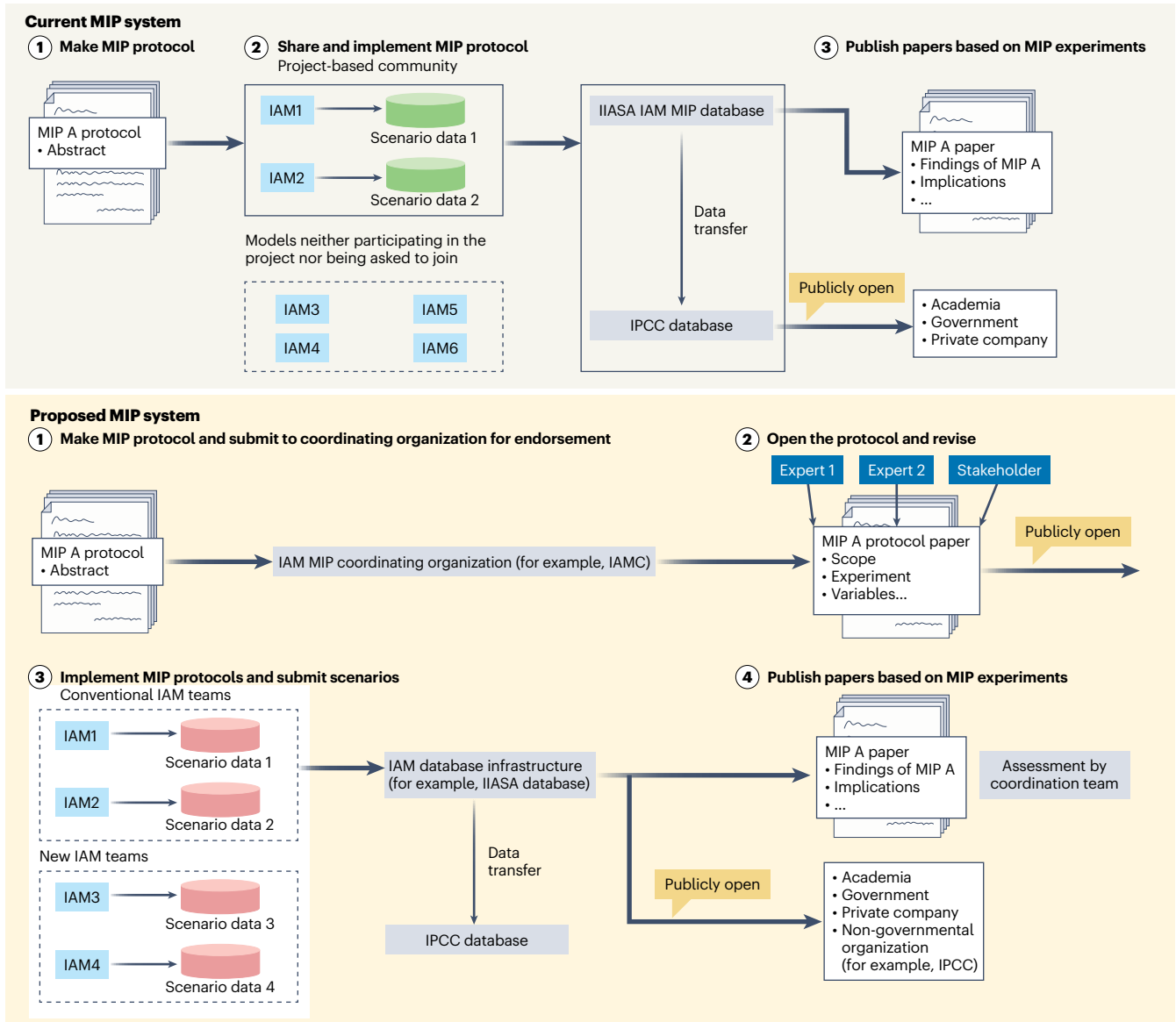


Fig. 1 | Current and proposed MIP systems for the IAM community. Top: current MIP system. Bottom: proposed MIP system.

Moreover, the standardization and automation of the vetting process would be key to keep the additional workload minimum level, and that is now an ongoing activity in the Scenario Compass Initiative (<https://scenariocompass.org/>), which will be available shortly.

Publish papers based on MIP experiments

Finally, the MIP steering committee writes a paper focusing on the proposed topic, and the data are released to the public after the paper is published, which should be informative to climate policymakers. The database can be transferred to IPCC if needed at this point.

Benefits and key feature of the proposed platform

The benefits of the proposed platform have already been perceived. First, the improved inclusivity of MIPs would allow IAMs that are currently unable to join MIPs to participate, which would provide broader perspectives, raise the capacity of such models within the research community and mitigate regional bias in IAMs. Second, researchers who were previously unable to join the IAM community would have new opportunities to do so and could leverage these opportunities to obtain funding in their own countries. Third, a public review of the MIP protocol in advance of model implementation would leave room

for improvement, particularly by non-IAM modellers, who would have different perspectives from conventional IAM modellers. Eventually, the IAM community would become more open, more transparent and better able to address critiques directed at it. Broadening participation could also lead to extending and enhancing the research agenda itself. While Zimm et al.³⁰ intensively discussed the importance, the research related to justice and inequality and its enhancement are still taken by developed countries. This proposal would further encourage the global south to take the initiative in such activities and establishing new relevant studies for the future. IPCC processes can directly benefit from this proposal, but this system can be easily extended to other topics and broader context. For example, nationally or regionally focused MIPs could be priorities, as well as MIPs not focused primarily on climate change, such as MIPs related to sustainable development, agriculture and technology diffusion under this platform.

Here maintaining flexibility could be critically important for considering the long-term shift of the community from the MIP proposal endorsement to the data publication rule. An IAM simulation requires fewer computational resources than an ESM, such that IAMs can make quick decisions and implement model runs that react to actual societal events. For example, some COPs may lead to international agreements

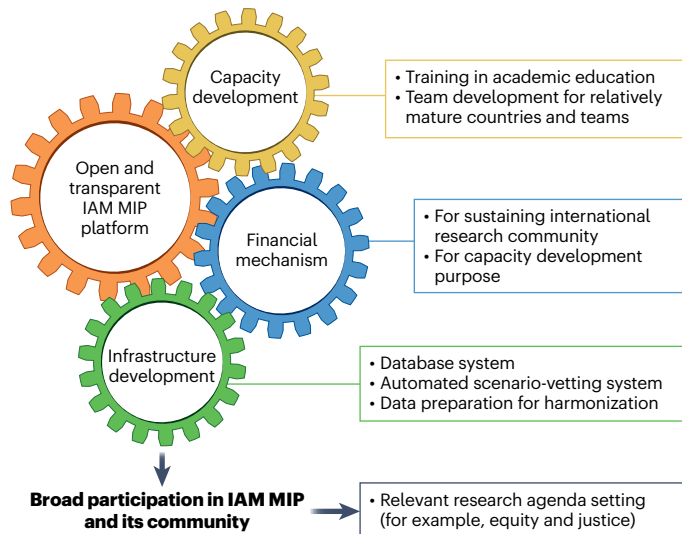


Fig. 2 | The relationship between this open and transparent IAM MIP platform and relevant supporting systems. Three relevant elements consist of multiple research community activities.

that have never been assessed by IAMs but would greatly benefit from such assessment. Under such circumstances, it would be natural to set up a corresponding MIP. The data publication rule can be similarly considered. Some MIPs need to have an urgent task to respond to actual societal demand (for example, assessment of the latest climate policies). In such cases, it would be beneficial to have flexibility here as well. Vetting criteria could be flexible depending on the MIPs and their objectives.

Challenges to increase participation

In the meantime, the proposed platform is not the perfect solution to the current situation. To comprehensively address the issue of inclusiveness in IAM scenarios, holistic approaches are necessary. At least three additional points can be highlighted, namely, capacity development, infrastructure development and financial support, which are further discussed in the following (Fig. 2). They are interlinked and enhance, support or catalyse the process through some relationship. The proposal in this Perspective could be a crucial trigger for enabling capacity development and financial support.

Capacity development

This proposal itself has a partial role in capacity development. Many IAM teams in the world have not been able to participate in previous MIPs. Providing more opportunities will facilitate engagement of many new modelling teams in climate policymaking in each country, which would help increase their chances for securing funding and human resources. As mentioned in the introduction, simply joining MIPs provides a great opportunity to improve models and advance modelling techniques.

However, there is no doubt that improvements in capacity building are essential to allow broader participation in the IAM MIPs. Meaningful MIPs are based on strong support and resources, which require sufficient investment and capacity to give modelling teams and countries sufficiently advanced IAMs. In the meantime, there should be a clear distinction between relatively mature and immature IAM teams. As comprehensively described by Fujimori et al.³¹, most capacity development activities have been focused on helping IAM teams in developing countries simply get started. For those regions that do not have a basis of the IAM modelling, conventional types of capacity development, such as educating and training models, play a vital role. Thus, long-term support for building capacity in the global south, with a particular focus on those countries and regions that currently have no or very

little capacity, is needed and ultimately depends on governmental and philanthropic funders.

However, while the primary concern in the past was to consider the broad participation of modelling teams from various regions in IAM MIPs, there are several well-recognized IAM teams in the global south, for example, in China and Brazil^{32,33}, that have relatively richer experiences and more time to be developed than others in the global south. For them, the proposed platform in this study would have a critical role, and in the meantime, the enhancement of team development and enforcement of modelling skills would be a critical element that would require sustained financial support and a team development plan within each country.

Infrastructure development

A data server or storage system would be needed. Although CMIP data are managed by multiple data centres³⁴, IAM outputs require a lower data-storage capacity than climate models, such that a single data centre may be sufficient. In the past, this role has been fulfilled by the IIASA, which may be sustainable for future IAM MIPs. The storage capacity required for ESM data outputs is very high; therefore, the CMIP has a specific data infrastructure³⁵, whereas IAM results could potentially be managed by a single institute. However, it would also be valuable to think about the redundancy and back-up options.

Some CMIP data preparation processes are commonly used in multiple MIPs, such as historical concentration data, air pollutant emissions³⁶, future emissions and land-use scenarios^{37–39}, which may also be required in IAMs, albeit less intensively. Such data preparation sometimes requires high-level model representation; support would be required for any models that cannot offer such representation. For example, few IAMs can fully represent all relevant greenhouse gas emissions, including non-CO₂, needed to run simplified climate models based on IAM scenarios. To address this issue, common emissions scenarios may be useful for supplementing scenarios for models that lack emissions from certain species, as observed in previous IPCC reports⁴⁰.

Financial support and mechanism

Governmental support is essential for sustaining activities relevant to IAM MIPs. In the ESM community, the World Climate Research Programme is supported by the governments of multiple countries and represents the foundation for all CMIP activities, whereas the IAMC is not. Although there are no specific funding mechanisms at this stage, there may be potential to have such ones if the scientific and societal demand is well recognized. In addition to a sufficient volume of financial support, funding sources should be diversified and should take into account the aim of avoiding bias among specific countries. Given the influence of the IAM scenarios and their value, we believe that this investment would be beneficial for the governments of many countries. While this type of investment would be necessary to sustain the research community, financial support for relatively immature modelling teams would also be required to develop the model and its associated teams, as mentioned earlier.

Final remarks

Overall IAM research activities could become less efficient because these types of community activities require substantial additional human and time resources. For example, the workload related to data quality control may be anticipated to pose many challenges. Thus, it may not be realistic to change the system directly and suddenly. Rather, we suspect that transition phases will eventually reach the inclusive community. It may be impractical for every MIP to be forced to follow the prescribed steps, such that some flexibility may be required. Moreover, if additional resources needed for this process cannot be obtained, the IAM community may have to reconsider its priorities and resource allocation strategy.

The IAM community has already initiated an attempt to create an open MIP for national scenarios. Specifically, the scenario protocol

to run national IAMs was posted openly on the IAMC website⁴¹, calling for scenario submissions; it was the first MIP to make such an open call in the IAM community, although the model coverage is national. Another example is CMIP7 ScenarioMIP⁴². As expected, there are many challenges to address during the timeline from setting up the protocol, database construction and model registration to obtaining scenario data. However, the community has made progress through learning by doing. The shift to open, transparent and inclusive MIPs should strengthen the IAM community, which must be able to inform climate change mitigation-related scientific knowledge better and thus contribute to improving climate policy and societal transformation towards climate neutrality.

References

- Weyant, J. Some contributions of integrated assessment models of global climate change. *Rev. Environ. Econ. Policy* **11**, 115–137 (2017).
- Byers, E. et al. *AR6 Scenarios Database hosted by IIASA* (IIASA, 2022).
- Vuuren, D. P. et al. The Representative Concentration Pathways: an overview. *Climatic Change* **109**, 5–31 (2011).
- Nakicenovic, N. et al. *IPCC Special Report on Emissions Scenarios* (Cambridge Univ. Press, 2000).
- Leggett, J. et al. Emissions scenarios for the IPCC: an update. *Climatic Change* **1040**, 75–95 (1992).
- Drouet, L. et al. Net zero-emission pathways reduce the physical and economic risks of climate change. *Nat. Clim. Change* **11**, 1070–1076 (2021).
- Hasegawa, T. et al. Land-based implications of early climate actions without global net-negative emissions. *Nat. Sustain.* **4**, 1052–1059 (2021).
- Riahi, K. et al. Cost and attainability of meeting stringent climate targets without overshoot. *Nat. Clim. Change* **11**, 1063–1069 (2021).
- Guivarch, C. et al. in *IPCC Climate Change 2022: Mitigation of Climate Change* (eds Shukla, P. R. et al.) 1841–1908 (Cambridge Univ. Press, 2022); <https://doi.org/10.1017/9781009157926.022>
- Wilson, C. et al. Evaluating process-based integrated assessment models of climate change mitigation. *Climatic Change* **166**, 3 (2021).
- Krey, V. et al. Looking under the hood: a comparison of techno-economic assumptions across national and global integrated assessment models. *Energy* **172**, 1254–1267 (2019).
- Guivarch, C. et al. Using large ensembles of climate change mitigation scenarios for robust insights. *Nat. Clim. Change* **12**, 428–435 (2022).
- Smith, S. J. et al. Long history of IAM comparisons. *Nat. Clim. Change* **5**, 391 (2015).
- Meadows, D. H., Meadows, D. L., Randers, J. & Behrens, W. W. III *The Limits to Growth Club of Rome* (Potomac Associates, Universe Books, 1972).
- Nordhaus, W. D. An optimal transition path for controlling greenhouse gases. *Science* **258**, 1315–1319 (1992).
- Nordhaus, W. D. Economic growth and climate: the carbon dioxide problem. *Am. Econ. Rev.* **67**, 341–346 (1977).
- Edmonds, J. & Reiley, J. *Global Energy—Assessing the Future* (Ballinger Publishing, 1985).
- Gaskins, D. W. & Weyant, J. P. Model comparisons of the costs of reducing CO₂ emissions. *Am. Econ. Rev.* **83**, 318–323 (1993).
- Fujimori, S. et al. Land-based climate change mitigation measures can affect agricultural markets and food security. *Nat. Food* **3**, 110–121 (2022).
- Hasegawa, T. et al. Risk of increased food insecurity under stringent global climate change mitigation policy. *Nat. Clim. Change* **8**, 699–703 (2018).
- Nelson, G. C. et al. Climate change effects on agriculture: economic responses to biophysical shocks. *Proc. Natl Acad. Sci. USA* **111**, 3274–3279 (2014).
- Stehfest, E. et al. Key determinants of global land-use projections. *Nat. Commun.* **10**, 2166 (2019).
- Schaeffer, R. et al. Comparing transformation pathways across major economies. *Climatic Change* **162**, 1787–1803 (2020).
- Schaeffer, R., Bosetti, V., Kriegler, E., Riahi, K. & van Vuuren, D. Climatic change: CD-Links special issue on national low-carbon development pathways. *Climatic Change* **162**, 1779–1785 (2020).
- Riahi, K. et al. in *IPCC Climate Change 2022: Mitigation of Climate Change* (eds Shukla, P. R. et al.) Ch. 3 (Cambridge Univ. Press, 2022); <https://doi.org/10.1017/9781009157926.005>
- Chavelli, F. & Connors, S. Analysis of the WGI contribution to the Sixth Assessment Report: review of the WGI AR6 references. *Zenodo* <https://doi.org/10.5281/zenodo.7615825> (2023).
- Eyring, V. et al. Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. *Geosci. Model Dev.* **9**, 1937–1958 (2016).
- Peters, G. P., Al Khourdajie, A., Sognaes, I. & Sanderson, B. M. AR6 scenarios database: an assessment of current practices and future recommendations. *npj Clim. Action* **2**, 31 (2023).
- Pirani, A. et al. Scenarios in IPCC assessments: lessons from AR6 and opportunities for AR7. *npj Clim. Action* **3**, 1 (2024).
- Zimm, C. et al. Justice considerations in climate research. *Nat. Clim. Change* **14**, 22–30 (2024).
- Fujimori, S. et al. A framework for national scenarios with varying emission reductions. *Nat. Clim. Change* **11**, 472–480 (2021).
- Zanon-Zotin, M. et al. Unaddressed non-energy use in the chemical industry can undermine fossil fuels phase-out. *Nat. Commun.* **15**, 8050 (2024).
- Jiang, K., He, C., Dai, H., Liu, J. & Xu, X. Emission scenario analysis for China under the global 1.5°C target. *Carbon Manag.* **9**, 481–491 (2018).
- Balaji, V. et al. Requirements for a global data infrastructure in support of CMIP6. *Geosci. Model Dev.* **11**, 3659–3680 (2018).
- Petrie, R. et al. Coordinating an operational data distribution network for CMIP6 data. *Geosci. Model Dev.* **14**, 629–644 (2021).
- Hoesly, R. M. et al. Historical (1750–2014) anthropogenic emissions of reactive gases and aerosols from the Community Emissions Data System (CEDS). *Geosci. Model Dev.* **11**, 369–408 (2018).
- Hurt, G. C. et al. Harmonization of global land use change and management for the period 850–2100 (LUH2) for CMIP6. *Geosci. Model Dev.* **13**, 5425–5464 (2020).
- Gidden, M. J. et al. Global emissions pathways under different socioeconomic scenarios for use in CMIP6: a dataset of harmonized emissions trajectories through the end of the century. *Geosci. Model Dev.* **12**, 1443–1475 (2019).
- O'Neill, B. C. et al. The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6. *Geosci. Model Dev.* **9**, 3461–3482 (2016).
- Kikstra, J. S. et al. The IPCC Sixth Assessment Report WGIII climate assessment of mitigation pathways: from emissions to global temperatures. *Geosci. Model Dev.* **15**, 9075–9109 (2022).
- Scientific Working Groups (SWGs) on national scenarios. *IAMC* <https://www.iamconsortium.org/scientific-working-groups/national-scenarios/> (2024).
- vanVuuren, D. et al. The Scenario Model Intercomparison Project for CMIP7 (ScenarioMIP-CMIP7). Preprint at *EGUsphere* <https://doi.org/10.5194/egusphere-2024-3765> (2025).
- van Soest, H. L. et al. Global roll-out of comprehensive policy measures may aid in bridging emissions gap. *Nat. Commun.* **12**, 6419 (2021).
- McCollum, D. L. et al. Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals. *Nat. Energy* **3**, 589–599 (2018).

45. Fujimori, S. et al. A multi-model assessment of food security implications of climate change mitigation. *Nat. Sustain.* **2**, 386–396 (2019).
46. Rose, S. K. et al. An overview of the Energy Modeling Forum 33rd study: assessing large-scale global bioenergy deployment for managing climate change. *Climatic Change* **163**, 1539–1551 (2020).
47. Smith, S. J. et al. The Energy Modeling Forum (EMF)-30 study on short-lived climate forcers: introduction and overview. *Climatic Change* **163**, 1399–1408 (2020).
48. Luderer, G. et al. Residual fossil CO₂ emissions in 1.5–2°C pathways. *Nat. Clim. Change* **8**, 626–633 (2018).
49. Luderer, G. et al. Assessment of wind and solar power in global low-carbon energy scenarios: an introduction. *Energy Econ.* **64**, 542–551 (2017).
50. van der Zwaan, B. C. C., Calvin, K. V. & Clarke, L. E. Climate mitigation in Latin America: implications for energy and land use: preface to the special section on the findings of the CLIMACAP-LAMP project. *Energy Econ.* **56**, 495–498 (2016).
51. Kriegler, E. et al. Making or breaking climate targets: the AMPERE study on staged accession scenarios for climate policy. *Technol. Forecast. Soc. Change* **90**, 24–44 (2014).
52. Tavoni, M. et al. Post-2020 climate agreements in the major economies assessed in the light of global models. *Nat. Clim. Change* **5**, 119–126 (2015).
53. Kriegler, E., Tavoni, M., Riahi, K. & Vuuren, D. P. V. Introducing The Limits Special Issue. *Clim. Change Econ.* **04**, 1302002 (2013).
54. Weyant, J. & Kriegler, E. Preface and introduction to EMF 27. *Climatic Change* **123**, 345–352 (2014).
55. Kriegler, E., Mouratiadou, I., Luderer, G., Edmonds, J. & Edenhofer, O. Introduction to the RoSE special issue on the impact of economic growth and fossil fuel availability on climate protection. *Climatic Change* **136**, 1–6 (2016).
56. Jakob, M., Luderer, G., Steckel, J., Tavoni, M. & Monjon, S. Time to act now? Assessing the costs of delaying climate measures and benefits of early action. *Climatic Change* **114**, 79–99 (2012).
57. Calvin, K., Fawcett, A. & Kejun, J. Comparing model results to national climate policy goals: results from the Asia modeling exercise. *Energy Econ.* **34**, S306–S315 (2012).
58. Berkhout, F., Marcotullio, P. & Hanaoka, T. Understanding energy transitions. *Sustain. Sci.* **7**, 109–111 (2012).
59. Huntington, H. *EMF 25: Energy Efficiency and Climate Change Mitigation* (Energy Modeling Forum, 2011).
60. Edenhofer, O. et al. The economics of low stabilization: model comparison of mitigation strategies and costs. *Energy J.* **31**, 11–48 (2010).
61. Clarke, L. et al. International climate policy architectures: overview of the EMF 22 International Scenarios. *Energy Econ.* **31**, S64–S81 (2009).
62. Grubb, M., Carraro, C. & Schellnhuber, J. Technological change for atmospheric stabilization: introductory overview to the Innovation Modeling Comparison Project. *Energy J.* **27**, 1–16 (2006).
63. Weyant, J. P., de la Chesnaye, F. C. & Blanford, G. J. Overview of EMF-21: multigas mitigation and climate policy. *Energy J.* **27**, 1–32 (2006).
64. Weyant, J. P. Introduction and overview. *Energy Econ.* **26**, 501–515 (2004).
65. Weyant J. P. The costs of the Kyoto Protocol: a multi-model evaluation. *Energy J.* **20** (special issue), vii–xliv (1999).
66. Richels, R., Edmonds, J., Gruenspecht, H. & Wigley, T. in *Energy and Environmental Policy Modeling International Series in Operations Research and Management Science Vol 18*. (ed. Weyant, J.) 67–83 (Springer, 1999).
67. Weyant, J. P. Costs of reducing global carbon emissions. *J. Econ. Perspect.* **7**, 27–46 (1993).
68. Edenhofer, O., Lessmann, K., Kemfert, C., Grubb, M. & Köhler, J. Induced technological change: exploring its implications for the economics of atmospheric stabilization: synthesis report from the Innovation Modeling Comparison Project. *Energy J.* **27**, 57–107 (2006).
69. Böhringer, C., Peterson, S., Rutherford, T. F., Schneider, J. & Winkler, M. Climate policies after Paris: pledge, trade and recycle: insights from the 36th Energy Modeling Forum Study (EMF 36). *Energy Econ.* **103**, 105471 (2021).
70. Köberle, A. C., Rochedo, P. R. R., Lucena, A. F. P., Szklo, A. & Schaeffer, R. Brazil's emission trajectories in a well-below 2°C world: the role of disruptive technologies versus land-based mitigation in an already low-emission energy system. *Climatic Change* **162**, 1823–1842 (2020).
71. Wang, H., Chen, W., Zhang, H. & Li, N. Modeling of power sector decarbonization in China: comparisons of early and delayed mitigation towards 2-degree target. *Climatic Change* **162**, 1843–1856 (2020).
72. Vishwanathan, S. S. & Garg, A. Energy system transformation to meet NDC, 2°C, and well below 2°C targets for India. *Climatic Change* **162**, 1877–1891 (2020).
73. Mathur, R. & Shekhar, S. India's energy sector choices—options and implications of ambitious mitigation efforts. *Climatic Change* **162**, 1893–1911 (2020).
74. Feijoo, F., Iyer, G., Binsted, M. & Edmonds, J. US energy system transitions under cumulative emissions budgets. *Climatic Change* **162**, 1947–1963 (2020).
75. Safonov, G. et al. The low carbon development options for Russia. *Climatic Change* **162**, 1929–1945 (2020).
76. Oshiro, K. et al. Mid-century emission pathways in Japan associated with the global 2°C goal: national and global models' assessments based on carbon budgets. *Climatic Change* **162**, 1913–1927 (2019).
77. Fragkos, P. et al. Energy system transitions and low-carbon pathways in Australia, Brazil, Canada, China, EU-28, India, Indonesia, Japan, Republic of Korea, Russia and the United States. *Energy* **216**, 119385 (2021).
78. Weyant, J., Knopf, B., De Cian, E., Keppo, I. & van Vuuren, D. P. Introduction to the Emf28 Study on Scenarios for Transforming the European Energy System. *Clim. Change Econ.* **04**, 1302001 (2013).
79. Böhringer, C., Rutherford, T. F. & Tol, R. S. J. The EU 20/20/2020 targets: an overview of the EMF 22 assessment. *Energy Econ.* **31**, S268–S273 (2009).

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Author contributions

S.F., V.K. and K.R. designed the research. S.F. wrote the first draft of the paper. All authors contributed to writing the paper.

Competing interests

The authors declare no competing interests.

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