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Navigating uncertainties: collaborative approaches to science-policy dialogues

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Science-policy dialogues are becoming increasingly relevant for guiding evidence-based action on complex environmental challenges, such as marine conservation. Yet, effective communication of scientific insights to policymakers remains difficult due to persistent uncertainties, complex problems, and the need for timely, actionable knowledge. This perspective paper explores the organization of effective science-policy dialogues, focusing on key challenges such as communicating uncertainty and establishing shared core messages. To address these challenges, we propose a structured approach that includes: (1) identifying specific policy information needs, (2) coordinating interdisciplinary, multi-institutional research teams, (3) tailoring scientific findings into clear, audience-focused core messages and options for actions, (4) conducting targeted dialogue events with policymakers, and (5) evaluating the dialogue process for continuous improvement. Drawing on experiences at the science-policy interface and case studies from German research institutions on sea-level rise and carbon dioxide removal, we present strategies for developing evidence-based core messages that resonate with policymakers. Our approach highlights the value of collaborative efforts among multiple research institutions, enabling a unified scientific voice that establishes both credibility and acceptance among policymakers. This upstream coordination process between different disciplines and institutions also improves the scientific quality of policy advice. Ultimately, this article advocates a structured, collaborative approach to science-policy dialogues, reinforcing the critical role of science in shaping robust, evidence-based environmental policy.

KEYWORDS

policy engagement, science-policy dialogue, parliamentary events, research synthesis, climate policy, science communication, knowledge transfer, scientific policy advice

1 Introduction

Science, through robust research outcomes, provides knowledge and valuable expertise to be integrated into policy processes. Simultaneously, science-policy dialogues have gained importance for addressing complex environmental issues (Tinch et al., 2018). However, many constraints hinder the direct integration of scientific findings into policymaking (Cash et al., 2003). It is commonly assumed that policymakers request evidence-based expertise, which is subsequently provided by scientists and ultimately transformed into

policy measures (Tinch et al., 2018). However, practical experiences indicate a more complex picture.

1.1 The challenges of academic policy engagement

Policymakers frequently require scientific findings that can be translated into concrete measures on short notice (Dilling and Lemos, 2011). In contrast, scientific studies often address narrowly defined research questions with limited relevance to broader policy debates. Further, such research outputs are generally published in specialized academic journals and the rapidly growing number of scientific publications (Bornmann and Mutz, 2015) makes it increasingly difficult to identify relevant information. From the perspective of the scientific community, synthesizing findings across multiple studies to produce robust conclusions tends to be resource-intensive and may not fit within standard academic reward structures, although high-profile initiatives, including the Intergovernmental Panel on Climate Change (IPCC), show that large-scale efforts to consolidate research findings can gain widespread recognition. From the policy perspective, however, the time required to produce inter- and transdisciplinary synthesis products often does not align with fast-paced policy agendas and the legislative or regulatory window of opportunity might be closed once syntheses are published. Many of these obstacles are heightened for multifaceted policy problems which commonly stretch across disciplines, involve multiple uncertainties, and do not yield to straightforward technical solutions.

However, policy measures tend to gain broader acceptance in contemporary democracies when grounded in scientific evidence (Jasanoff, 2005).

1.2 Established solutions and approaches from the literature

The Multiple Streams Framework (Kingdon, 2013) proposes that problems, potential solutions, and political contexts must converge before policy reforms can advance. Scientific insights hold influence when they address recognized challenges and fit established institutional structures. However, research by Freeman (2010) and Pierson (1993) indicates that political hesitation, competing interests, or inadequate resources can hinder even well-founded proposals, demonstrating how entrenched systems may resist recommended changes.

What is often described as "co-production" might reduce the gap between researchers and policymakers (Jasanoff, 2004) by enabling repeated discussions that establish a common understanding, jointly define objectives, and interpret evidence in a collaborative manner. This process is consistent with other published concepts like resilience thinking (Folke et al., 2010) and anticipatory governance (Quay, 2010), both of which emphasize flexible methods that address evolving conditions. These approaches acknowledge the complexity of policymaking (Weingart and Lentsch, 2008), consider possible long-term risks at an early stage, and promote cooperative solutions. Further, Weingart and Lentsch (2008) suggest that so-called 'mixed committees', consisting of researchers, industry representatives, and non-governmental organizations (NGOs), can guide governance by integrating specialized knowledge with societal concerns. Inter- and transdisciplinary experts can thus contribute both technical reliability and societal legitimacy in the policy engagement process. This indicates that research-based insights must be part of adaptive decision-making to remain effective under shifting conditions. While such processes are commonly framed as co-productive, the degree of mutuality and shared authority involved may vary considerably in practice. Co-production thus represents a promising approach—but not a universally applicable solution—for bridging science and policy under complex and dynamic conditions.

Close collaboration between researchers and policymakers does not in itself resolve the persistent difficulty of addressing uncertainty inherent in scientific knowledge. Uncertainty arises not only from limitations in data and models but also from differing interpretations and disciplinary perspectives. It also stems from the evolving nature of the problems under consideration. In climate-related fields, uncertainty is particularly challenging because it origins from various sources, such as natural internal climate variability, how models represent complex processes like cloud formation and ocean-atmosphere dynamics, the choice of model parameters, and assumptions about future greenhouse gas emissions. Communicating these uncertainties without undermining credibility is a key task in science-policy dialogues (Manski, 2019; Spiegelhalter et al., 2011). Woods et al. (2025) suggest that uncertainty can be made more accessible to the public by presenting it in familiar contexts. For example, they link climate projections to well-known British cultural and sporting events, such as the London Marathon and Glastonbury Festival. This connects abstract climate impacts to everyday reference points. Parliamentary technology assessment offers another avenue for continuous dialogue between science and policy under conditions of uncertainty and evolving political demands. By organizing research-based advice directly within legislative bodies, parliamentary technology assessment supports public debate and helps legislators make more informed decisions (Grunwald, 2011, p. 35). By combining analytical rigor with responsiveness to evolving legislative demands, technology assessment initiatives can embed scientific perspectives more systematically in the policymaking process and help reduce the fragmentation often associated with complex, multi-level governance (Grunwald et al., 2012). Omstedt, (2024) extends this idea by emphasizing the integration of scientific knowledge with broader value systems and creative thinking. He argues that empathy, curiosity, and collaborative engagement are essential for addressing complex ocean-related challenges. Such perspectives parallel co-production (Jasanoff, 2004) in highlighting the cultural and ethical dimensions of policymaking.

This perspective article draws on experiences from German research institutions in conducting science-policy dialogues on relevant societal problems, such as sea-level rise and carbon dioxide removal. We propose a structured, collaborative approach for science-policy dialogues that explicitly addresses scientific uncertainties, based on early discussions between scientists and policymakers to align scientific findings with legislative timelines and decision points, increasing the likelihood that results will be reflected in actual policy outcomes.

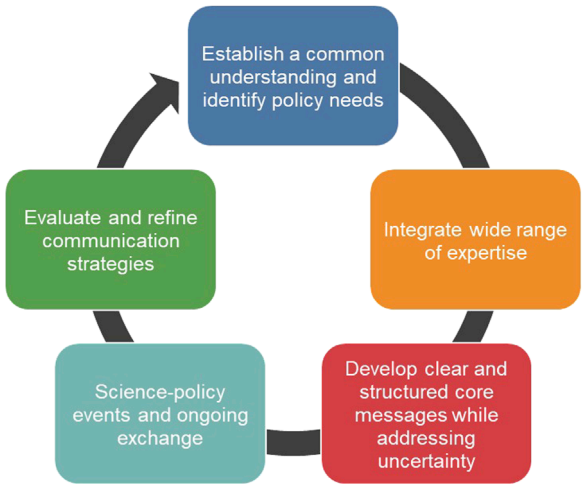

FIGURE 1
The Science-Policy-Cycle. Key requirements for a successful science-policy dialogue based on our proposed approach. After Ojha et al. (2020).

2 A structured collaborative approach for science-policy dialogues

To address the challenges of academic policy engagement, we propose a framework based on five principal steps: 1) identifying policy information needs, 2) coordinating multi-institutional research teams, 3) adapting inter- and transdisciplinary findings into clear core messages and options for action while addressing uncertainties, 4) conducting dialogue events with policymakers at pivotal moments in the political process, and 5) evaluating the science-policy dialogue to enhance future collaborations (Figure 1).

This framework draws on ideas from published approaches and emphasizes early collaboration, transparent communication of findings including uncertainties, and continuous feedback. It highlights the value of connecting scientists and policymakers to surface shared concerns and ensure research is presented at a time when it can genuinely inform legislative or administrative processes.

It is important to recognize that organizing and sustaining continuous science-policy interactions requires skills that differ from the typical academic repertoire. Such work is not part of regular academic roles, nor can most researchers reasonably be expected to take it on in addition to staying current with developments and publications in their own disciplines. Facilitating dialogue across diverse groups, navigating complex political environments, and translating knowledge into policy-relevant language require specialized experience typically found in professionals working at the intersection of science and policy. Therefore, universities and research organizations must consider establishing permanent structures that support long-term engagement with political decision-making in the spirit of evidence-informed policy. This could entail establishing liaison offices in political centers or collaborating through umbrella organizations, depending on institutional resources. In either case, it is crucial that these structures be staffed by individuals who understand both the workings of policy and the language of science.

To illustrate the application of our approach, we briefly introduce two case studies, namely, parliamentary breakfasts on i) sea-level rise and ii) carbon management. i) Sea-level rise is a pressing global issue with significant local implications for Germany's coastal regions. Understanding and preparing for its impacts requires integrating knowledge from polar research, oceanography, geology, and coastal engineering. ii) Germany's goal of achieving climate neutrality by 2045 requires not only reducing emissions, but also implementing negative emission technologies. Carbon management measures like Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Capture with Carbon Storage (DACCS) are critical components. Using these two examples, we show in the following sections how structured interactions can improve communication between scientists and policymakers, address uncertainties, and contribute to informed policy decisions.

2.1 Clarifying expectations and identifying needs (step 1)

Building on the idea that effective science-policy communication benefits from early dialogue and mutual understanding, we propose engaging in consultations with policymakers and ministry officials in advance of parliamentary events to identify mutual interests and questions, e.g., in the form of informal exchanges or synthesis workshops, allowing scientists and policymakers to discuss pressing issues and determine knowledge gaps, potential legislative initiatives, and what is relevant for federal politics.

With this approach, agenda setting becomes a collaborative process, ensuring that the discussions are relevant, timely, and focused on actionable insights (Young et al., 2014). Co-design involves scientists and policymakers working together to shape the agenda, content, and format of the event. This collaboration increases the likelihood that the information presented will be utilized in policy formulation and implementation, as it aligns with policymakers' needs and priorities.

In preparation for the two science-policy events discussed, we spoke directly with Members of Parliament through brief calls and informal conversations to understand their current policy priorities. These insights guided the agenda and helped to design pre-event synthesis workshops with researchers from various Helmholtz Centers. This ensured that the scientific input was relevant and grounded in actual political debates. The participating parliamentarians appreciated the opportunity to articulate priorities related to upcoming legislation, such as the Climate Adaptation Act (KAnG) and the German Long-term Strategy Negative Emissions, ensuring a more focused policy-relevant discussion. Although this was not a fully co-creative process, we included co-creative elements by discussing politically relevant issues with parliamentarians, parliamentary advisors, and ministry officials during preparatory synthesis workshops before the main events. We also held extensive conversations with the parliamentary patrons of the events and their staff. They were particularly committed to ensuring that our research would contribute to ongoing political discussions. These efforts kept

the scientific discussions closely tied to current policy debates and gave key political actors a stake in the process.

2.2 Finding suitable partners to present the best available expertise beyond institutional borders (step 2)

Given that relevant expertise is generally distributed across multiple institutions and disciplines, science-policy dialogues benefit substantially from a collaborative effort. Collaborating with research institutions and non-scientific stakeholders enhances the practical feasibility and increases the likelihood that policymakers will accept and act on the communicated key messages.

Including multiple research institutions and diverse expertise not only reduces the risk of a narrow perspective, but also supports a more structured synthesis of research.

Coordinated messages increase scientific independence, in contrast to some experts in parliamentary committees who are appointed by individual parties or groups. Generally, policy decisions benefit from integrating insights across multiple disciplines, promoting more balanced decision-making, as became clear during COVID-19 (Kraemer and Medzech 2023).

We therefore recommend cross-institutional collaboration at the science-policy-interface. This leads to dialogues that aim not primarily to cast a single institution in a favorable light in the sense of public affairs, but rather to bring the best available expertise from a range of different institutions into dialogue with policymakers. A further distinction from traditional lobbying is that the organizers do not derive any direct monetary benefit if their recommendations are followed.

For the sea-level rise event, researchers from Alfred-Wegener-Institute (AWI), GEOMAR Helmholtz Centre for Ocean Research Kiel, GFZ Helmholtz Centre for Geosciences, and Helmholtz-Zentrum Hereon convened regularly in virtual sessions and on-site workshops to integrate a broad range of expertise. They examined the various aspects of sea-level change: i) its sources (melting ice masses in the Arctic and Antarctic, AWI) and ii) transport pathways (warming oceans, changing ocean currents, GEOMAR), iii) the global dimension (rising sea levels and land subsidence, GFZ), and iv) the impacts on coasts (significance for German North and Baltic Sea coasts in terms of storm surges, coastal protection, inland drainage, and water supply, Hereon).

For the carbon management breakfast, experts from the federal research program CDRterra/Ludwig Maximilian University of Munich, Karlsruhe Institute of Technology, GFZ, and Helmholtz Centre for Environmental Research (UFZ) came together. They i) introduced carbon dioxide removal (CDR) methods and emphasized the need for a broad portfolio of CDR measures to reach CDR goals, spread risks, and increase acceptance, ii) discussed potential integration of bioenergy with carbon capture and storage (BECCS) into existing bioenergy infrastructure and the political requirements for implementation, iii) covered technological developments, challenges, cost considerations, and scaling potential of direct-air capture (DAC) technologies, and iv) addressed CO_2 storage potentials, particularly under the North Sea, and regulatory needs.

2.3 Research synthesis to develop clear core messages and options for action while addressing uncertainties (step 3)

Effective policy advice depends on synthesizing diverse research findings into clear core messages and coherent, accessible recommendations. Such key messages are crucial for all science-policy formats, including parliamentary events, statements in expert committees, fact sheets, and policy briefs.

A fundamental challenge in science-policy interaction is, however, the communication of uncertainty. Policymakers often require clear, actionable information to support decision-making, whereas scientists emphasize the limitations inherent in research findings. They may be reluctant to provide definitive figures due to (statistical) variability in study outcomes and concerns regarding the political implications of uncertain data. This difference in communication strategies can lead to a communication gap, in which scientific caution is interpreted as a lack of knowledge (Wynne, 1992). This hesitancy can result in a lack of clear guidance for policymakers, ultimately limiting the effectiveness of science-based policy advice.

Scientific uncertainty arises from multiple sources, including methodological constraints, data limitations, and the complexity of natural and social systems. For example, in Earth sciences, uncertainties stem from factors such as climate variability, geological processes, and ecological interactions, making precise predictions difficult. Nevertheless, the presence of uncertainty does not preclude the formulation of policy-relevant recommendations.

A structured approach to communicating uncertainty is essential. Rather than avoiding numerical estimates, researchers can provide outcome ranges, including potential impacts and their implications. Recommendations should not be limited to ideal solutions, but should also outline alternative courses of action, practical constraints, thresholds, and trade-offs, enabling informed choices within real-world limitations. Framing uncertainty as a normal aspect of scientific inquiry builds confidence in the research process. This clarity helps policymakers assess risks and trade-offs, supporting adaptive policy responses. Importantly, acknowledging uncertainty does not equate to inaction. On the contrary, recognizing the probabilistic nature of scientific predictions allows for more flexible and responsive policy measures and helps prevent a loss of trust when seemingly unequivocal but falsely presented as certain, evidence-based outcomes fail to materialize.

In the case of the parliamentary event on sea-level rise, the narrative contained the melting of the polar ice sheets, the change of currents/climate circulation patterns, land subsidence, and sea-level rise on the coast of the North and Baltic Sea. The participants received a fact sheet summarizing the experts' key messages (SynCom and Umwelt, 2023) informational brochures, and contact details to provide concise information for future reference. The key messages focused on coastal management of the North and Baltic Sea coasts: For instance, projections indicate that if greenhouse gas emissions remain high, sea levels could rise by up to 1.2 m by 2100. This would significantly reduce the time windows during which the drainage of low-lying coastal areas through sluices is possible, increasing reliance on energy-intensive and fail-safe pumping infrastructure. Many parts of the German

North Sea coast lie below or just above mean sea level and are already dependent on active water management systems. Moreover, decision-makers were informed of higher and more frequent storm surges and their critical impacts, such as effects on inland drainage, and increasing erosion and salinization. Current coastal protection strategies, while effective for now, are approaching their limits. Key messages addressed that integrative approaches that account for the interconnections between coastal defense, sediment management, inland drainage, and water supply are thus essential for long-term resilience.

The second example, the parliamentary breakfast on "Climate Neutrality 2045 – Opportunities and Challenges of DACCS and BECCS" focused on planning needs and uncertainties related to carbon dioxide removal (CDR). A fact sheet with key messages (SynCom and Umwelt, 2024) was developed, offering concise recommendations and contact details of the experts, facilitating future reference and sustained engagement. It was emphasized that while reducing emissions remains the top priority, additional CDR methods will be needed to offset residual emissions. Approaches such as Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS) were discussed, including their respective potentials, technical limitations, co-benefits, potential negative implications, and infrastructure requirements. Experts highlighted that BECCS could be integrated into existing bioenergy infrastructure, but requires clear political frameworks for sustainable biomass supply and CO_2 storage. For DACCS, early incentives and market creation are critical, given the long lead times for scaling and the high energy demands that must be met by renewable sources. Communicating these time horizons, infrastructure gaps, and dependencies on legal frameworks is essential to ensure that expectations align with feasibility (SynCom and Umwelt, 2024). This example illustrated how scientific advice can inform proactive governance, even when substantial uncertainty remains regarding cost trajectories, public acceptance, and cross-border coordination.

2.4 Conducting a science-policy event and follow-up processes to establish a sustainable dialogue (step 4)

Regular interaction contributes to a continuous exchange of knowledge, keeping research aligned with changing policy needs. Rather than viewing science-policy engagement as a one-way transmission of information, it is more appropriately conceptualized as an iterative process in which scientific evidence informs policy decisions while also being shaped by policy needs (Dilling and Lemos, 2011; Scott et al., 2012; Young et al., 2014). This requires institutional mechanisms that facilitate ongoing interaction between scientists and decision-makers, ensuring that scientific insights are both relevant and timely (Young et al., 2014).

We propose utilizing well-designed and collaborative parliamentary events as one element in the communication chain between science and policy. These events provide a structured setting for direct dialogue, allowing scientists to present and discuss latest research findings and policymakers to express their interests and needs. Beyond individual events, ongoing engagement builds trust, deepens understanding of challenges and goals, and contributes to a shared knowledge base.

During plenary weeks in the German Bundestag, numerous parliamentary events take place. The two parliamentary breakfasts discussed here—on the topics of sea level rise and carbon management—were likewise organized in the Reichstag building under the patronage of the respective parliamentary group spokespersons for these issues. The breakfasts were scheduled to coincide with relevant legislative processes—such as the German Climate Adaptation Act and the German Carbon Management Strategy, the Long-term Strategy Negative Emissions, and in connection with planned amendments to the German Carbon Dioxide Storage and Transport Act (KSpG). Each event brought together approximately 30 guests, including Members of Parliament from multiple parties and federal ministry representatives. The discussions were conducted under the Chatham House Rule, which allows participants to use the information received but prohibits identifying speakers or their affiliations. This format supported direct exchanges across party lines and made it possible to address politically sensitive issues as well as acknowledge gaps in knowledge without concern for attribution. Given the concurrent scheduling of events hosted by a wide range of interest groups, the attendance of a multi-digit number of parliamentarians, as observed at the breakfast meetings, is by no means guaranteed at such events. Equally significant as the number of participants, however, is the thematic responsibility and political influence of the attendees, which was ensured at both meetings through the participation of rapporteurs responsible for each respective subject area and state secretaries. Following both events, several parliamentarians reached out to the participating researchers, resulting in further meetings, invitations to contribute to specific policy processes, and continued exchanges on related legislative issues. These follow-up interactions suggest that the breakfasts functioned not merely as standalone events, but as starting points for longer-term engagement between science and policy.

2.5 Evaluating the science-policy dialogue for continuous improvement (step 5)

Evaluating the direct impact of science-policy engagement is inherently complex due to several factors. Policy decisions are influenced by political, economic, and social considerations. Additionally, time lags in observing effects, and difficulties in attribution (see Belcher and Halliwell, 2021) make it nearly impossible to isolate the impact of a single event.

An essential aspect of effective science-policy engagement is the temporal alignment of scientific input with policy development processes. By coordinating events and communications with key legislative milestones, scientists can provide relevant information when policymakers are most receptive to increase the likelihood that scientific insights will inform policy decisions. In the cited case studies, the parliamentary breakfasts were strategically timed to align with upcoming legislative initiatives, such as the Climate Adaptation Act (KAnG) and amendments to the Carbon Dioxide Storage Act (KSpG).

Continuous improvement of science-policy dialogues requires collecting systematic feedback. In both events, structured feedback was collected using printed questionnaires. The majority of responses placed the events in the top categories of perceived relevance and usefulness for parliamentary work. Free-text comments highlighted the clarity of the scientific messages, the concise format of the presentations, and the practical value of the discussions. The fact sheets distributed at the events were repeatedly mentioned as helpful reference tools. Some participants requested clearer policy recommendations, shorter event durations, and access to presentation slides, which was not possible in all cases due to copyright constraints.

To assess the continued dialogue after parliamentary events, we document subsequent interactions between scientists and policymakers. Follow-up meetings arranged for experts in both sea-level rise and carbon management indicated ongoing engagement. In the case of sea-level rise, further meetings focused on marine conservation and defense strategies in the Arctic, particularly concerning the future potential and strategic relevance of Arctic shipping routes. For carbon dioxide removal, the researchers contributed their expertise at various events, including stakeholder workshops by the German Energy Agency (dena) and the Tagesspiegel Future Sustainability Week 2024.

In conclusion, parliamentary events are valuable for both scientists and policymakers–supporting societally relevant research and evidence-informed policy. Scientists learn to present the range of data transparently while providing clear recommendations aligned with the policy context, thus enhancing the utility of their contributions to policy development. The dialogic format of these events encourages questions and discussions that are less restricted than formal parliamentary committees–even across party lines and in a more informal setting. Our structured five-step approach (Figure 1) helps translate complex research findings into practical insights, ultimately supporting better-informed decisions grounded in reliable evidence.

3 Discussion and conclusion

A structured and ongoing exchange between scientists and policymakers is essential for achieving evidence-informed decisions and developing policies that address interlinked societal and environmental challenges. By promoting a shared understanding, incorporating a broad range of expertise, formulating clear and well-structured messages, and ensuring that research contributions align with policy timelines, these interactions support informed and evidence-based decision-making. By communicating uncertainties transparently, offering scenario-based options, and clearly framing probabilities and risks, our approach helps policymakers navigate complex decisions without losing sight of practical next steps. Additionally, aligning scientific communication with policy priorities from the outset and maintaining ongoing dialogue ensures that scientific evidence remains both relevant and actionable. Beyond individual interactions, ongoing engagement and systematic evaluation strengthen the role of scientific knowledge in shaping policy discussions and outcomes.

Nevertheless, insights from our examples highlight enduring obstacles. For example, the lengthy analysis in inter- or transdisciplinary synthesis often clashes with sudden political developments, suggesting a need for mechanisms that can respond more flexibly to legislative windows. Moreover, multi-institutional collaborations enhance credibility and broaden scope, but depend on robust coordination and institutional commitment to balance diverse interests and timelines.

Our experiences suggest that iterative consultation formats in which researchers and policymakers periodically refine agendas and revisit findings improve the clarity of core messages and strengthen the integration of evidence into policy. Such formats, however, require opportunities for engagement over longer intervals rather than brief, one-off events. These observations indicate unresolved gaps, including the alignment of academic timescales with political exigencies and the challenge of distilling specialized knowledge into concise, actionable guidance. By applying resilience (Folke et al., 2010), anticipatory governance (Quay, 2010), and co-production principles (Jasanoff, 2004), subsequent efforts may address these deficiencies more effectively and ensure that scientific inputs remain timely, reliable, and suited to evolving policy conditions (Young et al., 2014). We therefore summarize key requirements for a successful science-policy dialogue (Figure 1).

By applying these principles, Earth system science can support the development of policies that are informed by the best available knowledge and capable of responding to future challenges. Presenting a range of well-founded possibilities while clearly outlining uncertainties and constraints ensures that policy initiatives are guided by rigorous and comprehensive scientific understanding. Through sustained commitment to accurate and policy-relevant research, the scientific community contributes to more informed and effective governance.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MH: Supervision, Methodology, Writing – review and editing, Investigation, Conceptualization, Writing – original draft, Formal Analysis, Project administration, Visualization. AB: Writing – review and editing, Writing – original draft. AM: Writing – review and editing, Writing – original draft. KS: Writing – review and editing, Investigation, Conceptualization, Writing – original draft, Formal Analysis, Project administration.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

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