Environmental Science and Policy 144 (2023) 174–186

Contents lists available at ScienceDirect

Environmental Science and Policy

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

A research agenda for the science of actionable knowledge: Drawing from a review of the most misguided to the most enlightened claims in the science-policy interface literature

Kripa Jagannathan [a,*], Geniffer Emmanuel [b], James Arnott [c], Katharine J. Mach [d,e], Aparna Bamzai-Dodson [f], Kristen Goodrich [g], Ryan Meyer [h], Mark Neff [i], K. Dana Sjostrom [j,k], Kristin M.F. Timm [l], Esther Turnhout [m], Gabrielle Wong-Parodi [n], Angela T. Bednarek [o], Alison Meadow [p], Art Dewulf [q], Christine J. Kirchhoff [r], Richard H. Moss [s], Leah Nichols [t], Eliza Oldach [u], Maria Carmen Lemos [v], Nicole Klenk [b]

[a] *Earth and Environmental Sciences Area, Lawrence Berkeley National Laboratory, Berkeley, CA, USA*
[b] *Department of Physical and Environmental Sciences, University of Toronto, Toronto, Ontario, Canada*
[c] *Aspen Global Change Institute, Basalt, CO, USA*
[d] *Department of Environmental Science and Policy, Rosenstiel School of Marine, Atmospheric, and Earth Science, University of Miami, Miami, FL, USA*
[e] *Leonard and Jayne Abess Center for Ecosystem Science and Policy, University of Miami, Coral Gables, FL, USA*
[f] *US Geological Survey North Central Climate Adaptation Science Center, CO, USA*
[g] *Tijuana River National Estuarine Research Reserve, Imperial Beach, CA, USA*
[h] *Center for Community and Citizen Science, University of California Davis, Davis, CA, USA*
[i] *College of the Environment, Western Washington University, Bellingham, WA, USA*
[j] *Memphis-Shelby County Division of Planning and Development, Memphis, TN, USA*
[k] *School of Urban Affairs and Public Policy, University of Memphis, Memphis, TN, USA*
[l] *International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, AK, USA*
[m] *University of Twente, Enschede, the Netherlands*
[n] *Department of Earth System Science and the Woods Institute for the Environment, Stanford University, Stanford, California, USA*
[o] *The Pew Charitable Trusts, Washington, DC, USA*
[p] *Office of Societal Impact, University of Arizona, Tucson, AZ, USA*
[q] *Public Administration and Policy Group, Wageningen University and Research, Hollandseweg 1, 6706 KN Wageningen, the Netherlands*
[r] *Law, Policy and Engineering Program, and Civil and Environmental Engineering, Penn State University, PA, USA*
[s] *Joint Global Change Research Institute, Pacific Northwest National Laboratory, Seattle, WA, USA*
[t] *Institute for a Sustainable Earth, George Mason University, Fairfax, VA, USA*
[u] *Center for Environmental Policy & Behavior, University of California Davis, Davis, CA, USA*
[v] *School for Environment and Sustainability, University of Michigan, Ann Arbor, MI, USA*

A R T I C L E I N F O

Keywords:
Science-policy interface
Actionable knowledge
Decision-making
Research agenda
Science-society engagements
Co-production

A B S T R A C T

Linking science with action affords a prime opportunity to leverage greater societal impact from research and increase the use of evidence in decision-making. Success in these areas depends critically upon processes of producing and mobilizing knowledge, as well as supporting and making decisions. For decades, scholars have idealized and described these social processes in different ways, resulting in numerous assumptions that now variously guide engagements at the interface of science and society. We systematically catalog these assumptions based on prior research on the science-policy interface, and further distill them into a set of 26 claims. We then elicit expert perspectives (n = 16) about these claims to assess the extent to which they are accurate or merit further examination. Out of this process, we construct a research agenda to motivate future scientific research on actionable knowledge, prioritizing areas that experts identified as critical gaps in understanding of the science-society interface. The resulting agenda focuses on how to define success, support intermediaries, build trust, and evaluate the importance of consensus and its alternatives – all in the diverse contexts of science-society-decision-making interactions. We further raise questions about the centrality of knowledge in these interactions,

* Correspondence to: Lawrence Berkeley National Laboratory, 1 Cyclotron Rd, Berkeley, CA 94720, USA.
E-mail address: kripajagan@berkeley.edu (K. Jagannathan).

https://doi.org/10.1016/j.envsci.2023.03.004
Received 18 September 2022; Received in revised form 23 February 2023; Accepted 6 March 2023
Available online 29 March 2023

discussing how a governance lens might be generative of efforts to support more equitable processes and outcomes. We offer these suggestions with hopes of furthering the science of actionable knowledge as a transdisciplinary area of inquiry.

1. Introduction

Decision-making ought to be informed by the best available science. This claim is often repeated by scientists and policy-makers. Yet, the actual connections between scientific knowledge, decision-making, resulting actions, and outcomes are not straightforward, especially in the context of complex issues with high stakes, risks, and uncertainties. Many urgent and escalating environmental issues share these characteristics, including for example: climate change, biodiversity loss, sustainable development, resilience initiatives, agriculture, and clean energy transitions. To the extent that science can help accelerate solutions to these issues, it becomes paramount to leverage a nuanced and realistic understanding of how science becomes actionable, that is, how science becomes used to inform decisions that enhance social and environmental well-being (Kirchhoff et al., 2013; Meadow and Owen, 2021; Meinke et al., 2006).

Systematic efforts to build this understanding comprise an emerging interdisciplinary area of inquiry called the "Science Of Actionable Knowledge" (or SOAK, for short). As a form of meta-research, SOAK applies empirical and critical methods to examine the processes, practices, and pathways by which knowledge meaningfully informs action (Arnott et al., 2020b). This entails several multi-, inter-, and trans-disciplinary topical areas, such as environmental psychology, decision support, engaged research (e.g., citizen science), boundary spanning, knowledge brokering, anticolonial and antiracist practices, etc. (Goodrich et al., 2020; Latulippe and Klenk, 2020; Mach et al., 2020; McKinley et al., 2017; Turnhout, 2018; Wong-Parodi et al., 2020; Wong-Parodi and Feygina, 2020). SOAK research builds on many prior lines of empirical and normative scholarship on science-society interactions, that urge the integration and mobilization of knowledge across and beyond disciplines and perspectives (Mach et al., 2020; Pohl et al., 2021). Over the years, several frameworks have characterized this evolving structure and relationship between science and society. These frameworks include science-policy interface(s) or SPI (van Ravenswaay et al., 1983), post-normal science (Ravetz, 1999), transdisciplinarity (Lang et al., 2012), translational science (Schlesinger, 2010), co-production (Lemos and Morehouse, 2005), and implementation science (Bammer et al., 2020). The assumption behind these conceptions, is that singular scientific or decision-analysis models tend to close down the solutions space, and that opening them back up (Stirling, 2008) requires multiple knowledge sources and approaches to support engagement and decision-making (Lubell and Morrison, 2021; Polk, 2015). Therefore these frameworks aspire to be epistemologically expansive and pluralistic, anticipating that knowledge use is influenced within a broader knowledge system that is co-constituted by actors beyond traditional knowledge producers, which may include practitioners, decision-makers, local communities, and other stakeholders (Cash et al., 2003).

Among these numerous frameworks, science-policy interface (SPI) (van Ravenswaay et al., 1983) is one of the earliest and most popular, that describes the exchange between science and decision-making. Many scholars have reified the SPI concept through theoretical, normative, and empirical contributions to the literature seeking to characterize, explain, and improve this particular form of science-society interaction. More recently, heightened attention about how to better mobilize science for action on urgent societal challenges, has catalyzed SOAK as a broader and more formalized area of scholarship that includes insights from frameworks such as the SPI. SOAK investigates questions about the drivers and mechanisms of knowledge creation and use, and about other ways of understanding 'knowledge systems' (Arnott et al., 2020b). SOAK aims to build a coordinated group of scholars, funders, and practitioners, who collectively and critically examine various types of science-society engagements (including engagements that take place at the SPI).

The purpose of this study is to identify claims (i.e., key insights and assertions) about the SPI and conduct an assessment of these claims to inform a future research agenda for SOAK. Although the SPI has been studied for decades, and there have been some recent systematic literature reviews on this body of scholarship, to our knowledge there has not been any in-depth analysis of how decades worth of studies about SPIs might inform the aims and scope of the broader emergent field of actionable knowledge scholarship (Gluckman et al., 2021; Sokolovska et al., 2019). This makes it difficult to know what ideas emerging out of SPI-related literature merit confident endorsement or rebuttal based on existing evidence, or further consideration based on additional evidence. We see a need for greater dialogue and mutual learning between these areas of inquiry since both attend to the relationship between science, society, and decision-making. They also share key concerns, such as the normative promises, the shortfalls in delivering on those promises of epistemological pluralism, and the practical implementation and assessment of collaborative approaches to decision-making. While science-policy interactions represent a smaller subset of the broader science-society engagements that encompass SOAK, they can provide a foundational set of questions to establish an initial SOAK research agenda, that we hope is further broadened by future work.

To affect this rapprochement between SPI and SOAK scholarship, we conducted a systematic review of the SPI literature to identify claims and insights generated by this body of scholarship. We then examined these claims through an expert elicitation exercise amongst scholars involved in the research and practice of the science of actionable knowledge, herein referred to as SOAK experts. Our overarching objective is to bring to bear the accumulated understandings in SPI scholarship to shape future research in SOAK. To do this, we use a short-hand phrasing of what SOAK experts perceive to be the most "enlightened" and the most "misguided" claims made about the SPI. Although our examination of claims further challenges the simplistic expectation that science will, or should, clearly and unequivocally provide optimal solutions to complex environmental issues, it opens-up the possibility for a broader range of pathways for science-society interfaces, that will ideally achieve goals around actionability.

We begin by describing the systematic literature review, and the expert elicitation methods. We then present the 26 claims that were identified from the SPI literature review which anchor our expert elicitation results. The elicitation results detail the level of agreement for each of the identified claims and highlight the claims that were ranked as most enlightened, most misguided, and those that warrant further research. We then discuss these results and end with a proposed research agenda that identifies specific avenues of research that our analysis suggests as deserving greater attention in future SOAK scholarship.

2. Methods

Fig. 1 describes the different steps in the methodological approach. We further describe each of these steps in the paragraphs below.

2.1. Systematic review of SPI literature

Through the systematic literature review, we examined the meaning of the SPI, including how scholars have studied it, and what understandings emerged as most relevant to advancing future work in this space. We searched the term "science-policy interface" in the academic literature using Scopus and Web of Science databases and identified 113 peer-reviewed articles published between 1983 and May 2018. These 113 articles encompassed various disciplines and journals (Appendix A). While we are aware that a much larger body of literature addresses matters related to SPI using related terminology or without reference to SPI in the title, our restricted search to explicit mentions was designed to produce a robust sample from which to focus a deep reading and extraction of claims.

We then developed a codebook to extract common bibliometric information as well as information on key aspects of SPI (Appendix A). This included information about theoretical constructs used, problem framing, science-policy engagement processes, capacities involved in working at the SPI, criteria for success of SPIs, how knowledge at the SPI becomes evidence for decision-making, and broader outcomes from SPI.

2.2. Iterative clustering and refining of SPI claims

A subset of the author team, as assessment facilitators (NK, GE, JA, KJ, & KJM), distilled recurring themes, criteria, aims, definitions, and theories from the SPI literature into key assertions about the SPI that for the purposes of this paper we call "claims". Initially our assessment of empirical findings, theoretical advancements, and normative assertions across the SPI literature were distilled into a list of 70 + empirical and normative claims. We used a card-sorting research approach (using the Optimal Sort Software) combined with repeated rounds of dialogue among the assessment facilitators, to cluster, sort, and iteratively distil the list of 70 + claims. Through this iterative method, we identified a summary list of 26 claims spanning five topical areas.

2.3. Survey of SOAK experts for level of agreement on claims

Next, we developed an expert elicitation survey to measure agreement or disagreement with the 26 SPI summary claims, across SOAK experts. Expert elicitation is an approach to document the judgments of experts about available evidence on a topic (Mach et al., 2019), in this case, the SPI claims. SOAK experts here refer to scholars involved in the research and practice of the science of actionable knowledge who are members of a SOAK research-practice collaborative that the author team is also a part of. This SOAK collaborative was initiated in 2017, as part of a workshop series on how to advance the science of knowledge use. This expert group includes researchers, practitioners, as well as boundary spanners. For the survey, we drew from methods of expert elicitation and best practices to minimize biases in the judgments of individual experts about evidence and its uncertainties (Mach et al., 2017; Morgan, 2014). It was designed to create a foundation for subsequent group deliberation on the status of SPI understanding and priorities for future SOAK research (e.g., following methods of (Mach et al., 2019)). The expert survey questions focused on each expert's level of agreement with each of the 26 SPI claims, using a 7-point Likert scale. Each question in the expert survey allowed for open-ended reflection through an open text box for additional comments and details on each claim. In addition, experts identified the claims that they deemed to be most misguided versus most enlightened (i.e., reflective of current understanding), as well as the claims that they judged as requiring further research. They also identified other gaps and priorities for future SOAK exploration and advancement. A total of 16 individuals from the SOAK research–practice collaborative completed the survey. The assessment facilitators who designed the survey were not included as survey respondents.

2.4. Quantitative and qualitative analysis of survey results

We examined the closed-form responses of the survey to assess the level of agreement for each claim through frequency plots, summary statistics, and quantitative measurements of individual and group agreement. Based on the level of agreement results, we grouped each of the claims into three bins:

- **Claims with majority agreement:** Where a majority of experts somewhat agreed, agreed, or strongly agreed with the claim

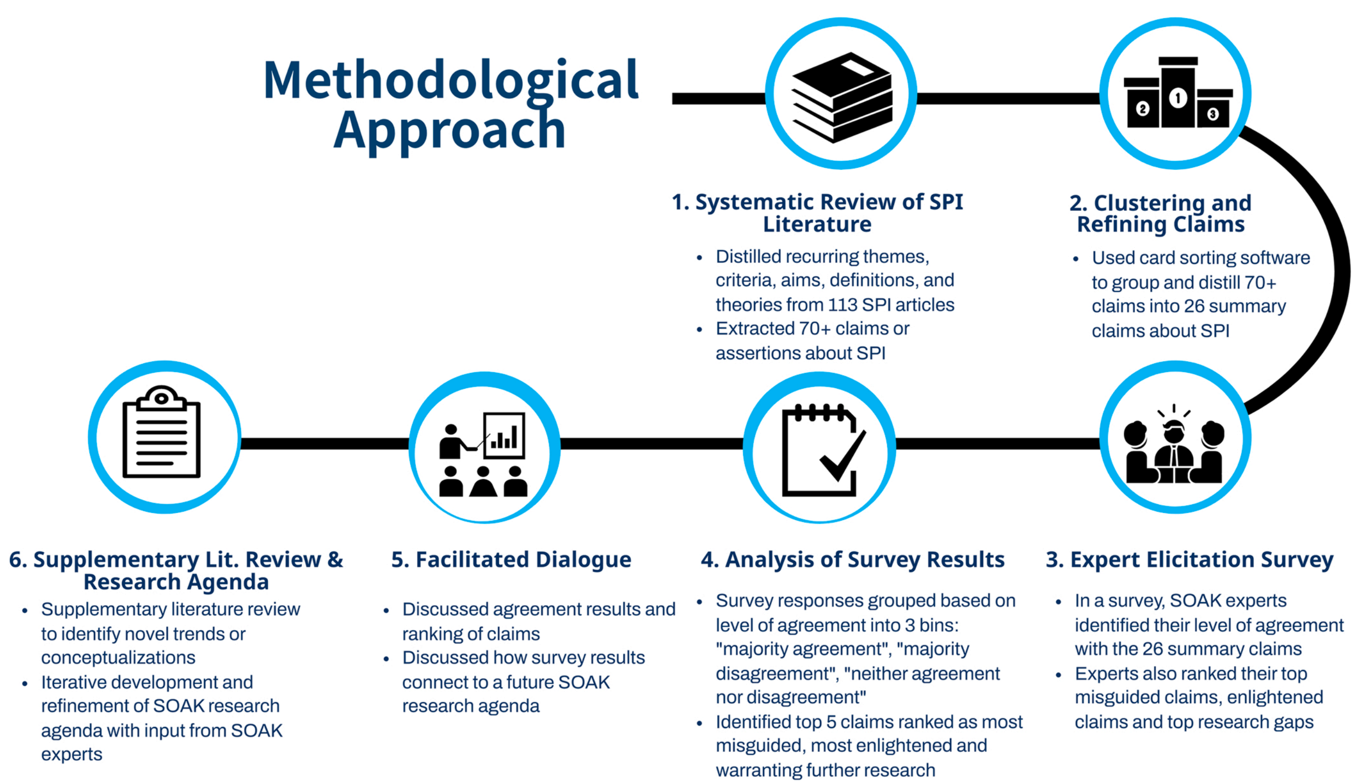

Fig. 1. Stepwise description of the methodological approach to develop the SOAK research agenda.

- **Claims with majority disagreement:** Where a majority of experts somewhat disagreed, disagreed, or strongly disagreed with the claim
- **Claims with neither agreement nor disagreement:** Claims were classified under this bin if (a) a majority experts were fence sitting, i. e., each individual neither agreed nor disagreed with a claim or (b) when there was low group consensus i.e., where some experts agreed with the claim while others disagreed with it and overall agreement results of the group were spread across the Likert scale spectrum

The open-ended responses were summarized to add details and nuances to the closed-ended responses. We also collated the results on top 5 claims that were ranked by the group (based on total number of votes for each claim) as most misguided, most enlightened and those that need more research.

2.5. Dialogue on survey results with SOAK experts

Based on the survey results, a facilitated dialogue with SOAK experts was organized to further discuss their views on the results, as well as their ranking of the claims. In the dialogue, experts discussed whether we should "move past" the top-misguided claims (and if yes then why?). They were also asked whether the top-enlightened claims and the claims that warrant further research provide a strong foundation for moving forward a SOAK research agenda. This dialogue also served as a precursor to identify future SOAK research questions. Based on the results and the workshop dialogue, the assessment facilitators drafted a list of future SOAK research areas and questions, which were iteratively refined through written feedback from the other SOAK experts.

2.6. Supplementary literature review

As the subsequent steps of the research following our initial literature review took a few more years, we also conducted a supplementary review to update our initial literature review which had an end date of May 2018 (see Appendix A for a list of articles reviewed). The main purpose of this supplementary review was to identify any novel trends or conceptualizations in the SPI literature between late 2018 and 2021, and compare these with the claims that we had identified. Overall, we did not find any evidence of new claims that were outside of our list of 26 claims, indicating this list remains comprehensive. In fact, we found that the updated literature supported the research gaps identified in this paper – hence we used this literature to further support our discussion and conclusions.

3. Results

3.1. Systematic literature review and SPI claims

The term "science-policy interface" first appeared in the title of a peer-reviewed journal article in 1983. This article focused on the regulation of polychlorinated biphenyls (PCBs) in order to reduce risks to human health (van Ravenswaay et al., 1983). Between 1983 and 2000, only six peer-reviewed articles referred to the "science-policy interface" in their title. Most of the articles with SPI in the title were published in the last 20 years. Since 2007, a growing number of the articles refer to the work of international bodies as instances of SPIs, such as the European Commission's network project on air pollution and health or AIRNET, and the Intergovernmental Panel on Climate Change or IPCC (Lange and Garrelts, 2007; Quevauviller, 2007; Totlandsdal et al., 2007; van den Hove, 2007; Wallis, 2007). Of the 113 articles reviewed, 57 were empirical research papers examining the SPI. Common methods in these empirical studies included surveys, risk assessments, participant observation, network analysis, interviews, ethnographic accounts, and mixed methods. Other types of articles included theoretical articles, perspective pieces, and reviews.

The term "science-policy interface" is often defined as "social processes which encompass relations between scientists and other actors in the policy process, and which allow for exchanges, coevolution, and joint construction of knowledge with the aim of enriching decision-making" (van den Hove, 2007). Definitions of the science-policy interface have commonly drawn influence from a linear model where knowledge producers provide information for decision makers. In more recent SPI literature, definitions of the term acknowledge the "complexities, diverse interactions, interrelations, and interdependencies of science and politics" (Faehnrich and Ruser, 2019).

In our review, we identified a core set of aims, approaches, and attributes of the SPI. With regard to the stated aims of SPI, the most common themes include informing decision-making, effective mobilization of knowledge, improving knowledge and practices, addressing uncertainties, identifying problems or impacts, and bridging gaps between science and policy. To do this, a variety of recurring processes and types of work take place at the SPI, including co-production, joint construction of knowledge, deliberation, generation of socially robust knowledge, and integration & operationalization of knowledge**.** With regard to the qualities or values that define the structures and capabilities of an SPI, the literature suggests that the SPI is adaptive or dynamic, it is complex, participatory, and political, and that successful SPIs build trust and facilitate reflexivity between those involved. Supplementary Table -1 (Appendix B) provides a list of keywords identified through the literature review.

There has also been some acknowledgement in recent SPI literature of the importance of formulating decision-relevant research, given the current dissonance between knowledge production and action (Coreau et al., 2018). Some articles also highlight a gap in how scientific knowledge is integrated into policy outcomes, a disconnect which is compounded by the slow pace of exchange at the interface of science and policy (Katyaini et al., 2020). The results of this review of SPI literature are notable because they are reflective of many of the themes at the core of the aspiration to produce actionable knowledge. Fig. 2 presents the 26 claims that were synthesized based on the literature review.

3.2. Expert elicitation results

Overall, 13 of the 26 claims had broad agreement, 2 claims were rejected (or disagreed on) by the expert group, and 11 claims were neither agreed nor disagreed on. A full list of the claims along with the results of the agreement Likert scale is provided as Table 1. Supplementary Table 2 (Appendix B) provides a synthesis of the qualitative comments received for each claim.

3.2.1. Claims with majority agreement

There was consistent agreement that SPIs facilitate systematic pursuit of knowledge (Claim 1) and that SPIs could be improved through further study of their characteristics (Claim 2). Further, there was also agreement that when functioning well, SPIs bring together different groups with specialized knowledge (Claim 10), bridge the divide between science and policy-making while brokering connections (Claim 15), and enable iteration and deliberation among diverse knowledge and value systems (Claim 22). Although there was agreement that SPIs encourage collaboration and social learning (Claim 17), some experts noted that fostering either can be difficult, and thus accomplishment of these goals is not guaranteed. It was also agreed that SPIs, when successful, can support trust in science (Claim 19) as well as trust between scientists and policymakers. There was also agreement that SPIs needed participatory and multidisciplinary approaches (Claim 12) as well as intermediaries to bridge the divide between science and policy (Claim 16).

3.2.2. Claims with majority disagreement

There were fewer claims that were consistently rejected. There was strong disagreement with the claim that SPIs facilitate a linear flow of knowledge from science to policy (Claim 14); rather experts indicated

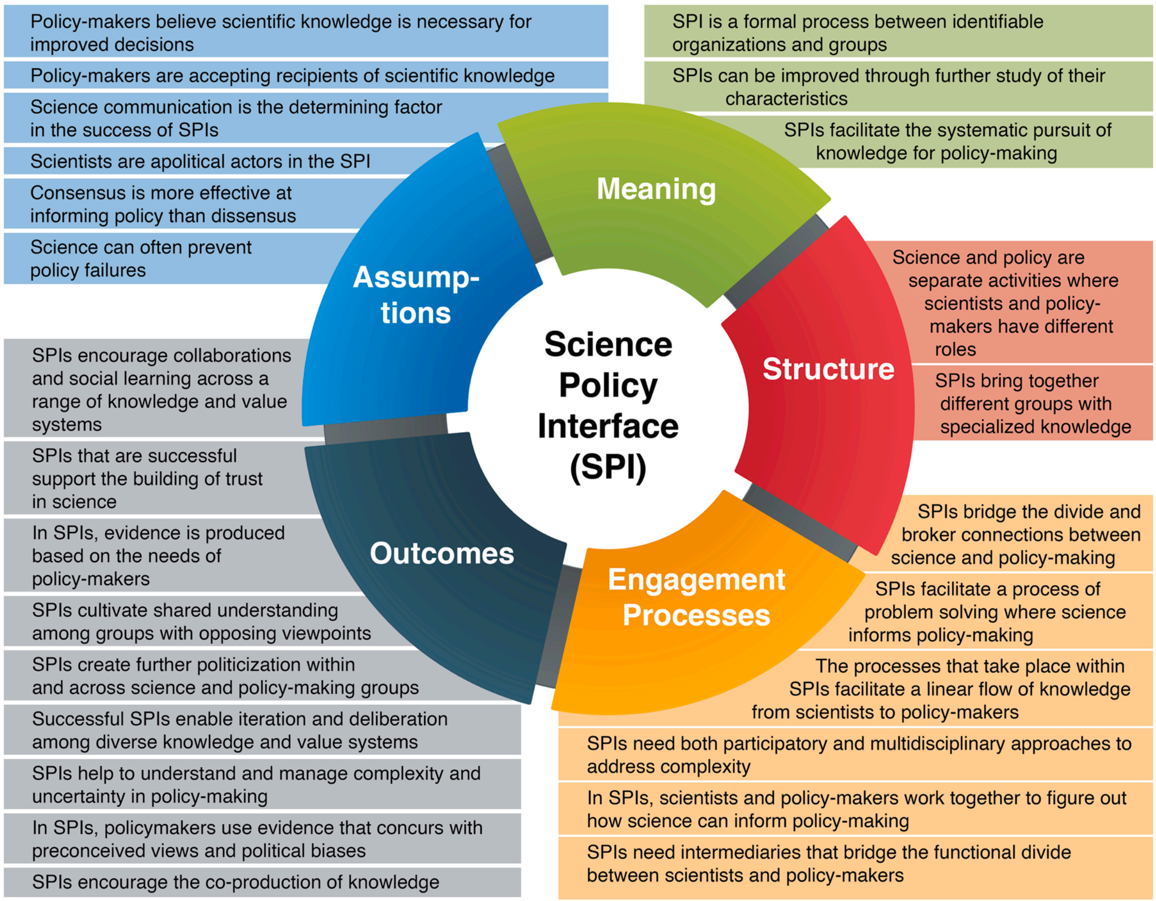

Fig. 2. The list of 26 claims relating to the SPI, identified based on a systematic review of literature, cluster analysis, and synthesis. These claims span five topical categories, namely – SPI assumptions, Meaning of SPI, SPI structure, Engagement processes in SPI, and SPI outcomes. These categories were identified inductively through a reading of each claim to denote its connection to the SPI literature.

that in fact (well-functioning) SPIs promote a bi-directional flow of knowledge. Experts also challenged the claim that scientists are apolitical actors (Claim 5), this claim received the greatest number of comments and generated enthusiastic discussion during the group deliberation. Most experts were of the opinion that no one is truly an apolitical actor, but some argued for the value of scientists in seeking to maintain independence from politics to the extent possible.

3.2.3. Claims that were neither agreed nor disagreed on

For the claim of whether science can often prevent policy failures (Claim 4), experts noted that there are many factors (including science) that can determine policy success and failures. Claim 3 on whether policy-makers believe scientific knowledge to be necessary for improved decision-making, also resulted in some differences among the responses. While some experts noted that many policymakers believe that scientific evidence is necessary, others indicate that this depends on the type of policymaker (e.g., level of government). Claim 6 relatedly was about whether policymakers are accepting recipients of scientific knowledge. Some comments suggest that in current politicized conditions, policy-makers are more accepting of certain types of information that appeal to their convictions. Some also noted that generally policymakers are open recipients of scientific knowledge when such information is communicated to them in an effective manner. Some experts agreed that consensus was effective at informing policy (Claim 8) since scientific consensus is easier to communicate. However, others also noted the importance of dissensus and informed disagreement, particularly in situations where power imbalances exist between groups participating in the decision-making process. The claim that SPIs cultivate shared understanding (Claim 20) was also neither agreed nor disagreed on. Comments indicated that whether this held true would very much depend on the context. Another claim that resulted in neither agreement nor disagreement, was about whether SPIs create further politicization (Claim 21). Here the term politicization is used more broadly, inclusive of both traditional conceptualizations of politics (e.g., left and right) as well as politics that more broadly occurs in practice (e.g., hierarchies, power dynamics, knowledge sovereignty). Respondents noted that there have been examples in both directions. While SPIs can, at times, depoliticize issues and solutions, there are also cases where they have further politicized solutions. Further some experts also noted that sometimes depoliticization could have the unintended consequence of masking value-laden decisions. For the claim that science communication is the determining factor in the success of SPIs (Claim 7), experts noted that while communication is critical for SPI success, it is effective two-way communication (not just the traditional one-way communication from scientists to policy-makers) that is most important.

Overall, we found that there was broad agreement in ranking of claims relating to “Meaning of SPIs” and “Engagement processes in SPIs” (taking from topical categories in Fig. 2). However, agreement results for claims relating to the “SPI assumptions” were largely ambivalent. For claims relating to “SPI outcomes” - about half were largely agreed on whereas the remaining half were neither agreed nor disagreed on.

3.2.4. Ranking of top claims

Fig. 3 presents overall results on the ranking of top 5 most enlightened (most normatively ideal in the experts’ views) and most misguided claims (claims that are most erroneous or problematic), along with the

Table 1
Full list of 26 claims, along with the results of the expert elicitation survey on level of agreement with each of the claims. The numbers in the table represent the number of survey respondents who chose that specific level of agreement on the 7-point Likert scale: SD - **S**trongly **D**isagree, D - **D**isagree, SWD - **S**ome**W**hat **D**isagree, NDOA - **N**either **D**isagree n**O**r **A**gree, SWA - **S**ome**W**hat Agree, A - **A**gree, SA - **S**trongly **A**gree.

Claims with Majority Agreement							
Claim	SD	D	SWD	NDOA	SWA	A	SA
Claim 1: SPIs facilitate the systematic pursuit of knowledge for policy-making.			1	3	5	7	
Claim 2: SPIs can be improved through further study of their characteristics.					3	10	3
Claim 10: SPIs bring together different groups with specialized knowledge.					2	10	4
Claim 11: In SPIs, scientists and policy-makers work together to figure out how science can inform policy-making.			1	3	3	8	1
Claim 12: SPIs need both participatory and multidisciplinary approaches to address complexity.					1	10	5
Claim 13: SPIs facilitate a process of problem solving where science informs policy-making.			1	3	4	8	
Claim 15: SPIs bridge the divide and broker connections between science and policy-making.					8	6	2
Claim 16: SPIs need intermediaries (i.e. boundary spanners) that bridge the functional divide between scientists and policy-makers.			1		3	7	5
Claim 17: SPIs encourage collaborations and social learning across a range of knowledge and value systems.		1		3	3	5	4
Claim 19: SPIs that are successful support the building of trust in science.		1		1	1	12	1
Claim 22: Successful SPIs enable iteration and deliberation among diverse knowledge and value systems.	1				2	12	1
Claim 23: SPIs help to understand and manage complexity and uncertainty in policy-making.			1	3	3	6	3
Claim 25: SPIs encourage the co-production of knowledge.			1	4	6	5	
Claims with Majority Disagreement							
Claim	**SD**	**D**	**SWD**	**NDOA**	**SWA**	**A**	**SA**
Claim 5: Scientists are apolitical actors in the SPI.	6	5	2		2	1	
Claim 14: The processes that take place within SPIs facilitate a linear flow of knowledge from scientists to policy-makers.	6	5	2	1	1	1	
Claims that were neither agreed nor disagreed on							
Claim	**SD**	**D**	**SWD**	**NDOA**	**SWA**	**A**	**SA**
Claim 3: Policy-makers believe scientific knowledge is necessary for improved decisions.			4	4	6	1	1
Claim 4: Science can often prevent policy failures.	1	6	1	2	3	3	
Claim 6: Policy-makers are accepting recipients of scientific knowledge.	1	3	1	5	5	1	
Claim 7: Science communication is the determining factor in the success of SPIs.	3	5	1	3	4		
Claim 8: Consensus more effective at informing.	1	1	5	7		2	
Claim 9: Science and policy are separate activities where scientists and policy-makers have different roles.		1	3	2	5	5	
Claim 18: In SPIs, evidence is produced based on the needs of policy-makers.		3	1	4	7	1	
Claim 20: SPIs cultivate shared understanding among groups with opposing viewpoints.	1		1	4	6	3	1
Claim 21: SPIs create further politicization within and across science and policy-making groups.		3	4	8	1		
Claim 24: In SPIs, policymakers use evidence that concurs with preconceived views and political biases.	1	1	2	4	3	4	2
Claim 26: SPI is a formal process between identifiable organizations and groups.	2	4	2	3	5		

top 5 claims that would most warrant further research. Claims that were ranked as the most misguided include the two claims that had majority disagreement, and some claims that were neither agreed nor disagreed on. During the facilitated discussion, we asked the experts if we should “move past” these misguided claims, to which they responded that even if they are misguided, some nuances within these claims could be better examined and provide valuable lessons to inform SOAK. Particularly, the top two misguided claims - scientists as apolitical actors and SPIs facilitating a linear flow of knowledge - garnered a lot of discussion. Experts discussed whether there are some instances when the linear flow of knowledge might work, and also how SPIs can, at times, be political practices to support inclusion of diverse knowledge systems and anti-colonial work.

The top enlightened claims related to the approaches and agents needed for effective SPIs, and the outcomes from successful SPIs. Although all of the top 5 enlightened claims were largely agreed upon by the experts, the discussion suggested that further research on the nuances of these claims could be valuable for SOAK. Particularly, there was a lot of discussion on the conditions or supporting resources (such as intermediaries or boundary spanners) that lead to successful outcomes in SPIs such as social learning or trust.

The claims that were identified as warranting further research overlapped quite a bit with the top enlightened claims. Most of these claims also fell under the category of “SPI outcomes” suggesting a general interest among SOAK experts in further examining this topic. The top claim that experts felt warranted most research, was the debate on whether consensus is more effective at informing policy than dissensus. In addition, we also asked the experts to identify other gaps in SPI research that are not covered by these claims. The open-ended answers to this question, which also came up in the facilitated discussion, brought up some additional research gaps relating to governance,

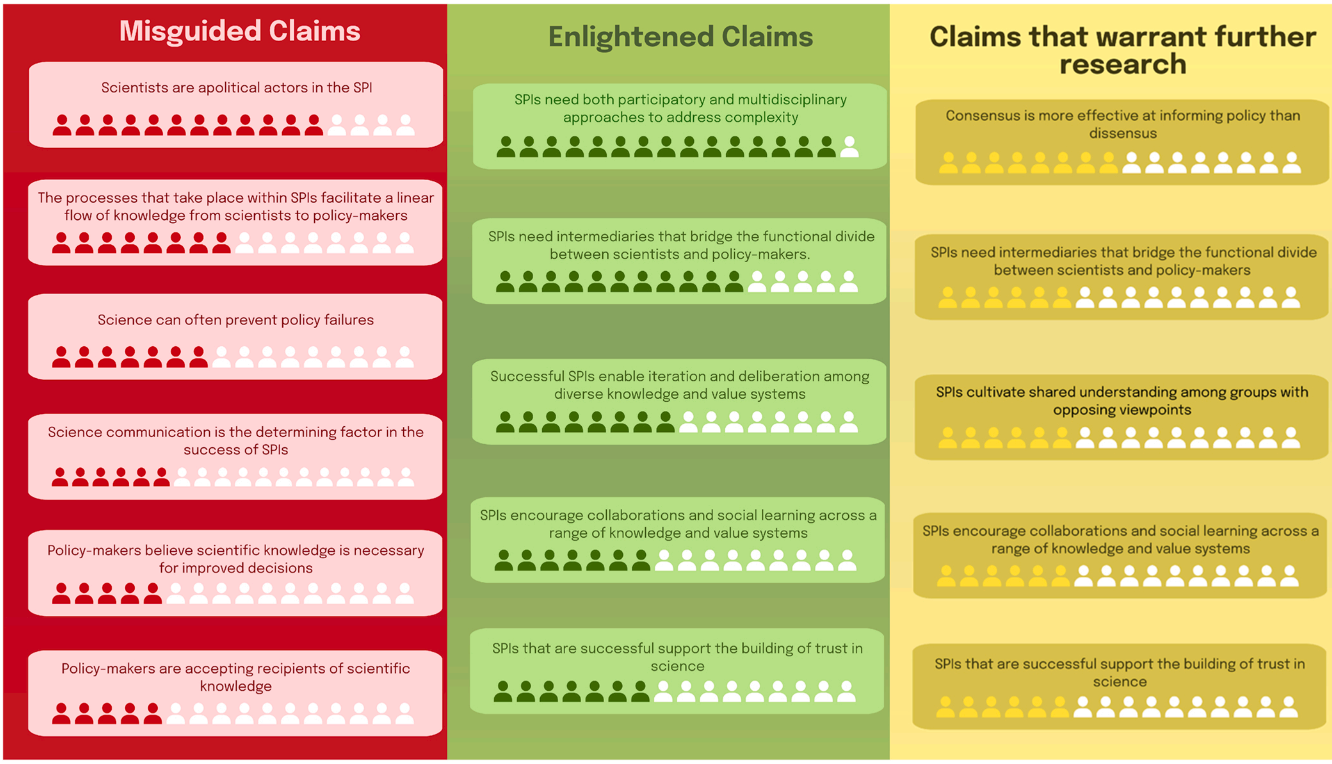

Fig. 3. Ranking of top 5 most enlightened and most misguided claims, along with the top 5 claims that would most warrant further research. The shaded people icons represent the number of respondents (out of 16) that identified that claim as misguided/enlightened/research gap. Please note that there are 6 misguided claims since the last two received the same number of votes.

politics, and power dynamics in SPIs. For example, experts suggested the need to reflect on potential power imbalances in SPIs such as who makes decisions, whose voice is heard, or whose knowledge is valued.

Based on a synthesis of the survey results, the ranking of claims, and the facilitated discussions, we identified four key themes for future SOAK research: (1) Evaluating success (2) Supporting intermediaries (3) Examining the meaning of trust, and (4) Role of consensus. These themes form the backbone of our SOAK research agenda which we detail in the next section.

4. Discussion

4.1. A research agenda for SOAK

The results of the systematic literature review and expert elicitation exercise raised many questions about current understanding of the SPI. Interestingly, even for those claims for which there was consistent agreement, the qualitative responses to these claims raised additional questions. Many SOAK experts agreed upon the claims as normative ideals, but suggested that when put into practice, the validity of these claims can be highly context dependent. They pointed out that the normative ideal of the SPI and its actualization are two different objects of study, or alternatively are co-constructed. Similar comments arose in the discussion of claims that were neither agreed nor disagreed on. It is also notable that the two claims that were consistently rejected by the expert group (i.e., that SPI facilitates a linear transfer of science to decision-makers, and that scientists are apolitical) were also identified as misguided and were empirical claims that contradict the normative heuristic. Yet, many SOAK experts acknowledged that such claims do sometimes reflect actual SPIs. For example, they discussed that the "loading dock model" in which science is used to set regulatory standards and inform public policy (like how epidemiological science informs public health measures during the pandemic), does happen in practice, even if this model is contradictory to the deliberative, co-production, and two-way communication models that the agreed-upon claims make about the SPI. Overall, SOAK experts agreed on what the SPI ought to be from a normative perspective, but indicated that empirical research on SPIs in practice may not entirely reflect the normative model of SPI in all contexts.

In addition to the question of normative versus practical interpretation of claims, our results also indicate that there is some uncertainty about how the ideals of SPI work in different practical settings, which is also consistent with the SPI literature (Felt, 2017). The diverse conceptions of the SPI may be because each SPI is highly contextual, uniquely constructed, influenced by varied cultural and political settings (Ojanen et al., 2021), and therefore can manifest in different forms (Kaaronen, 2016; Singer-Brodowski et al., 2021). SPIs also tend to differ in their purpose, processes, outputs, structures, and scale and may take the form of advisory committees, multistakeholder forums, and even locally conducted transdisciplinary research (Ojanen et al., 2021). Indeed, some SPIs are deliberately constructed and managed in order to stabilize and facilitate productive exchange across social worlds (e.g., a scientific advisory committee), while others may be relatively unmediated and characterized by political and epistemic conflict (Guston, 2001; Olson and Pinto da Silva, 2019). It was noted throughout the literature and from discussions with SOAK experts, that these varying forms of SPIs can affect the assessment and validity of some of the SPI claims. In other words, our results highlight that there are many different kinds of SPIs, and the claims presented cannot possibly capture all of these potentially different functions, structures, and outcomes of SPIs. These two interpretations (normative versus empirical nature of claims, and the context specificity of the claims) raise questions about whether claims from SPIs are meant to be viewed as aspirational normative heuristics to guide and assess SOAK practice, or as empirical models that are more explanatory and predictive of science-society processes and outcomes.

Despite these deep questions on how the claims should be viewed, overall our results imply that SOAK experts better understand as well as largely agree on claims that refer to the *knowledge exchange and production dimensions* of SPIs (e.g., claims 1, 2, 10, 15, 22). However, there is more uncertainty about its *policy and governance dimensions* (e.g., claims 9, 21, 26) as well as on *the outcomes and metrics of success* for SPIs (e.g., claims 4, 7, 8, 20, 21). The ranking and discussion on top claims and research needs, further highlighted the need to critically examine the *politics and power dynamics in SPIs* such as whose knowledge counts and is included in decision-making; practices that support the inclusion of diverse knowledge systems (Latulippe and Klenk, 2020); and the uneven distribution of power and knowledge hierarchies (Turnhout et al., 2020). Such questions further speak to the governance dimension of the SPI as a political arrangement of societal actors involved in shaping the values, rules, norms and practices of decision-making, an area of research that is under-developed in SPI scholarship (Chilvers and Kearnes, 2020; Keeney, 1996; Klenk and Meehan, 2017; Latulippe and Klenk, 2020; van Breda and Swilling, 2019). Our discussions also suggest that SPIs can implement “gate-keeping” functions that steer decision-making, by controlling the participants, roles, and scope of involvement of different actors, as well the topics, values, and norms that get opened-up or closed-down in discussions of problem framing and solution spaces.

Taking from these discussions holistically, our research agenda focuses on 4 key areas that were identified as warranting further examination: (1) Evaluating success of actionable knowledge, (2) Supporting intermediaries in facilitating science-society engagements, (3) Examining whether and how trust about knowledge is built, and (4) Exploring the role of consensus in science-society engagements. Many of these themes have overlapping concepts, in particular the theme of governance (including power and politics at the science-society interface) cuts across several of these areas. Due to its centrality, we conclude our paper by raising questions about the generative potential of using governance as a lens for future studies of SOAK.

4.1.1. How do we define and evaluate success in producing actionable knowledge?

SOAK experts questioned the implicit assumption in many of the SPI claims, that it is generally known what an effective SPI ought to look like. The various interpretations and contextual nature of SPI raises several questions in understanding the meaning of success in SPI. Science-society engagements for SOAK, similarly, have several meanings and definitions (Bremer and Meisch, 2017; Chambers et al., 2021; Mach et al., 2020), and hence raise similar questions on what constitutes success. What successful actionable knowledge development looks like depends on who is involved, the problem context and framing, as well as the objectives pursued by bringing together different societal actors to address complex problems (Englund et al., 2022; Norström et al., 2020). For example, we do not necessarily know what will be considered actionable in cross-cultural contexts or in contexts where practical or experiential knowledge is more widely trusted than technocratic Western science (Latulippe and Klenk, 2020; Smith, 2012; Stern et al., 2021; Yua et al., 2022). Yet, funders and other organizations are seeking guidance on how to achieve successful actionable knowledge production and promote sustained and equitable partnerships (Arnott et al., 2020a; Hopkins et al., 2021). SOAK experts reiterated the importance of not portraying success as the straightforward application of a protocol. They also suggested that participatory evaluations that emphasize the process and principles of actionable knowledge production, and involve its participants in defining success and its indicators, might be applicable across different contexts (Mach et al., 2020). As the criteria for assessment may be diverse, methodological pluralism is to be expected, where multiple and possibly mixed methods would need to be used for evaluations.

Further, SOAK experts also highlighted the methodological complexities and challenges in defining and evaluating success of actionable knowledge. There exists a time-lag between when actionable knowledge is developed and when its impact can become apparent (Arnott and Lemos, 2021). Hence, evaluations of success necessarily require long-term monitoring and tracking of science-society engagements, which is rare and under-funded (Arnott et al., 2020a; Karcher et al., 2021; Meadow and Owen, 2021). There is also a gap in documenting failures or unintended consequences of actionable knowledge development processes, which can further deter effective advancement of evaluation processes (Jagannathan et al., 2020; Lemos et al., 2018; Turnhout et al., 2020). There exists a diversity of empirical applications to develop principles and practices that provide guidance without imposing standards in a one-size-fits-all approach. Work on typologies, criteria and indicators, and assessment frameworks (Bamzai-Dodson et al., 2021; Jagannathan et al., 2022; VanderMolen et al., 2020; Walter et al., 2007), as well as on stories and rich case studies of other people’s experiences, can offer such guidance (Ferguson et al., 2022; King’s College London and Digital Science, 2015; Meadow and Owen, 2021; Muhonen et al., 2019). Specific research questions for each of the research agenda topics are presented in Fig. 4.

4.1.2. How do we best situate and support intermediaries to accelerate actionable knowledge production?

SOAK experts highlighted the critical need for intermediaries (i.e., boundary spanners) to bridge the functional divide between science and decision-making (and scientists and decision-makers) (Bednarek et al., 2018; Goodrich et al., 2020; Neal et al., 2022). While affirming the importance of boundary spanners, they also identified this topic as a top priority for future research. Many SOAK experts work within boundary spanning organizations and/or have studied boundary spanning as a practice and a theoretical concept. One of the main points raised by these experts is that such roles and their associated practices, expectations, institutional supports, and capacities vary greatly (Bednarek and Tseng, 2022). Yet, empirical analyses of such boundary functions are far and few (Bednarek et al., 2018; Cvitanovic et al., 2021; Goodrich et al., 2020; Safford et al., 2017). Additionally, though attributes of boundary spanners such as having knowledge of both the science and the policy space, or being ‘star communicators’ and optimists, can be characterized and categorized broadly (Crosno et al., 2009; Jesiek et al., 2018), there are still gaps in understanding how and to what extent they are able to navigate complex webs of interests, perspectives, needs, and values at the science-society interface (Kearns, 2021; Tseng et al., 2022). There is also limited examination of the risks they may face while engaging in such a crucial role.

More broadly, there is a limited understanding of how to evaluate boundary functions, especially since they may involve difficult-to-measure (also, often longitudinal) metrics such as improved trust or relationship building, that are not typically described in reports and published literature, unless, for example, specifically requested by funders (Arnott et al., 2020a; Neal et al., 2022; Oliver and Boaz, 2019; Posner and Cvitanovic, 2019; Weber and Yanovitzky, 2021). Another acknowledged need is in the realm of education (formal and informal), incentives, and other institutional mechanisms that provide academic and professional training and support to fulfill the growing need for boundary spanning intermediaries and cultivate inherent attributes (Enenkel and Kruczkiewicz, 2022; Goodrich et al., 2020; Rozance et al., 2020). The limited research on how boundary spanning shapes the SPI and its outcomes, resides in different knowledge domains (including international development, engineering, climate change, education, and public health), and have not been examined holistically (Posner and Cvitanovic, 2019; Tseng et al., 2022). Such holistic examinations are essential for advancing effective boundary work for example by defining ethical practices, and identifying approaches for negotiating power relations between different actors (Tseng et al., 2022; York et al., 2020). Future SOAK research would benefit from more systematic and integrative analyses of boundary spanning at the science-society interface to generate greater cross-fertilization of ideas.

How do we define and evaluate success in producing actionable knowledge?

- How do attributes of actionable knowledge (e.g., credibility, relevancy, legitimacy) differ across cultural contexts? How does engagement with different knowledge systems influence the meaning and evaluation of these attributes?
- What are methodological approaches to examine success in actionable knowledge production and its impact? How might these vary with different contexts and scales?
- How do we incorporate justice, equity, and distribution of power (especially for marginalized groups) in our framing of success? To what extent can SOAK address accessibility, inclusivity, diversity, and equity in its processes and outcomes?
- What are the ways in which we can monitor and respond to the unintended consequences or potential harms from the production or use of actionable knowledge?
- How can we design & fund evaluations that identify links between near term impacts of actionable knowledge (e.g. instrumental use of knowledge) and long-term, sustainable improvements to social and ecological systems?

How do we situate and support intermediaries to accelerate actionable knowledge production?

- To what extent and how can boundary spanners render different voices of participants when engaging at the science-society interface? How do they gain and retain credibility and legitimacy when working within conflict-riddled contexts?
- To what extent & how can boundary spanners create and stabilize the science-society interface in precarious contexts where governance institutions may be informal (e.g. lack of formal agencies representing the knowledge and interests of marginalized communities)?
- What are different approaches to examining the impacts of boundary functions?
- What are the relational (e.g., affective, reputational, career, trust) risks that boundary spanners face as representatives at the science-society interface, and how can they be mitigated?
- What are capacities and skills needed to work in and navigate, power dynamics and politics at the science-society interface? What trainings and institutional mechanisms are needed to foster the increasing need for effective intermediaries?

What is the meaning and role of trust in science-society engagements?

- What are different facets of trust (i.e. trust in science, trust in scientists, trust in the scientific process, trust in institutions, etc.) in the science-society interface, and how are they related to one another?
- What is known or unknown about the types of connections and trust that is built in participatory or collaborative processes? What have these processes been able to achieve or not, in terms of trust?
- What roles do trusted messengers play in science-society engagements?
- How does trust manifest in topics that are politicized and/or have different schools of thought or varying and evolving interpretations?
- Can and should trust be scaled-up? And if yes, how?

Is consensus required for informing policies and what could alternative approaches look like?

- Is consensus an appropriate objective for science-society engagements? Are successful science-society collaborations necessarily based on consensus?
- Is creating a "shared understanding" antithetical to allowing different perspectives to co-exist?
- Are there contexts (for example managing complex problems) where productive conflicts are desirable? How?
- How do science-society collaborations work in highly contentious scientific or political domains and why do they sometimes break down even when there is strong consensus (in either science or politics)?
- Are there political practices or theoretical models about productive conflict that can be leveraged to better understand this topic?

Fig. 4. Research agenda for Science of Actionable Knowledge (SOAK), developed based on expert elicitation, facilitated dialogue and iterative discussions with SOAK experts. The figure presents the four key topic areas of research that were identified as most warranting further work, and specific sub-questions under each topical area.

4.1.3. What is the meaning and role of trust in science-society engagements?

An oft-cited claim in both SPI as well as SOAK is that trust can be developed through long-term collaborations (Morgan and Di Giulio, 2018). Existing literature makes many assertions about the role that trust (or lack thereof) has played in exchange of knowledge at the science-society interface (Buizer et al., 2016; Clark et al., 2016, p. 201; Dilling and Lemos, 2011; McNie, 2007). Yet, SOAK experts highlighted that, as a construct, trust can have several facets, which have not been investigated empirically (Cvitanovic et al., 2021; Lacey et al., 2018). Some recent work has started to break down this concept, for example, distinguishing between 'affinitive'(trust based on liking), 'rational' (trust based on positive evaluation), and 'systems-based' (trust in procedures governing interactions) (Lacey et al., 2018; Stern et al., 2021) or between trust in individuals, trust in organizations, and trust in a process (Cvitanovic et al., 2021). Some work also discusses how trust in scientists is a multidimensional construct consisting of competence as well as personal characteristics like integrity, benevolence, and openness (Besley et al., 2021; Stern and Coleman, 2015). More such research is needed to better understand how and what types of trust exist in science-society collaborations, whether there is a trust deficit, and if yes, how trust should be enhanced.

SOAK experts also reiterated that understanding of trust at the science-society interface has been largely uncritical (Lacey et al., 2018). For instance, they questioned the popular narrative that lack of trust in science is the reason that science-based decisions are not made (Krause et al., 2021). New research has shown that trust in science and scientists can be quite high (Funk et al., 2019), but that trust is highly specific to the individual scientist or organization, to who is perceived to be making the decisions, what is being communicated, and the decision context (Krause et al., 2021). Furthermore, our discussions also highlighted that science is a dynamic process where trust can change, for example, as Krause et al. note "uncritical trust in science would be democratically undesirable…Stable and broad trust is prerequisite for evidence-based policy making in enlightened democracies, but both too little and too much trust is democratically dysfunctional (p. 230–1)." As an added complication, there were also discussions about how trust in science can vary across issue areas (e.g., climate change versus materials science), especially surrounding contested issues. Experts also pointed out that because of these complexities, trust becomes very difficult to measure and compare across different contexts. The widely varied nature of discussions of trust suggests a need for syntheses and empirical investigations that look across a greater number of cases and contexts.

4.1.4. Is consensus required for informing policies and what could alternative approaches look like?

Perhaps one of the most transcending debates that arose in the facilitated dialogue exercise was whether consensus is required for informing decision-making. Here, consensus refers to both scientific agreement about the facts of an issue of concern as well as a shared meaning of the issue of concern. Typically, such consensus requires the integration of relevant knowledge in a way that can address a shared problem in an authoritative, unambiguous, and clear way. The trouble with consensus is that not all kinds of knowledge and known facts are necessarily amenable to straightforward knowledge integration (Klenk and Meehan, 2015), nor is reaching a shared meaning of problems always possible given different histories, relationships and interests of the parties involved. The role of consensus as a mode of decision-making and knowledge production, and the politics of bringing different ways of knowing together to create a shared set of objectives, are very important for further research, particularly in relation to complexity and uncertainty (and equity, justice, and legitimacy). As the review of the SPI literature illustrates, power, tension, conflict, and difference are central concerns and dimensions of knowledge co-production. Too often, such troublesome dimensions are eclipsed by the aspirational and transformative discourse that characterize the current imperative to bring societal actors together to address complex problems. They key question is how to effectively harness difference and pluralism in science-society interactions (Díaz-Reviriego et al., 2019; Klenk, 2018; Klenk and Meehan, 2015, 2017; Pascual et al., 2021; Pearce et al., 2017; Wyborn et al., 2019).

Many questions related to consensus and its alternatives arose in our discussions with SOAK experts. These included questions on whether decision-making really needs consensus, because if it did, it might exclude quite a lot. It also gave rise to anecdotal evidence of consensus being achieved by ignoring, excluding, or co-opting diverse perspectives. Experts asked whether there are political practices or theoretical models that would render the practices of assembling different knowledges and desires in a way that is attentive to the potential positive aspects of certain forms of contestation. Some examples of such models that were discussed as avenues of further research included agonistic spaces that accept and channel conflict in productive ways (Mouffe, 2005) and deliberative democracy models such as hybrid forums (Callon et al., 2011). Specific research questions for this topic as well as the other research agenda topics are presented in Fig. 4.

5. Limitations

A systematic literature review of academic literature offers a useful description of the landscape of a body of scholarship, its significant contours, its points of interest, and its most and least visited sites. It can also point to the areas of research that scholars have sought to know in great depth, and other areas that have been less observed and therefore are not well-known. The authors of this research agenda have used this map of the SPI literature, not to provide a complete traveler's guide which would also include grey literature and testimonies of practitioners, but to think about what they perceive as directions that would be productive and interesting to take in future SOAK studies. Our analysis and proposed research agenda stems from a structured dialogue and discussions between the SPI literature and a limited group of SOAK experts. Several of the SOAK experts have contributed to the SPI literature and are now engaging with the concept of actionable knowledge. Our proposed research agenda and the specific questions are those that seemed to puzzle, interest, or trouble this group the most. Thus, we believe that these questions are likely to catalyze debate, reflection, and lead to research on paths less traveled. However, we also acknowledge that numerous potentially fruitful avenues of future SOAK research did not come up in our review and discussions, for instance: decision-sciences (Keeney, 1996), science diplomacy (Adamson and Lalli, 2021; Gore et al., 2020; Kaltofen and Acuto, 2018; Polejack, 2021; Young et al., 2022), conflict resolution (Nath et al., 2022; Stepanova et al., 2020; Tafon et al., 2022), Indigenous research approaches (Nikolakis and Hotte, 2022; Zurba et al., 2022), etc. We expect that additional work, for example, a complementary expert elicitation exercise solely with decision-makers, or literature reviews on other types of science-society engagements, could help to further expand this foundational set of research questions.

6. Conclusions

6.1. Centering governance rather than knowledge in the study of science-society interactions

Our survey and discussions suggest that there tends to be more focus on the technical outputs from science-society interactions (i.e., its knowledge dimensions) and less on the ways in which these interactions affect the governance dimensions of the science-society interface. A similar trend has also been noted by recent SOAK studies that highlight how power, politics, and other governance issues relating to actionable knowledge, are only beginning to be examined (Kirsop-Taylor and Russel, 2022; Turnhout et al., 2020; Wyborn et al., 2019). Indeed, there is often an implicit or explicit expectation that scientific evidence can and should be the primary source of reliable knowledge to inform decisions (Antonello and Howkins, 2020). Some decision scientists, however, have long argued that the structure of decision arenas means that scientific facts may often take a back seat to other considerations (March, 1982; Sarewitz, 2004). Although to acknowledge this limited role for science in decision-making is contrary to the normative claims about the SPI, the SOAK experts did, in fact, acknowledge the need to ask these probing questions on when, how, why, and to what extent the products of science and the processes of scientific co-production, can be useful in different decision venues. Several SOAK researchers are hence starting to reframe co-production and other science-society engagements as governance processes that navigate politics and tensions (as opposed to primarily *collaborative research and knowledge generation* processes) (Chambers et al., 2021; Kirsop-Taylor and Russel, 2022; Maas et al., 2022; Wyborn et al., 2019), which opens up a broader range of pathways for science-society engagements to achieve actionability.

Our research suggests that, in addition to a focus on the utilization of its empirical products (such as evaluation of actionable knowledge), we should seek to understand how institutions and efforts can be designed to build mutual accountability, political legitimacy, and trust among participants and within broader societal contexts (Mach et al., 2020; Meadow and Owen, 2021; Strumińska-Kutra and Scholl, 2022; Turnhout et al., 2020). Such a turn to politics also raises questions about the barriers to implementation of science-society engagements in contexts of conflict between stakeholder and right-holder groups, in the context of persistent colonial struggles, and in contexts of informal settlements where local knowledge holders are not recognized by official decision-makers. It has long been observed that in contexts where existing power structures and other systemic issues come to the forefront, research around re-balancing power and governance roles in science-society engagements is important (Lövbrand, 2011; Lövbrand et al., 2017). Some of the issues raised within this debate highlight the need to study actionable knowledge from a governance perspective, informed by more nuanced and deep engagement with theories of politics and justice.

Looking back on the research conducted on SPIs, our study offers several substantive knowledge claims that can help guide future research in SOAK. Although there are claims about the SPI that are consistently disagreed upon and some claims that are viewed as decidedly misguided, our expert elicitation results suggest that SOAK experts are reticent to disregard any of these claims. Rather, such claims are deemed useful to "think with", to clarify, problematize, and to achieve a more nuanced understanding of the assumptions of, the processes involved, and the outcomes of science-society engagements. Our analysis, therefore, is one step in building capacity for reflexive attunement to differences, tensions, and ambiguities at the science-society interface, while building upon the strong empirical and normative foundations that SPI scholarship has produced.

Author contributions

KJ, GE, JA, KJM and NK lead the design and drafting of the manuscript. NK initiated the conceptualization of the paper with GE and provided overall leadership of the manuscript. GE and NK undertook the systematic SPI literature review, coding, and initial identification of SPI claims. NK, GE, KJM, JA and KJ undertook the cluster analysis to refine the list of claims. They also designed and facilitated the expert elicitation survey and subsequent dialogue (none of the other authors were part of this process). All co-authors except for KJ, GE, JA, KJM and NK responded to the expert elicitation survey. AB-D, KG, RM, MN, KDS, KMFT, ET, GW-P, AD, CJK, RHM, LN and EO participated in the facilitated dialogue on the survey responses and provided feedback on manuscript drafts. AB-D, KG, RM, MN, KDS, KMFT, ET, GW-P, AB and AM supported the conceptual development of the research agenda through iterative discussions and provided writing support to build out key areas of the discussion and research agenda. KJ with support from GE and JA managed the multi-author collaboration during the manuscript development process.

Declaration of Competing Interest

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

Data Availability

Research data has been presented as supplementary material.

Acknowledgements

The authors would like to thank the members of the Science of Actionable Knowledge (SOAK) group (those who were not authors of this manuscript) who provided feedback and inspiration for this work. KJ's work was partially funded by Department of Energy Office of Science award number DE-SC-0016605 titled, A Framework for Improving Analysis and Modeling of Earth System and Intersectoral Dynamics at Regional Scales (HyperFACETS). JA's work is funded by the General Fund of the Aspen Global Change Institute. NK and GE gratefully acknowledge financial support for this research from the University of Toronto Scarborough International Research Collaboration Fund, the Social Sciences and Humanities Research Council (SSHRC) Institutional Fund and the SSHRC University of Toronto Excellence Award. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2023.03.004.

References

Adamson, M., Lalli, R., 2021. Global perspectives on science diplomacy: exploring the diplomacy-knowledge nexus in contemporary histories of science. Centaurus 63, 1–16. https://doi.org/10.1111/1600-0498.12369.
Antonello, A., Howkins, A., 2020. The rise of technocratic environmentalism: the United States, Antarctica, and the globalisation of the environmental impact statement. J. Hist. Geogr. 68, 55–64. https://doi.org/10.1016/j.jhg.2020.03.004.
Arnott, J.C., Lemos, M.C., 2021. Understanding knowledge use for sustainability. Environ. Sci. Policy 120, 222–230. https://doi.org/10.1016/j.envsci.2021.02.016.
Arnott, J.C., Kirchhoff, C.J., Meyer, R.M., Meadow, A.M., Bednarek, A.T., 2020a. Sponsoring actionable science: what public science funders can do to advance sustainability and the social contract for science. Curr. Opin. Environ. Sustain., Adv. Sci. Action. Knowl. Sustain. 42, 38–44. https://doi.org/10.1016/j.cosust.2020.01.006.
Arnott, J.C., Mach, K.J., Wong-Parodi, G., 2020b. Editorial overview: the science of actionable knowledge. Curr. Opin. Environ. Sustain. 42, A1–A5. https://doi.org/10.1016/j.cosust.2020.03.007.
Bammer, G., O'Rourke, M., O'Connell, D., Neuhauser, L., Midgley, G., Klein, J.T., Grigg, N.J., Gadlin, H., Elsum, I.R., Bursztyn, M., Fulton, E.A., Pohl, C., Smithson, M., Vilsmaier, U., Bergmann, M., Jaeger, J., Merkx, F., Vienni Baptista, B., Burgman, M.A., Walker, D.H., Young, J., Bradbury, H., Crawford, L., Haryanto, B., Pachanee, C., Polk, M., Richardson, G.P., 2020. Expertise in research integration and implementation for tackling complex problems: when is it needed, where can it be found and how can it be strengthened? Palgrave Commun. 6, 5. https://doi.org/10.1057/s41599-019-0380-0.
Bamzai-Dodson, A., Cravens, A.E., Wade, A., McPherson, R.A., 2021. Engaging with stakeholders to produce actionable science: a framework and guidance. Weather, Clim., Soc. https://doi.org/10.1175/WCAS-D-21-0046.1.
Bednarek, A., Tseng, V., 2022. A global movement for engaged research. Issues Sci. Technol. 38, 53–56.
Bednarek, A.T., Wyborn, C., Cvitanovic, C., Meyer, R., Colvin, R.M., Addison, P.F.E., Close, S.L., Curran, K., Farooque, M., Goldman, E., Hart, D., Mannix, H., McGreavy, B., Parris, A., Posner, S., Robinson, C., Ryan, M., Leith, P., 2018. Boundary spanning at the science–policy interface: the practitioners' perspectives. Sustain Sci. 13, 1175–1183. https://doi.org/10.1007/s11625-018-0550-9.
Besley, J.C., Lee, N.M., Pressgrove, G., 2021. Reassessing the variables used to measure public perceptions of scientists. Sci. Commun. 43, 3–32.
Bremer, S., Meisch, S., 2017. Co-production in climate change research: reviewing different perspectives. WIREs Clim. Change 8. https://doi.org/10.1002/wcc.482.
Buizer, J., Jacobs, K., Cash, D., 2016. Making short-term climate forecasts useful: Linking science and action. Proc. Natl. Acad. Sci. U. S. A. 113, 4597–4602. https://doi.org/10.1073/pnas.0900518107.
Callon, M., Lascoumes, P., Barthe, Y., 2011. Acting in an uncertain world: an essay on technical democracy. In: First, M.I.T. (Ed.), Press paperback edition. MIT Press, Cambridge, Massachusetts London, England.
Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. PNAS 100, 8086–8091. https://doi.org/10.1073/pnas.1231332100.
Chambers, J.M., Wyborn, C., Ryan, M.E., Reid, R.S., Riechers, M., Serban, A., Bennett, N.J., Cvitanovic, C., Fernández-Giménez, M.E., Galvin, K.A., Goldstein, B.E., Klenk, N.L., Tengö, M., Brennan, R., Cockburn, J.J., Hill, R., Munera, C., Nel, J.L., Österblom, H., Bednarek, A.T., Bennett, E.M., Brandeis, A., Charli-Joseph, L., Chatterton, P., Curran, K., Dumrongrojwatthana, P., Durán, A.P., Fada, S.J., Gerber, J.-D., Green, J.M.H., Guerrero, A.M., Haller, T., Horcea-Milcu, A.-I., Leimona, B., Montana, J., Rondeau, R., Spierenburg, M., Steyaert, P., Zaehringer, J.G., Gruby, R., Hutton, J., Pickering, T., 2021. Six modes of co-production for sustainability. Nat. Sustain 4, 983–996. https://doi.org/10.1038/s41893-021-00755-x.
Chilvers, J., Kearnes, M., 2020. Remaking participation in science and democracy. Sci., Technol., Hum. Values 45, 347–380. https://doi.org/10.1177/0162243919850885.
Clark, W.C., Tomich, T.P., van Noordwijk, M., Guston, D., Catacutan, D., Dickson, N.M., McNie, E., 2016. Boundary work for sustainable development: Natural resource management at the Consultative Group on International Agricultural Research (CGIAR). Proc. Natl. Acad. Sci. U. S. A. 113, 4615–4622. https://doi.org/10.1073/pnas.0900231108.
Coreau, A., Narcy, J.-B., Lumbroso, S., 2018. Who really wants an ambitious large-scale restoration of the seine estuary? A strategic analysis of a science–policy interface locked in a stalemate. Environ. Manag. 61, 834–847.
Crosno, J.L., Rinaldo, S.B., Black, H.G., Kelley, S.W., 2009. Half full or half empty: the role of optimism in boundary-spanning positions. J. Serv. Res. 11, 295–309. https://doi.org/10.1177/1094670508328985.
Cvitanovic, C., Shellock, R., Mackay, M., van Putten, E., Karcher, D., Dickey-Collas, M., Ballesteros, M., 2021. Strategies for building and managing 'trust'to enable knowledge exchange at the interface of environmental science and policy. Environ. Sci. Policy 123, 179–189.
Díaz-Reviriego, I., Turnhout, E., Beck, S., 2019. Participation and inclusiveness in the intergovernmental science–policy platform on biodiversity and ecosystem services. Nat. Sustain 2, 457–464. https://doi.org/10.1038/s41893-019-0290-6.
Dilling, L., Lemos, M.C., 2011. Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy. Glob. Environ. Change 21, 680–689. https://doi.org/10.1016/j.gloenvcha.2010.11.006.
Enenkel, M., Kruczkiewicz, A., 2022. The humanitarian sector needs clear job profiles for climate science translators now more than ever. Bull. Am. Meteorol. Soc. 103, E1088–E1097. https://doi.org/10.1175/BAMS-D-20-0263.1.

Englund, M., André, K., Gerger Swartling, Å., Iao-Jörgensen, J., 2022. Four methodological guidelines to evaluate the research impact of co-produced climate services. Front. Clim. 4, 909422 https://doi.org/10.3389/fclim.2022.909422.
Faehnrich, B., Ruser, A., 2019. 'Operator, please' — connecting truth and power at the science-policy interface (E.). JCOM 18. https://doi.org/10.22323/2.18030501.
Felt, U. (Ed.), 2017. The handbook of science and technology studies, fourth ed. The MIT Press, Cambridge, Massachusetts.
Ferguson, D.B., Meadow, A.M., Huntington, H.P., 2022. Making a difference: planning for engaged participation in environmental research. Environ. Manag. 69, 227–243. https://doi.org/10.1007/s00267-021-01585-5.
Funk, C., Hefferon, M., Kennedy, B., Johnson, C., 2019. Trust and mistrust in Americans' views of scientific experts. Pew Res. Cent. 2, 1–96.
Gluckman, P.D., Bardsley, A., Kaiser, M., 2021. Brokerage at the science–policy interface: from conceptual framework to practical guidance. Humanit Soc. Sci. Commun. 8, 84. https://doi.org/10.1057/s41599-021-00756-3.
Goodrich, K.A., Sjostrom, K.D., Vaughan, C., Nichols, L., Bednarek, A., Lemos, M.C., 2020. Who are boundary spanners and how can we support them in making knowledge more actionable in sustainability fields? Curr. Opin. Environ. Sustain. 42, 45–51. https://doi.org/10.1016/j.cosust.2020.01.001.
Gore, M.L., Nichols, E.S., Lips, K.R., 2020. Preparing scientists for science diplomacy requires new science policy bridges. Hague J. Dipl. 15, 424–434. https://doi.org/10.1163/1871191X-BJA10024.
Guston, D.H., 2001. Boundary organizations in environmental policy and science: an introduction. Sci., Technol., Hum. Values 26, 399–408.
Hopkins, A., Oliver, K., Boaz, A., Guillot-Wright, S., Cairney, P., 2021. Are research-policy engagement activities informed by policy theory and evidence? 7 challenges to the UK impact agenda. Policy Des. Pract. 4, 341–356. https://doi.org/10.1080/25741292.2021.1921373.
van den Hove, S., 2007. A rationale for science–policy interfaces. Futures 39, 807–826. https://doi.org/10.1016/j.futures.2006.12.004.
Jagannathan, K., Arnott, J.C., Wyborn, C., Klenk, N., Mach, K.J., Moss, R.H., Sjostrom, K. D., 2020. Great expectations? Reconciling the aspiration, outcome, and possibility of co-production. Curr. Opin. Environ. Sustain. 42, 22–29. https://doi.org/10.1016/j.cosust.2019.11.010.
Jagannathan, K., Jones, A.D., Buddhavarapu, S., Ullrich, P., 2022. Typologies of actionable climate information and its use. SSRN J. https://doi.org/10.2139/ssrn.4243312.
Jesiek, B.K., Mazzurco, A., Buswell, N.T., Thompson, J.D., 2018. Boundary spanning and engineering: a qualitative systematic review. J. Eng. Educ. 107, 380–413. https://doi.org/10.1002/jee.20219.
Kaaronen, R., 2016. Scientific support for sustainable development policies. A Typology of Science-Policy Interfaces with Case Studies. Sitra Stud. 118.
Kaltofen, C., Acuto, M., 2018. Science diplomacy: introduction to a boundary problem. Glob. Policy 9, 8–14. https://doi.org/10.1111/1758-5899.12621.
Karcher, D.B., Cvitanovic, C., Colvin, R.M., van Putten, I.E., Reed, M.S., 2021. Is this what success looks like? Mismatches between the aims, claims, and evidence used to demonstrate impact from knowledge exchange processes at the interface of environmental science and policy. Environ. Sci. Policy 125, 202–218. https://doi.org/10.1016/j.envsci.2021.08.012.
Katyaini, S., Barua, A., Duarte, R., 2020. Science-policy interface on water scarcity in India: Giving 'visibility' to unsustainable virtual water flows (1996–2014). J. Clean. Prod. 275, 124059 https://doi.org/10.1016/j.jclepro.2020.124059.
Kearns, F., 2021. Getting to the heart of science communication: a guide to effective engagement. Island Press, Washington.
Keeney, R.L., 1996. Value-focused thinking: a path to creative decisionmaking. Harvard University Press.
King's College London, Digital Science, 2015. The nature, scale and beneficiaries of research impact: an initial analysis of Research Excellence Framework (REF) 2014 impact case studies. HEFCE, Bristol, United Kingdom.
Kirchhoff, C.J., Carmen Lemos, M., Dessai, S., 2013. Actionable knowledge for environmental decision making: broadening the usability of climate science. Annu. Rev. Environ. Resour. 38, 393–414. https://doi.org/10.1146/annurev-environ-022112-112828.
Kirsop-Taylor, N., Russel, D., 2022. Agencies navigating the political at the science-to-policy interface for nature-based solutions. Environ. Sci. Policy 127, 303–310. https://doi.org/10.1016/j.envsci.2021.10.029.
Klenk, N., 2018. From network to meshwork: Becoming attuned to difference in transdisciplinary environmental research encounters. Environ. Sci. Policy 89, 315–321. https://doi.org/10.1016/j.envsci.2018.08.007.
Klenk, N., Meehan, K., 2015. Climate change and transdisciplinary science: problematizing the integration imperative. Environ. Sci. Policy 54, 160–167. https://doi.org/10.1016/j.envsci.2015.05.017.
Klenk, N.L., Meehan, K., 2017. Transdisciplinary sustainability research beyond engagement models: toward adventures in relevance. Environ. Sci. Policy 78, 27–35. https://doi.org/10.1016/j.envsci.2017.09.006.
Krause, N.M., Scheufele, D.A., Freiling, I., Brossard, D., 2021. The Trust Fallacy: Scientists' search for public pathologies is unhealthy, unhelpful, and ultimately unscientific. Am. Sci. 109, 226–232.
Lacey, J., Howden, M., Cvitanovic, C., Colvin, R.M., 2018. Understanding and managing trust at the climate science–policy interface. Nat. Clim. Change 8, 22–28. https://doi.org/10.1038/s41558-017-0010-z.
Lang, D.J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., Thomas, C.J., 2012. Transdisciplinary research in sustainability science: practice, principles, and challenges. Sustain Sci. 7, 25–43. https://doi.org/10.1007/s11625-011-0149-x.
Lange, H., Garrelts, H., 2007. Risk management at the science–policy interface: two contrasting cases in the field of flood protection in Germany. J. Environ. Policy Plan. 9, 263–279.
Latulippe, N., Klenk, N., 2020. Making room and moving over: knowledge co-production, Indigenous knowledge sovereignty and the politics of global environmental change decision-making. Curr. Opin. Environ. Sustain. 42, 7–14. https://doi.org/10.1016/j.cosust.2019.10.010.
Lemos, M.C., Morehouse, B.J., 2005. The co-production of science and policy in integrated climate assessments. Glob. Environ. Change 15, 57–68. https://doi.org/10.1016/j.gloenvcha.2004.09.004.
Lemos, M.C., Arnott, J.C., Ardoin, N.M., Baja, K., Bednarek, A.T., Dewulf, A., Fieseler, C., Goodrich, K.A., Jagannathan, K., Klenk, N., Mach, K.J., Meadow, A.M., Meyer, R., Moss, R., Nichols, L., Sjostrom, K.D., Stults, M., Turnhout, E., Vaughan, C., Wong-Parodi, G., Wyborn, C., 2018. To co-produce or not to co-produce. Nat. Sustain 1, 722–724. https://doi.org/10.1038/s41893-018-0191-0.
Lövbrand, E., 2011. Co-producing European climate science and policy: a cautionary note on the making of useful knowledge. Sci. Pub. Pol. 38, 225–236. https://doi.org/10.3152/030234211X12924093660516.
Lövbrand, E., Hjerpe, M., Linnér, B.-O., 2017. Making climate governance global: how UN climate summitry comes to matter in a complex climate regime. Environ. Polit. 26, 580–599. https://doi.org/10.1080/09644016.2017.1319019.
Lubell, M., Morrison, T.H., 2021. Institutional navigation for polycentric sustainability governance. Nat. Sustain 4, 664–671. https://doi.org/10.1038/s41893-021-00707-5.
Maas, T.Y., Pauwelussen, A., Turnhout, E., 2022. Co-producing the science–policy interface: towards common but differentiated responsibilities. Humanit Soc. Sci. Commun. 9, 93. https://doi.org/10.1057/s41599-022-01108-5.
Mach, K.J., Mastrandrea, M.D., Freeman, P.T., Field, C.B., 2017. Unleashing expert judgment in assessment. Glob. Environ. Change 44, 1–14.
Mach, K.J., Kraan, C.M., Adger, W.N., Buhaug, H., Burke, M., Fearon, J.D., Field, C.B., Hendrix, C.S., Maystadt, J.-F., O'Loughlin, J., Roessler, P., Scheffran, J., Schultz, K. A., von Uexkull, N., 2019. Climate as a risk factor for armed conflict. Nature 571, 193–197. https://doi.org/10.1038/s41586-019-1300-6.
Mach, K.J., Lemos, M.C., Meadow, A.M., Wyborn, C., Klenk, N., Arnott, J.C., Ardoin, N. M., Fieseler, C., Moss, R.H., Nichols, L., Stults, M., Vaughan, C., Wong-Parodi, G., 2020. Actionable knowledge and the art of engagement. Curr. Opin. Environ. Sustain. 42, 30–37. https://doi.org/10.1016/j.cosust.2020.01.002.
March, J.G., 1982. Theories of choice and making decisions. Society 20, 29–39. https://doi.org/10.1007/BF02694989.
McKinley, D.C., Miller-Rushing, A.J., Ballard, H.L., Bonney, R., Brown, H., Cook-Patton, S.C., Evans, D.M., French, R.A., Parrish, J.K., Phillips, T.B., Ryan, S.F., Shanley, L.A., Shirk, J.L., Stepenuck, K.F., Weltzin, J.F., Wiggins, A., Boyle, O.D., Briggs, R.D., Chapin, S.F., Hewitt, D.A., Preuss, P.W., Soukup, M.A., 2017. Citizen science can improve conservation science, natural resource management, and environmental protection. Biol. Conserv. 208, 15–28. https://doi.org/10.1016/j.biocon.2016.05.015.
McNie, E.C., 2007. Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. Environ. Sci. Policy 10, 17–38.
Meadow, A., Owen, G., 2021. Planning and Evaluating the Societal Impacts of Climate Change Research Projects: A guidebook for natural and physical scientists looking to make a difference. The University of Arizona. https://doi.org/10.2458/10150.658313.
Meinke, H., Nelson, R., Kokic, P., Stone, R., Selvaraju, R., Baethgen, W., 2006. Actionable climate knowledge: from analysis to synthesis. Clim. Res. 33, 101–110.
Morgan, E.A., Di Giulio, G.M., 2018. Science and evidence-based climate change policy: collaborative approaches to improve the science–policy interface. In: Serrao-Neumann, S., Coudrain, A., Coulter, L. (Eds.), Communicating Climate Change Information for Decision-Making, Springer Climate. Springer International Publishing, Cham, pp. 13–28. https://doi.org/10.1007/978-3-319-74669-2_2.
Morgan, M.G., 2014. Use (and abuse) of expert elicitation in support of decision making for public policy. Proc. Nat. Acad. Sci. 7176–7184.
Mouffe, C., 2005. The return of the political. Verso.
Muhonen, R., Benneworth, P., Olmos-Peñuela, J., 2019. From productive interactions to impact pathways: understanding the key dimensions in developing SSH research societal impact. Res. Eval. https://doi.org/10.1093/reseval/rvz003.
Nath, S., Shams, J., van Laerhoven, F., Driessen, P., 2022. The impact of decision-making on conflict: rethinking the roles of technocrats and residents during Tidal River Management in coastal Bangladesh. Land Use Policy 117, 106103. https://doi.org/10.1016/j.landusepol.2022.106103.
Neal, J.W., Neal, Z.P., Brutzman, B., 2022. Defining brokers, intermediaries, and boundary spanners: a systematic review. Evid. Policy 18, 7–24. https://doi.org/10.1332/174426420X16083745764324.
Nikolakis, W., Hotte, N., 2022. Implementing "ethical space": an exploratory study of Indigenous-conservation partnerships. Conserv. Sci. Pr. 4 https://doi.org/10.1111/csp2.580.
Norström, A.V., Cvitanovic, C., Löf, M.F., West, S., Wyborn, C., Balvanera, P., Bednarek, A.T., Bennett, E.M., Biggs, R., de Bremond, A., Campbell, B.M., Canadell, J.G., Carpenter, S.R., Folke, C., Fulton, E.A., Gaffney, O., Gelcich, S., Jouffray, J.-B., Leach, M., Le Tissier, M., Martín-López, B., Louder, E., Loutre, M.-F., Meadow, A.M., Nagendra, H., Payne, D., Peterson, G.D., Reyers, B., Scholes, R., Speranza, C.I., Spierenburg, M., Stafford-Smith, M., Tengö, M., van der Hel, S., van Putten, I., Österblom, H., 2020. Principles for knowledge co-production in sustainability research. Nat. Sustain 3, 182–190. https://doi.org/10.1038/s41893-019-0448-2.

Ojanen, M., Brockhaus, M., Korhonen-Kurki, K., Petrokofsky, G., 2021. Navigating the science-policy interface: forest researcher perspectives. Environ. Sci. Policy 118, 10–17. https://doi.org/10.1016/j.envsci.2021.01.002.
Oliver, K., Boaz, A., 2019. Transforming evidence for policy and practice: creating space for new conversations. Palgrave Commun. 5, 60. https://doi.org/10.1057/s41599-019-0266-1.
Olson, J., Pinto da Silva, P., 2019. Knowledge production at the science–policy interface: lessons from fisheries scientists. Sci. Public Policy scz045. https://doi.org/10.1093/scipol/scz045.
Pascual, U., Adams, W.M., Díaz, S., Lele, S., Mace, G.M., Turnhout, E., 2021. Biodiversity and the challenge of pluralism. Nat. Sustain 4, 567–572. https://doi.org/10.1038/s41893-021-00694-7.
Pearce, W., Grundmann, R., Hulme, M., Raman, S., Hadley Kershaw, E., Tsouvalis, J., 2017. Beyond counting climate consensus. Environ. Commun. 11, 723–730. https://doi.org/10.1080/17524032.2017.1333965.
Pohl, C., Klein, J.T., Hoffmann, S., Mitchell, C., Fam, D., 2021. Conceptualising transdisciplinary integration as a multidimensional interactive process. Environ. Sci. Policy 118, 18–26. https://doi.org/10.1016/j.envsci.2020.12.005.
Polejack, A., 2021. The importance of ocean science diplomacy for ocean affairs, global sustainability, and the UN decade of ocean science. Front. Mar. Sci. 8, 664066 https://doi.org/10.3389/fmars.2021.664066.
Polk, M., 2015. Transdisciplinary co-production: designing and testing a transdisciplinary research framework for societal problem solving. Futures 65, 110–122. https://doi.org/10.1016/j.futures.2014.11.001.
Posner, S.M., Cvitanovic, C., 2019. Evaluating the impacts of boundary-spanning activities at the interface of environmental science and policy: a review of progress and future research needs. Environ. Sci. Policy 92, 141–151. https://doi.org/10.1016/j.envsci.2018.11.006.
Quevauviller, P., 2007. Water protection against pollution. Environ. Sci. Poll. Res Int 14, 297–307. https://doi.org/10.1065/espr2007.06.432.
Ravetz, I., 1999. What is post-normal science. Futures- J. Forecast. Plan. Policy 31, 647–654.
Rozance, M.A., Krosby, M., Meadow, A.M., Snover, A., Ferguson, D.B., Owen, G., 2020. Building capacity for societally engaged climate science by transforming science training. Environ. Res. Lett. 15, 125008 https://doi.org/10.1088/1748-9326/abc27a.
Safford, H.D., Sawyer, S.C., Kocher, S.D., Hiers, J.K., Cross, M., 2017. Linking knowledge to action: the role of boundary spanners in translating ecology. Front Ecol. Environ. 15, 560–568. https://doi.org/10.1002/fee.1731.
Sarewitz, D., 2004. How science makes environmental controversies worse. Environ. Sci. Policy 7, 385–403. https://doi.org/10.1016/j.envsci.2004.06.001.
Schlesinger, W.H., 2010. Translational Ecology, 609–609 Science 329. https://doi.org/10.1126/science.1195624.
Singer-Brodowski, M., Brock, A., Grund, J., de Haan, G., 2021. Reflections on the science–policy interface within education for sustainable development in Germany. Environ. Educ. Res. 27, 554–570. https://doi.org/10.1080/13504622.2020.1813691.
Smith, L.T., 2012 (ed.). Decolonizing methodologies: research and indigenous peoples, second ed. Zed Books, London.
Sokolovska, N., Fecher, B., Wagner, G.G., 2019. Communication on the science-policy interface: an overview of conceptual models. Publications 7, 64. https://doi.org/10.3390/publications7040064.
Stepanova, O., Polk, M., Saldert, H., 2020. Understanding mechanisms of conflict resolution beyond collaboration: an interdisciplinary typology of knowledge types and their integration in practice. Sustain Sci. 15, 263–279. https://doi.org/10.1007/s11625-019-00690-z.
Stern, M.J., Coleman, K.J., 2015. The multidimensionality of trust: applications in collaborative natural resource management. Soc. Nat. Resour. 28, 117–132. https://doi.org/10.1080/08941920.2014.945062.
Stern, M.J., Briske, D.D., Meadow, A.M., 2021. Opening learning spaces to create actionable knowledge for conservation. Conserv. Sci. Pr. 3 https://doi.org/10.1111/csp2.378.
Stirling, A., 2008. "Opening up" and "closing down": power, participation, and pluralism in the social appraisal of technology. Sci., Technol., Hum. Values 33, 262–294. https://doi.org/10.1177/0162243907311265.
Strumińska-Kutra, M., Scholl, C., 2022. Taking power seriously: towards a power-sensitive approach for transdisciplinary action research. Futures 135, 102881. https://doi.org/10.1016/j.futures.2021.102881.
Tafon, R., Glavovic, B., Saunders, F., Gilek, M., 2022. Oceans of conflict: pathways to an ocean sustainability PACT. Plan. Pract. Res. 37, 213–230. https://doi.org/10.1080/02697459.2021.1918880.
Totlandsdal, A.I., Fudge, N., Sanderson, E.G., van Bree, L., Brunekreef, B., 2007. Strengthening the science–policy interface: experiences from a European Thematic Network on Air Pollution and Health (AIRNET). Environ. Sci. Policy 10, 260–266.
Tseng, V., Bednarek, A., Faccer, K., 2022. How can funders promote the use of research? Three converging views on relational research. Humanit Soc. Sci. Commun. 9, 219. https://doi.org/10.1057/s41599-022-01157-w.
Turnhout, E., 2018. The politics of environmental knowledge. Conserv. Soc. 16, 363–371.
Turnhout, E., Metze, T., Wyborn, C., Klenk, N., Louder, E., 2020. The politics of co-production: participation, power, and transformation. Curr. Opin. Environ. Sustain. 42, 15–21. https://doi.org/10.1016/j.cosust.2019.11.009.
van Breda, J., Swilling, M., 2019. The guiding logics and principles for designing emergent transdisciplinary research processes: learning experiences and reflections from a transdisciplinary urban case study in Enkanini informal settlement, South Africa. Sustain Sci. 14, 823–841. https://doi.org/10.1007/s11625-018-0606-x.
van Ravenswaay, P., Luborsky, L., Childress, A., 1983. Consistency of the transference in vs. out of psychotherapy. Society for Psychotherapy Research, Sheffield, England. [LL].
VanderMolen, K., Meadow, A.M., Horangic, A., Wall, T.U., 2020. Typologizing stakeholder information use to better understand the impacts of collaborative climate science. Environ. Manag. 65, 178–189. https://doi.org/10.1007/s00267-019-01237-9.
Wallis, M.K., 2007. Clean air strategies: an environmental nongovernmental organization perspective on the science–policy interface. J. Toxicol. Environ. Health, Part A 70, 369–376. https://doi.org/10.1080/15287390600885070.
Walter, A.I., Helgenberger, S., Wiek, A., Scholz, R.W., 2007. Measuring societal effects of transdisciplinary research projects: Design and application of an evaluation method. Eval. Program Plan. 30, 325–338. https://doi.org/10.1016/j.evalprogplan.2007.08.002.
Weber, M.S., Yanovitzky, I., 2021. Knowledge brokers, networks, and the policymaking process. In: Weber, M.S., Yanovitzky, I. (Eds.), Networks, Knowledge Brokers, and the Public Policymaking Process. Springer International Publishing, Cham, pp. 1–25. https://doi.org/10.1007/978-3-030-78755-4_1.
Wong-Parodi, G., Feygina, I., 2020. Understanding and countering the motivated roots of climate change denial. Curr. Opin. Environ. Sustain. 42, 60–64. https://doi.org/10.1016/j.cosust.2019.11.008.
Wong-Parodi, G., Mach, K.J., Jagannathan, K., Sjostrom, K.D., 2020. Insights for developing effective decision support tools for environmental sustainability. Curr. Opin. Environ. Sustain. Adv. Sci. Action. Knowl. Sustain. 42, 52–59. https://doi.org/10.1016/j.cosust.2020.01.005.
Wyborn, C., Datta, A., Montana, J., Ryan, M., Leith, P., Chaffin, B., Miller, C., van Kerkhoff, L., 2019. Co-producing sustainability: reordering the governance of science, policy, and practice. Annu. Rev. Environ. Resour. 44, 319–346. https://doi.org/10.1146/annurev-environ-101718-033103.
York, A., Valladares, S., Valladares, M.R., Snyder, J., Garcia, M.V., 2020. Community Research Collaboratives.
Young, J.C., Young, J.R., Aubert, B.A., 2022. Insights from diplomacy for the prevention and resolution of conservation conflicts. Conserv. Lett. 15 https://doi.org/10.1111/conl.12891.
Yua, E., Raymond-Yakoubian, J., Daniel, R.A., Behe, C., 2022. A framework for co-production of knowledge in the context of Arctic research. E&S 27, art34. https://doi.org/10.5751/ES-12960-270134.
Zurba, M., Petriello, M.A., Madge, C., McCarney, P., Bishop, B., McBeth, S., Denniston, M., Bodwitch, H., Bailey, M., 2022. Learning from knowledge co-production research and practice in the twenty-first century: global lessons and what they mean for collaborative research in Nunatsiavut. Sustain Sci. 17, 449–467. https://doi.org/10.1007/s11625-021-00996-x.