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TOWARDS PRODUCTIVE SCIENCE-POLICY INTERFACES: A RESEARCH AGENDA

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Science-policy interactions are often contested, due to strategic production and use of knowledge. This is problematic because the potential of science to enrich decision-making is underexploited. Scientific literature suggests that these problems are related to a lack of credibility, salience and/or legitimacy of knowledge. Science-policy interfaces (SPIs), such as knowledge brokers, are suggested to enhance science-policy interactions by promoting the production of credible, salient and legitimate knowledge. However, the current scientific debate provides little clarity on which SPIs are most useful in solving which science-policy interaction problems and what strategies should be employed. Based on a profound literature review, this paper aims to arrive at a better understanding of SPIs, by providing conceptual clarity and linking typical SPIs to distinct problems and the contexts in which they emerge. We suggest an empirical research agenda to test theoretical claims about SPIs and our own refinements thereof, and to identify best practices.

Keywords: Science-policy interfaces; knowledge; salience; credibility; legitimacy.

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Note: The literature review presented in this paper forms part of a larger research project in which empirical testing of the conceptual framework and hypotheses that are discussed in this paper is planned. We aim to publish the results of our empirical work in the near future. We invite readers of JEAPM to comment on, and discuss our framework and hypotheses.

Introduction

In recent decades, scientific knowledge has been extremely important in informing the policy-making processes to improve or solve environmental problems dealing with, for example, air and water quality (e.g. Ferranti *et al.*, 2013; Totlandsdal *et al.*, 2007; Quevauviller *et al.*, 2005; Sundqvist *et al.*, 2002; Ducrotoy and Elliott, 1997; Klabbers *et al.*, 1996; Jasanoff, 1990). Specific arrangements, such as Environmental Impact Assessment (EIA), were put in place to connect science and policy and enhance their interactions (e.g. Fischer and Onyango, 2012; Morrison-Saunders and Fischer, 2006; Bartlett and Kurian, 1999; Bailey, 1997; Caldwell, 1998). However, although in some cases scientific knowledge clearly plays a decisive role in solving these issues, the relationship between science and policy is often still a troubled and contested one (e.g. Holmes and Clark, 2008; Lackey, 2007; Pielke, 2004; Sarawitz, 2004; Ozawa, 1996), especially in the arena of environmental policy. This is explained by the complex and multi-layered character of the field and the involvement of an array of stakeholders with conflicting stakes and needs (Driessen *et al.*, 2010).

Problems with science-policy interactions

Difficulties regarding the relationship and interactions between science and policy arise in both domains,[1] and take the form of the strategic (mis)use of knowledge (e.g. Runhaar and Van Nieuwaal, 2010), the strategic production of knowledge (Pielke, 2007), a misfit of demand for and supply of knowledge (e.g. Jones *et al.*, 1999), and issues with the handling of scientific uncertainties (e.g. Van der Sluijs *et al.*, 2010). As a consequence, opportunities to enrich problem analyses and the exploration of policy options by means of scientific knowledge are not fully exploited (Pielke, 2007). Inspired by the influential paper by Cash *et al.* (2003), many authors have tried to explain knowledge use in decision-making and the above problems in science-policy interactions from a lack of credibility, salience or legitimacy of the knowledge at issue (e.g. Richardson, 2013; Bauler, 2012; Hegger *et al.*, 2012). *Salience* refers to the relevance of information for the decision-maker and the problem at stake. *Credibility* refers to whether an actor perceives information as meeting standards of scientific plausibility and technical adequacy, and whether sources are trustworthy and/or believable. *Legitimacy*

[1] With the concept of "science" we mean a "body of research, where knowledge is the outcome of social processes and institutional guided actions of researchers" (Van Buuren and Edelenbos, 2004: 291); with the concept "policy" we mean a course of action designed to resolve or mitigate problems in the political sphere (Fischer, 1997).

refers to the extent to which the produced knowledge has been respectful of the divergent values and beliefs of stakeholders, unbiased in its conduct and fair in its treatment of opposing views and interests (Hegger *et al.*, 2012; Cash *et al.*, 2003). Based on this discussion, we may expect that overcoming problems of misuse and mis-production of science require the production and use of science that is credible, salient and legitimate.

Solution: science-policy interfaces?

Literature suggests a variety of "solutions" in the shape of so called "science-policy interfaces" (SPIs) (e.g. Holmes and Clark, 2008; Van den Hove, 2007; Bradshaw and Borchers, 2000; Jones *et al.*, 1999). SPIs aim at overcoming, amongst others, the previously mentioned science-policy interaction problems and contribute to enriched decision-making; decisions that are well-informed about the problems at stake and the range of available intervention strategies, which facilitates a better handling of those environmental problems (Pielke, 2007; Van den Hove, 2007), acknowledging at the same time that science is just one part of the complex decision-making processes (Lackey, 2007; Pielke, 2007).

Examples of SPIs can be process designs, such as joint knowledge production (e.g. Hegger *et al.*, 2012; Edelenbos *et al.*, 2011) or joint fact finding (e.g. Karl *et al.*, 2007; Ehrmann and Stinson, 1999), but also institutions such as boundary organisations ("organisations that 'straddle the shifting divide between science and policy', mediating between science and policy and facilitating the interaction between actors on either side or who cross the boundary" (Cash, 2001: 432)) or boundary work(ers) (e.g. Pesch *et al.*, 2012; Huitema and Turnhout, 2009; Hoppe, 2009; McNie, 2007).

Knowledge gap

However, the descriptions of these interfaces are often highly abstract, and it is unclear how they differ from each other, and in which situation a specific interface could be used to enhance the science-policy interaction. Although literature provides us with some empirical cases of SPIs (e.g. Boezeman *et al.* (2013) and Huitema and Turnhout (2009) on boundary organisations; Hegger *et al.* (2012) on knowledge co-production), we argue that little focus is placed on the correlation between the used SPI and the interaction problems, and the possible strategies which the interfaces entail which ought to lead to a better science-policy interaction and thus into enriched decision-making. In particular still little is known about how different types of SPIs contribute to the production of knowledge that is credible, legitimate and salient — as discussed above, important requirements for the actual use of knowledge in decision-making. It leaves us wondering, *which SPI works where, when and how?*

Research aim

As a first step in answering the above question, the goal of this paper is to develop a more cohesive framework on the relation between the science-policy interaction problems and SPIs, which we feel is currently lacking. Not only do we aim to provide conceptual clarity and structure in the scientific literature about SPIs and science-policy interaction problems and the contexts in which they emerge, we will also propose a research agenda for further empirical research on SPIs. We argue that empirical research is needed to enhance our insight into when, where and how these SPIs work, by testing hypotheses and identifying best practices.

The following section will describe different problems as suggested by various authors with regard to the science-policy interaction. The research question of this section is: "*Which problems regarding the science-policy interactions are identified in the literature and what is their adverse influence on the effectiveness of scientific knowledge?*". Based on a literature review, we will develop a new typology regarding the types of problems and will link this typology to the three criteria for scientific knowledge (salience, credibility and legitimacy) by Cash *et al.* (2003). In order to develop hypotheses about *when* the types of science-policy interaction problems occur we employ the typology of policy problems developed by Hoppe (2005). The third section will consist of the determination of a definition and typology of SPIs, which will then be linked to the specific interaction problems that they, theoretically, solve. The main question addressed in this section is "*Which interfaces are predominantly suggested in the literature and how are they linked to the interaction problems?*". Finally, we will present a research agenda consisting of suggestions towards the next steps for empirical research on SPIs and our concluding hypotheses.

Problems Influencing the Science-Policy Interactions

In this section, we identify specific problems which negatively influence the science-policy interactions which are most dominantly present in the literature. We sub-divide these problems into three different clusters, or "meta problems": (1) the *strategic use of knowledge by policy*, (2) the *strategic production of knowledge by science*, and, finally (3) the *operational misfit of demand for and supply of knowledge*.

In this clustering (Fig. 1), we make a clear distinction between strategic and operational problems. As we will demonstrate further on, literature clearly defines different SPIs with their own goals and strategies. In this context, "goal" refers to the science-policy interaction problems that the interface (and its actors) aim/s to solve; "strategy" refers to the specific actions taken by the actors involved. By making the differentiation between strategic and operational interaction problems, it will become apparent that, in order to resolve these problems, different strategies and thus SPIs are required. By presenting these relationships, we aim to get a step closer to answering the question "*What works where, when and how?*"

By *strategic*, we mean the deliberate influencing of the relations between science and policy by both, scientists and policy-makers, often in controversial situations, for example in the case of environmental issues (Michaels, 2009; Pielke, 2007; Owens *et al.*, 2006). This strategic behaviour is displayed in order to promote specific, selectively used and produced information, rather than to promote the production and use of salient, credible and legitimate knowledge in order to enrich policy decisions. A result of strategic use and production of knowledge might thus be that the policy decisions made are not based on and thus do not represent or entail all the available knowledge, which could lead to inadequate (i.e. less credible and legitimate) decisions. An example of a situation where knowledge was used in a strategic way can be found in the Wadden Sea case, discussed by Runhaar (2009). In his article he states that the knowledge derived from EIAs was "ignored for a long time. (…) environmental knowledge has been used in a strategic way, i.e. linked to stakeholders' objectives and interests. The Wadden Sea case demonstrates that the use of environmental knowledge fits into a dominant discourse", i.e. it is used at will (Runhaar, 2009: 207). To place this case into the terminology of Cash *et al.*, in this situation we would expect that the produced knowledge lacked salience — the information bared little relevance to the decision-makers.

The scientific literature that defines *operational* problems, such as differences in expectations regarding the speed with which scientific knowledge can be produced. However, we expect these problems to be less deliberate, as they are mainly caused by institutional differences between science and policy; no manipulative behaviour of actors (as described above) is involved.

Figure 1 depicts the specific problems in science-policy interactions associated with the above-mentioned general strategic and operational problems. These specific problems are derived from the literature and will be further explained below.

Strategic use of knowledge by policy

The first set of problems arises from problems that concern the *strategic use of knowledge by policy*; oppositions and actors with conflicting interests or views using either existing knowledge or their own knowledge and reports in a strategic

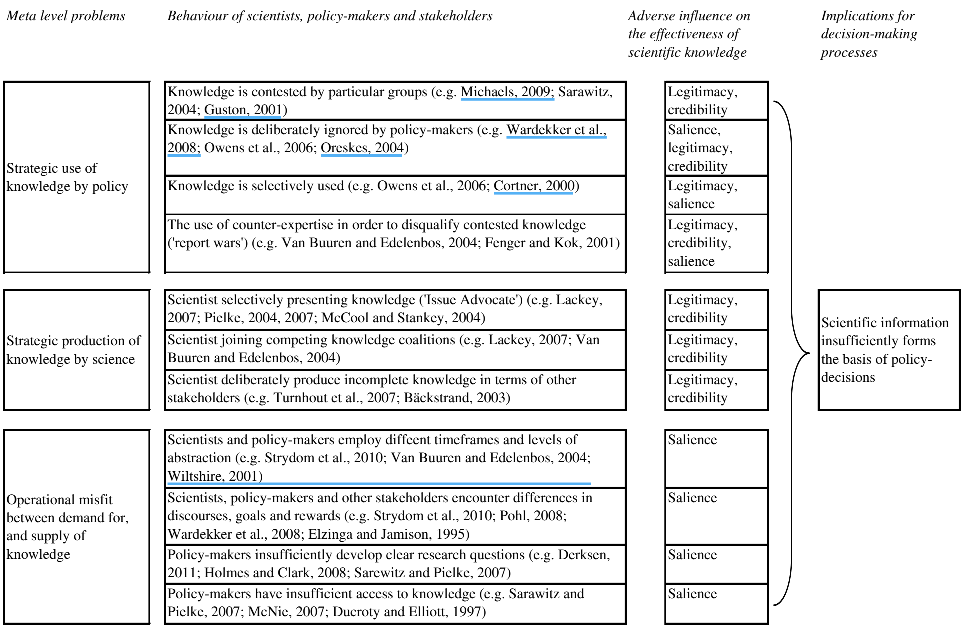

Fig. 1. Problems influencing the interaction between science and policy.

way, defending their interests, resulting in trade-off decision-making (e.g. Retief *et al.*, 2013; Lackey, 2007; Sarawitz, 2004; Ehrmann and Stinson, 1999). Or, as Cortner states, "[W]e know that policymakers frequently call for research or form study commissions to postpone facing problems. They invoke science to speak when it is in concert with their preferred policy preferences and ignore it when it is not" (2000: 23). This problem of the strategic use of knowledge consists of more concrete problems that influence the interaction between science and policy.

The first problem dealing with the strategic use of knowledge, concerns the situation that *knowledge is contested by particular groups*, and thus disputable, because the knowledge does not (fully) represent the interests or concerns at stake, and science becomes politicized (e.g. Sarawitz, 2004; Guston, 2001). Scientific knowledge on environmental issues becomes disputable because the environmental issues in themselves are disputable. Another point lies within the concept of "uncertainty". The existence of uncertainty in scientific knowledge is used by opposing stakeholders to claim that this knowledge is contested (Michaels, 2009). Knowledge, thus, is either being ignored or selectively used. Based on the framework by Cash *et al.* (2003), we would expect this is related to a lack of legitimacy and credibility.

This leads to the second problem: *knowledge is deliberately ignored by policy-makers*. Owens *et al.* refer to this as the "problem of limited impact". They argue that "policy-relevant, or even policy-oriented, knowledge is not deployed in policymaking and decision-making processes. (…) Many researchers have suggested that particular policies are pursued in spite of their efforts to convince policy-makers to do otherwise", but also that knowledge can be controversial, or "uncomfortable ahead of contemporary policy agendas" (Owens *et al.*, 2006: 636, 637). Therefore, although scientific knowledge is generated, when it comes to the use of knowledge by policy-makers, it is strategically ignored, because it is considered irrelevant or inconvenient (i.e. not in line with preferences or policy decisions) (Oreskes, 2004). Based on the three criteria for usable scientific knowledge by Cash *et al.* (2003), as first glance it would appear that in this case there is a lack of salience — decision-makers do not consider the knowledge at hand relevant to the decision at stake. However, it is our understanding that arguments could also be made that the knowledge does not only lack salience, but policy-makers could also perceive this knowledge as lacking legitimacy and credibility, due to problems with communication — especially on uncertainties.

A third issue is connected with *knowledge being used selectively*. This selective use may have different reasons, e.g. "politicians ask for advice only to legitimize their pre-formed decisions" (Hoppe, 2005). In terms of Cash *et al.* (2003), in this situation we would expect the problem with scientific knowledge lies not so much with its credibility, but rather with the lack of legitimacy and salience in the eyes of the decision-makers.

A result of the disputable character of knowledge presents the final example of the strategic use of knowledge: *the production and use of counter-expertise in order to disqualify contested knowledge*, leading to "report wars" or "knowledge fights" (van Buuren and Edelenbos, 2004; Fenger and Klok, 2001). For the production of this counter-expertise two reasons can be identified. The first reason refers to situations where there is little agreement on the produced knowledge and where knowledge is misused or misunderstood by coalitions other than the one in which it is generated (Owens *et al.*, 2006; Van Buuren and Edelenbos, 2004; Jones *et al.*, 1999). Secondly, counter-expertise and reports may be produced in order to delay discussions and decision-making processes, leading to little recognition of the importance of certain (for example) environmental issues, resulting in little political will and involvement of stakeholders (Watson, 2005). Based on the criteria set by Cash *et al.* (2003), in the first case, we expect there is a lack of credibility and legitimacy due to the lack of agreement on the produced knowledge; in the second case there is a lack of salience of the knowledge to the decision-makers involved, because the produced knowledge is not relevant to the policy problem in itself, but because it is being used as a delaying technique.

Strategic production of knowledge by science

The second set of problems evolves surrounding problems with the *strategic production of knowledge by science*. In his article, Hoppe (2005) formulates a couple of clichés regarding the troubled science-policy relationship: "politics are safely 'on top' and experts are still 'on tap' " and "science advisors follow their own interests, unless better paid by other interests". What can be concluded is that scientists (either individual or within coalition-type groups) appear to strategically place their interests and agenda within research, possibly leaving out other valuable information. This will be shown in further detail through the explanation of the three problems we relate to the strategic production of knowledge.

One of the problems here can be found in the existence of so called "*Issue Advocates*" (Pielke, 2007). These Issue Advocates are seen as scientists who selectively present or advocate certain aspects of information or knowledge that they find important and which fit their own agendas, "in order to participate in the decision-making process" (Pielke, 2007: 15). This is in contrast to the Honest Broker, who is claimed to "engage in decision-making by clarifying and seeking to expand the scope of choice available to decision-makers" (ibid.: 17). The Issue Advocates, for example, select what they consider to be policy-relevant indicators without involving other stakeholders (McCool and Stankey, 2004). This could also be traced back to so-called "Mode 1"-science "characterized by the hegemony of theoretical or experimental science; by an internally driven taxonomy of disciplines; and by the autonomy of scientists and their host institutions" (Nowotny *et al.*, 2003). The Issue Advocate thus produces and advocates knowledge in a strategic way, according to their own agendas or interests instead of presenting an honest review of the knowledge available. Or, as Strydom *et al.* (2010) state: "scientists keep science out of reach of policy-makers to ensure that they retain their control on the interpretation of science". Resulting from this strategic behaviour, we expect the produced knowledge lacks both legitimacy and credibility; legitimacy because the knowledge is far from biased and unfair in its treatment of opposing views, credibility because there is little clarification of the science available and expanding the scope of choice to the decision-makers (Pielke, 2007).

Similar to the Issue Advocates are *scientists that deliberately produce knowledge that is incomplete in terms of addressing other stakeholders* (Turnhout *et al.*, 2007; Bäckstrand, 2003). By strategically not involving other stakeholders, knowledge can be kept out of the knowledge production process, with the risk of barriers appearing at the interaction and thus with the enrichment of policy by science, since the knowledge is far from holistic and integrated (Cortner, 2000).

This can cause difficulties, especially in situations where decisions can have a large impact on civil society (Bäckstrand, 2003). Again, following Cash *et al.* (2003), this knowledge thus is expected to lack legitimacy (the knowledge does not contain all available views) and credibility.

The final issue related to the strategic production of knowledge relates to *"scientists who join competing knowledge coalitions"*, involving the "departmentalisation of different knowledge coalitions that consist of both knowledge providers (scientists, advisors and so on) and users (such as policy-makers)" (Van Buuren and Edelenbos, 2004: 290). It links back to the Issue Advocate, but on a more collective scale; i.e. it not only involves scientists, but also other involved stakeholders, which form coalitions. As a consequence, Jasanoff (1990) suggests that the idea that advisory bodies "speak truth to power" should be abandoned. Rather, the production of knowledge is "plural and contextual" as its outcomes will be (Van Buuren and Edelenbos, 2004: 290). The implication this has for the usability of the produced knowledge (within the policy-making arena) is that it probably lacks both legitimacy and credibility, even though the produced knowledge is likely to be both legitimate and credible *within* its coalition.

Operational misfit of demand for and supply of knowledge

Finally there are the problems that are connected with the *operational misfit of demand for and supply of knowledge*. Here, we see a range of operational issues surfacing. These are often linked to the differences in culture, between the "world of science" and the "world of policy".

Examples of such problems can be found where *scientists and policy-makers employ different time frames and levels of abstraction*. Van Buuren and Edelenbos (2004) discuss this issue based on Wiltshire's (2001) suggesting that the timeframe of research and policy, their language and mutual images and their notion of reality differ fundamentally, which could lead to problems regarding their interactions. This includes the delivery of knowledge science might take longer to produce the knowledge than policy is willing to wait for. This could result in so called "policy-making on the run"; politicians making pre-emptive decisions without environmental knowledge or expertise (Crowley, 1997). Furthermore, the knowledge produced might not be as understandable to policy-makers as it is to scientists, due to the difference in language and abstraction levels. "The failure of scientists to relate to the decision-making context, and the policymakers' often limited understanding of science form obstacles in the communication process" (Strydom *et al.*, 2010), leading to limited understanding of each other's research demands and produced knowledge. The implication this has on the usability of the scientific knowledge is that it appears to lack salience.

Strydom *et al.* also point at the issue that *scientists, policy-makers and other stakeholders encounter differences in discourses, goals and rewards*. They claim that scientists and policy-makers experience and understand the world differently. In this light, Elzinga and Jamison (1995) discuss four cultures within the field of trans disciplinary research; bureaucratic, academic, economic and civic policy culture. Pohl (2008: 47) argues that "the bureaucratic culture is concerned with effective administration, coordination and organisation; the academic culture seeks to preserve autonomy, integrity, objectivity and control over the funding and organisation of science; the economic culture is interested in transforming scientific results into successful innovations to be diffused in commercial marketplaces; and the civic policy culture is concerned with the consequences and implications of developments in science and technology". In other words, the bureaucratic culture aims at salient knowledge, the scientific culture at credible knowledge and the economic and civic cultures focus more on legitimate knowledge. The fact that these "cultures" or "institutions" all have different discourses towards concepts like "knowledge", but also "policy", could lead to difficulties between them. All this does not mean that it is impossible to interact with each other, but those that do need to be aware of these problems (Strydom *et al.*, 2010: 2). If this awareness is lacking we argue that it is likely that the knowledge used in the decision-making processes might lack relevance, and thus salience.

A third issue regarding this operational misfit can be found with *policy-makers who insufficiently develop clear research questions*. The communication between what information is demanded and whether the information is already available or needs to be supplied can be difficult to achieve (Holmes and Clark, 2008; Sarawitz and Pielke, 2007). Derksen (2011) discusses the difficulty of constructing proper research questions from a policy point of view. He also argues that whilst the problem a (governmental) department can have is often clear, the right research question is not developed, resulting in the possible supply of knowledge which lacks significance to the policy makers and the problems at stake, or, according to Cash *et al.* (2003), salience.

Finally, *policy-makers who have insufficient access to knowledge* is also being mentioned as an issue in this operational misfit (Sarawitz and Pielke, 2007); policy-makers' decisions could be affected if they are unable to access the knowledge they need for their decision-making process because they are not aware of the existence of this knowledge. This results in a lack of available salient knowledge.

In which situations do problems occur?

Science-policy interaction problems are often associated with so-called wicked or unstructured problems. An unstructured problem can be defined as a societal problem for which there is no definite solution, as opposed to structured problems, for which both the formulation and thus the needed solution is clear (Rittel and Webber, 1973). Decisions made on these so-called "unstructured problems" are often based on a range of values and interests of the (many) stakeholders involved (Karl *et al.*, 2007), but that is also what makes the problem unstructured. As Fischer *et al.* (2010) and Hoppe (2005) show in a framework on policy problems, the level of "structuredness" depends on two contextual factors; the level of certainty on relevant knowledge and the level of consensus on relevant norms and values (Fig. 2).

		Certainty on relevant knowledge	
		No	Yes
Consensus on relevant norms and values	No	**Unstructured problem**	**Moderately structured problem (ends)**
	Yes	**Moderately structured problem (means)**	**Structured problem**

Fig. 2. Types of policy problems (derived from Hoppe, 2005).

Relating this quadrant to Cash *et al.* (2003), we argue that the more unstructured a policy problem appears to be, the more there is a need for credible, salient and legitimate knowledge. We acknowledge, though, that this may be difficult to achieve.

Using our key question, *"What works where, when and how?"*, in the development of a further (empirical) research agenda, we want to know in which situations problems occur — i.e. at which level of structuredness. Accordingly, we have analysed the science-policy interaction problems in relation to the policy problem quadrant. Based on the descriptions of these problems, we were able to categorise the problems as seen in Fig. 3. We do not claim the figure is complete regarding typical problems in science-policy interactions. The figure represents the problems and associated circumstances found in the literature and, as we suggest, can serve as a hypothesis.

		Certainty on relevant knowledge	
		No	Yes
Consensus on norms and values	No	Lack of legitimate, credible and salient knowledge Types of interaction problems: - Strategic use of knowledge o all specific problems - Strategic production of knowledge o all specific problems - Operational misfit o all specific problems	Lack of legitimate and salient knowledge Types of interaction problems: - Strategic use of knowledge o Selectively used knowledge o Use of counter expertise - Strategic production of knowledge o Issue Advocates o Competing knowledge coalitions - Operational misfit o all specific problems
	Yes	Lack of legitimate and credible knowledge Types of interaction problems: - Strategic use of knowledge o Ignored knowledge o Selectively used knowledge - Strategic production of knowledge o Deliberate production of incomplete knowledge - Operational misfit o all specific problems	Lack of salient knowledge Types of interaction problems: - Operational misfit o all specific problems

Fig. 3. Policy problems linked to the science-policy interactions; table derived from Hoppe, 2005.

We conclude that, in the case of structured policy problems, it is likely that only problems regarding the operational misfit between science and policy will occur. Furthermore, we see that the majority of interaction problems do not seem to be related to one specific policy problem and that the level of (un)structuredness appears to have little impact.

Finally, with regard to the three criteria that Cash *et al.* (2003) provide us with when determining the usefulness of the knowledge to form the basis for policy-decisions, our initial hypothesis is endorsed. In the case of structured policy problems, the scientific knowledge only lacks some salience. However, the more unstructured the policy problem becomes, due to higher levels of uncertainty regarding knowledge and less consensus on the norms and values, the more there appears to be a lack of legitimate, credible and/or salient knowledge.

Science-Policy Interfaces: A Typology

After depicting the problems that are discussed in the literature as the causes of interaction difficulties between science and policy, we suggest possible solutions.

Those solutions presented in the literature often refer to the concept "SPI". The concept of "interfaces" can have a variety of meanings and shapes, ranging from an interface being a process, an organisation, an individual or a collective understanding (e.g. Huitema and Turnhout, 2012; Pielke, 2007; Van Buuren and Edelenbos, 2004). In addition, a range of functions can be identified. Subsequently, the most dominantly discussed interfaces, as described in scientific literature are described. They are then categorized according to our typology. We will then connect these SPIs to the science-policy interaction problems, which we presented earlier.

As we did in the previous section ("Problems Influencing the Science-Policy Interactions"), we have tried here to characterise the interfaces into typologies, rather than describing all the interfaces which, in our opinion, often only have minimal differences between them. In order to provide such a typology, we used the definition Van den Hove presents for SPIs "social processes which encompass relations between scientists and other actors in the policy process, and which allow for exchanges, co-evolution, and joint construction of knowledge with the aim of enriching decision-making" (Van den Hove, 2007: 807). From this definition, we derived three variables which make up the arrangement of an SPI: *initiating and participating actors* ("scientists and other actors in the policy process"), *presupposed goals* ("the aim of enriching decision-making") and *a strategy for steering the involved actors towards this goal* ("exchanges, co-evolution, and joint construction of knowledge"). As discussed at the beginning of the previous section, "goal" refers to the science-policy interaction problems that the interface (and its actors) aim to solve; "strategy" refers to the specific actions taken by the involved actors. From the literature on interfaces, multiple variations can be derived. Subsequently, we will discuss the most frequently used.

A typology

Based on the above three variables (i.e. actors, goals and strategies), we have analysed interfaces and suggest the following typology on SPIs: (i) individual science-policy mediators; (ii) the process of participatory knowledge development; and (iii) boundary organisations (see Table 1).

The first interface relates to the *individual science-policy mediators*. An example of such individuals serving as interfaces is the so-called "Honest Broker", a knowledge broker or boundary worker (e.g. Meyer, 2010; Sheate and Partidário, 2010; Michaels, 2009; Pielke, 2007). Essentially, they are individual scientists or experts whose goal it is to facilitate the creation, sharing and use of knowledge (Pielke, 2007). Their strategy involves functioning as a bridge between science

Table 1. Typology of science-policy interfaces.

Science-policy interface	Actors (I: initiating; P: participating)	Goal	Strategy
Individual science-policy mediators	Individual, renowned scientist or expert (I); scientists, policy-makers (P)	Facilitate the creation, sharing and use of knowledge. Focus on identifying and producing salient and legitimate knowledge.	Function as bridge between science and policy through mediating, explaining and translating.
Process of participatory knowledge development	Scientists from different disciplines, policy-makers, other involved stakeholders (all both I as P)	Create common understanding and knowledge in a participatory way. Focus on the increase of legitimate and salient knowledge.	Through participatory gatherings and processes with all involved stakeholders, exchange of and negotiations on ideas, visions and knowledge take place.
Boundary organisations	Organisations consisting of e.g. scientists, (environmental) experts and/or policy related advisory boards members (I); scientists, policy-makers, other involved stakeholders (P)	Bridging the gap between science and policy. Focus on the salience and credibility of knowledge.	Collect and distribute scientific knowledge, structure research questions and knowledge demands, develop and translate scientific reports for policy-makers.

and policy through mediation in the development of research questions, explaining the visions, goals or ideas of both sides to each other, having knowledge of the different processes undertaken by both scientists and policy-makers and being able to create awareness and acceptance of these differences (Meyer, 2010). Pielke describes the Honest Broker as someone who "engages in decision-making by clarifying and seeking to expand the scope of choice available to decision-makers. (…) [He] seeks to place scientific understandings in the context of a *smorgasbord* of policy options. Such options may appeal to a wide range of interests." (2007: 17). The goal of these mediators is thus to raise the level of salience and legitimacy of the scientific knowledge involved in the policy-making process, in order for the policy problem to be solved.

The second interface involves the *process of participatory knowledge development*, with which we mean processes such as stakeholder participation in, for instance, EIA. These processes aim at joint fact finding and knowledge co-production (Glucker *et al.*, 2013; Hegger *et al.*, 2012; Pohl, 2008; Karl *et al.*, 2007; Van Buuren and Edelenbos, 2004; Bäckstrand, 2003; Ehrmann and Stinson, 1999). They also include more theoretical approaches such as post-normal science, Mode-2 and the process of hybridization (Nowotny *et al.*, 2003; Van de Kerkhof and Leroy, 2000; Hunt and Shackley, 1999; Ravetz, 1999; Funtowicz and Ravetz, 1993; Jasanoff, 1990). The actors involved in these processes range from scientists from different disciplines and policy-makers to civil society and the private sector. They include all stakeholders who have a stake in, or are influenced by, the decision-making process and want to be involved in the process of knowledge development. The goal of this interface is essentially to create common understanding and knowledge in a participatory way. Or, as Nowotny *et al.* describe it: "socially distributed, application-oriented, trans-disciplinary and subject to multiple accountabilities" (2003: 179). The strategy to do so is through participatory processes in which all stakeholders are involved and stimulated to develop research questions and exchange and produce knowledge (scientific, expert, lay). This exchange of ideas and knowledge should ideally lead to more legitimacy of the produced knowledge; creating a common understanding of the problem at hand, mutual understanding of individual stakes and insight into the available bodies of knowledge surrounding a problem (Van Buuren and Edelenbos, 2004). Although participation is often considered to promote the production of useful knowledge, Wassen *et al.* (2011) show that this is often the case but also that useful knowledge does not always translate into the actual use of it in decision-making.

The third type of interface we discuss here is the so-called *boundary organisation* (Pesch *et al.*, 2012; Huitema and Turnhout, 2009; McNie, 2007;

Niederberger, 2005; Cash *et al.*, 2003; Guston, 2001; Gieryn, 1983). This can be described as formal institutions, often having a legal basis, which serve as an institutional bridge between the worlds of science and policy. An example could be the IPCC (Intergovernmental Panel on Climate Change). The driving actors in these organisations can be scientists, but also (environmental) experts or members of ministerial advisory boards, aiming at bridging the gap between science and policy by positioning their organisation at the (dynamic) boundary between the two "worlds". They do this by "employ[ing] various kinds of specialists, offer[ing] opportunities for interdisciplinary collaboration, and serve[ing] as a platform for addressing environmental issues" (Huitema and Turnhout, 2009: 591). Their strategy is to collect scientific knowledge in order to make it available and/or distribute it to those who need it (policy-makers for instance). Furthermore, they help to structure research questions and knowledge demands but also put scientific and political issues on research and policy agendas. They also develop reports for policy-makers, containing scientific knowledge from a variety of sources, which are presented in a less scientific manner (Niederberger, 2005; Guston, 2001). In doing so, they increase the level of salience and legitimacy of the scientific knowledge.

SPIs and interaction problems connected

In order to move further in our analysis of the SPIs, we need to connect the interfaces we have identified above with the interaction problems explained in the previous section ("Problems Influencing the Science-Policy Interactions"). In Table 2, we connect these two based on the scientific literature on SPIs. An important conclusion is that the authors who identify the problems with the science-policy interactions do not necessarily explain what interfaces can be used to overcome them. Furthermore, on multiple occasions, authors who do discuss the concept of SPIs appear to fail to connect interfaces with the problems and interactions they aim to solve.

One of the first questions which arises from this table is when to use or implement which interface. The literature provides little guidance on this.

Table 2 clearly shows that there still is no definite answer to our question "*What works where, when and how?*", when linking the interaction problems to the SPIs. On the contrary, it shows us the complexity of the question and the scientific concept of SPIs, and even leads to more questions; not only with regards to when you would use or implement a specific interface, but also whether or not you should even make a choice, or whether you could use multiple interfaces at the same time.

Table 2. Problems with science-policy interactions and science-policy interfaces connected.

	Problems	Individual science-policy mediators	Process of participatory knowledge production	Boundary organisation
Strategic use of knowledge by policy	Knowledge is contested	Meyer, 2010	Reed, 2008	
	Knowledge is deliberately ignored	Michaels, 2009		
	Knowledge is selectively used	Meyer, 2010; Michaels, 2009		
	Counter expertise is used to disqualify contested knowledge		Van Buuren and Edelenbos, 2004	
Strategic production of knowledge by science	Scientists selectively present knowledge	Pielke, 2007	Karl *et al.*, 2010	Huitema and Turnhout, 2009
	Scientists join competing knowledge coalitions	Sheate and Partidário, 2010	Van Buuren and Edelenbos, 2004	Huitema and Turnhout, 2009
	Scientists deliberately produce incomplete knowledge	Meyer, 2010	Karl *et al.* 2010; Pohl, 2008; Bäckstrand, 2003	McNie, 2007
Operational misfit between demand for, and supply of knowledge	Scientists and policy-makers employ different timeframes and levels of abstraction	Meyer, 2010; Michaels, 2009		Niederberger, 2005
	Scientists, policy-makers and other stakeholders encounter differences in discourses, goals and rewards	Niederberger, 2005	Pohl, 2008	Niederberger, 2005; Guston, 2001
	Policy-makers insufficiently develop research question	Michaels, 2009	Pohl, 2008	
	Policy-makers have insufficient access to knowledge	Michaels, 2009; McNie, 2007		Guston, 2001

Before we can draw up our conclusions and develop hypotheses for guiding further research on this question, a final analysis needs to be made, by placing the SPIs into context.

Interfaces placed into context

In the previous section ("Problems Influencing the Science-Policy Interactions"), we placed the problems regarding science-policy interactions in relation to the policy problems, as described by Hoppe (2005). We did so in order to show the circumstances, or context, in which these issues occurred; and whether they occurred in structured, unstructured or moderately structured policy problems. As with these problems, and with regards to our question "*What works where, when and how?*", it is also important to look at contextual factors when analysing SPIs. In this paper, we have distinguished the following two; the level of structuredness of the policy problems and the presence of legal frameworks for knowledge production and use.

First, we discuss the level of structuredness of policy problems here. If we combine Table 2, in which we connect the SPIs with interaction problems with Fig. 3 (interaction problems can be connected to one or more policy problems), it is possible to recommend on what interface to use. However, since the four different policy problems do not have specific interaction problems, (as various issues appear in multiple policy problems) and some of the problems may (at least in theory) be solved by multiple interfaces, this combination would likely add more confusion, rather than providing for a better insight. This is in line with the literature where the conditions under which the interfaces take place are hardly and not systematically discussed.

Furthermore, we suspect that the presence of legal frameworks may have an influence on the SPIs. If there are legal frameworks in place, such as for instance the need to perform an Environmental Impact Assessment (EIA) for a particular project, this is likely to have strong implications on the use of the knowledge that the EIA produces. Environmental knowledge namely needs to be produced and considered, and its use publicly justified. This could reduce opportunities for ignorance and / or selective use of such knowledge. However, even with regards to EIA, Runhaar *et al.* found that the actual use of EIAs often depends on whether or not the presented knowledge fits into the dominant policy discourse (Runhaar *et al.*, 2010). We still expect the number of formal regulations to influence the existing room for manoeuvre for strategically producing and using scientific knowledge. The more formal regulations there are, the fewer possibilities there are to use knowledge in a strategic way. This, however, does not imply that the solution to the problem with regards to science-policy interactions should be found in the number of formal regulations. The required outcomes of these formal regulations are often scientific reports, excluding possible other views or "knowledges". Whilst these can be credible and salient, they would lack legitimacy.

Conclusion

As we have shown in this paper, the literature provides us with a variety of SPIs, but with little recognition of its best practices and answers to our main question "*What works where, when and how?*". This article is meant to be a first step towards further empirical research by providing a systematic overview of the literature on the concept of SPIs.

The concept of SPIs and the interaction between science and policy is discussed by numerous authors and in multiple ways. Based on these debates we developed a new typology for the science-policy interaction problems, in which we made the distinction between three "meta-problems": (i) strategic use of knowledge by policy; (ii) strategic development of knowledge by science; and (iii) the operational misfit between demand for and supply of knowledge. We argue that these problems are narrowly related to a lack of legitimacy, credibility and/or salience of the knowledge at issue. In turn, the relevance of each of these criteria depends on the structuredness of the policy problem in terms of certainty of knowledge and consensus about norms and values. A second contribution of this paper is a further conceptualisation of the concept of SPIs by elaborating three key dimensions (actors, goals and strategies) that make up SPIs and which has resulted in the identification of the three distinct SPIs : (i) individual science-policy mediators; (ii) the process of participatory knowledge development; and (iii) boundary organisations.

The conceptual clarity offered in this paper and the linking of typical SPIs to distinct problems and the contexts in which they emerge in our view are important ingredients for empirical research on SPIs, centred round our wondering of "*What works where, when and how?*" with which we started this paper. We therefore encourage researchers to apply and further refine our conceptualisation of SPIs and to identify best practices of the SPIs by means of empirical research. EIA and SEA can be an interesting empirical field of analysis. They can be seen as an example of formalised science-policy interactions that are in place in many countries worldwide (Arts *et al.*, 2012), allowing for international comparative analyses. We expect various types of SPIs to be found in this field. Since participation is usually an important element of EIA and SEA, EIA and SEA can be considered what we called "processes of participatory knowledge production" — one of the three types of SPIs identified in this paper. In the Netherlands, the well-known Netherlands Commission for Environmental Assessment (NCEA) could be understood an example of a "boundary organisation", another type of SPI.

In our view, key questions for further research in the field of science-policy interfaces are:

(1) What are the processes and strategies through which science-policy interactions take place and to what extent can they be influenced?
(2) How are science-policy interfaces enabled and constrained by social, economic and political dynamics, and what other contextual factors influence the performance of science-policy interfaces?
(3) In what manner can design principals be formulated for science-policy interfaces in addressing a diverse set of problems in specific contexts , and in particular to what extent can science-policy interfaces be complementary to each other?
(4) To what extent does an increased level of credibility, legitimacy and salience in knowledge, established through the use of SPIs, indeed lead to enriched decision-making on environmental issues?

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