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Improving the public value of science: A typology to inform discussion, design and implementation of research

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ABSTRACT

Decision makers call upon and fund science to solve urgent problems, catalyze innovation, and inform policy decisions. But the standard categories for describing, planning and assessing research, especially the persistence of "basic" and "applied," conceal much of the complexity and diversity of the contexts for conducting and using research, especially the role of knowledge users in the research process. Here we provide an entirely new typology aimed at allowing a more complete view of research activities and expectations, in order to improve deliberation and decision-making about research and its desired contribution to public values. Our multi-dimensional research typology divides research into three general activities: knowledge production, learning and engagement, and organizational and institutional processes, all of which are further subdivided into fifteen attributes. These idealized attributes are expressed in terms of a spectrum of value criteria ranging from strongly science-centric to strongly user-oriented. This enables consideration of the isolated knowledge value of science, the consideration and context of use, and the engagement of intended users. Used as a heuristic device, the typology can help inform and improve science-policy planning and decisions, aid in assessing the potential of existing projects, programs and institutions to achieve particular goals, and yield insights about the strengths and weaknesses of completed projects.

1. Introduction: the problem with science policy

1.1. The goal: producing more useful information for decision support

Society calls upon and funds natural, physical and social science to help clarify and resolve numerous problems including those related to coupled-human environmental systems, biotechnology, poverty reduction, economic development, energy independence, healthcare, etc. (America COMPETES Act, 2007; Bush, 1945; OECD, 2002). Some argue, however, that in its present form, science has not fulfilled expectations that it will serve society by responding to its needs and priorities (Kitcher, 2003; Dilling and Lemos, 2011; Sarewitz and Pielke, 2007). Decision makers need useful information to help inform solutions to these problems, information that educates, but also expands alternatives, clarifies choices, and aids in formulating and implementing policy decisions (Sarewitz and Pielke, 2007). Useful information must be salient and relevant to the problem, credible and of high quality, and legitimate, in that users believe that the information was produced without political suasion or bias (Cash et al., 2002). Producing useful information to inform policy also requires iterative engagement between producers and users (Sarkki et al., 2015; Lemos and Morehouse, 2005). One way to facilitate the production of useful information is to give engaged and knowledgeable stakeholders a larger role in shaping scientific research agendas (Lemos et al., 2012; Simpson et al., 2016; Dilling et al., 2015; Lackstrom et al., 2014; NRC, 2009). In the U.S., this insight has now been explicitly endorsed at the highest levels of national science-policy making. In its annual research and development priorities memo for 2017 (Donovan and Holdren, 2015), the

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Directors of the Executive Office of Science and Technology Policy and the Office of Management and Budget state, "In order to maximize the societal benefits of R&D investments, research planning and design should be guided by stakeholder and user engagement." Yet this call merely formalizes a long-standing recognition among science policy scholars and practitioners alike that the public value of research activities may often be enhanced through various types of stakeholder guidance (McNie, 2007).

How, then, should science-policy decision makers develop, implement, and assess the processes necessary to achieve such guidance? The dominant (and much debated) basic-versus-applied paradigm addresses knowledge generation, but does not speak to the multiple and complex roles that stakeholders may play in influencing knowledge generation and use. Thus, the basic-versus-applied paradigm limits recognition of science policy processes that may seek to address both knowledge generation and "stakeholder and user engagement," and it also limits comparison between science policy processes. The typology presented herein is a systematic framework for such comparison.

This paper introduces a new, multi-dimensional typology that describes three activities and related attributes that together can help inform the design, deliberation, implementation and evaluation of research. The activities and attributes introduced in this paper are idealized and intended to be heuristics. In reality the boundaries between different activities and attributes are fuzzy, with substantial 'gray areas' between them. Clarifying and characterizing types of research is important because such definitions can 'stabilize expectations' and support 'unquestioned assumptions', that influence science-policy funding and support (Calvert, 2006; Gieryn, 1999; Pielke, 2012). Application of this typology may help improve science-policy decisions by revealing the ways in which science programs may or may not be appropriately reconciled with the problem context they are supposed to address.

1.2. The problem with existing science policy

Producing useful scientific information is difficult. The worlds of science and society are far apart culturally and epistemologically, and thus directing interaction between them is challenging (McNie, 2007). Basic and applied research approaches, detached from users' needs and values, fail to adequately address the inherent uncertainties in the "problem-solving work itself" (Funtowicz and Ravetz, 1993, p. 740). Nor do these research approaches adequately integrate knowledge from multiple disciplines, cultural contexts, or the physical, natural and social sciences together. Although improving, we still have a poor understanding of how useful information is incorporated into the decision-making process (Eden, 2011; NRC, 2006). Many scientists believe their research outputs are inherently valuable to aid in learning or effective action, yet, research shows that such value is not inevitably achieved (Kropp and Wagner, 2010).

At the heart of the problem are current science policies that favor basic and applied research approaches which alone are inadequate to address the growing complexity of problems we seek to solve and simply reinforce a structural gap between the "production and use of scientific information" (Kirchhoff et al., 2013, p. 407; see Sarewitz and Pielke, 2007). Science-policy decision makers often respond to calls for more useful information by funding more science using the same basic and applied approaches. This may result in more credible and high quality information, but not necessarily useful information, resulting in missed opportunities of reconciling the supply of scientific information with the capabilities, demands, and needs of users (NRC, 2006; Sarewitz and Pielke, 2007) (See Fig. 1).

Over two dozen different terms describing scientific research have been described or adopted by the National Science Foundation, National Science Board, Office of Management and Budget,

DEMAND: Do users have specific information needs?

SUPPLY: Is scientific information produced?		**YES**	**NO**
	YES	***SUPPLY & DEMAND RECONCILED:*** Users' information needs reconciled with the production of scientific information.	***MISSED OPPORTUNITY:*** Research priorities misaligned or users are unaware of possible utility of information produced.
	NO	***MISSED OPPORTUNITY:*** Research priorities need modification in order to respond to users' information needs.	***SUPPLY & DEMAND RECONCILED:*** Information not produced nor needed by users.

Fig. 1. Missed opportunity matrix.
Adapted from Sarewitz and Pielke (2007).

Organization for Economic Cooperation and Development (OECD), science-policy researchers and others during this century and last (see Table 1). Research types have been defined by many variables, although the differences between many types are often minor or semantic (Calvert, 2006; Stokes, 1997).

Indeed, OECD, which includes the world's most research-active nations, through it's Frascati manual, is almost militant in the narrowness of its definition of research. The latest (2002) version of the manual asserts: "The basic criteria for distinguishing R&D from related activities is the presence in R&D of an appreciable element of novelty and the resolution of scientific and/or technological uncertainty, i.e., *when the solution to a problem is not readily apparent to someone familiar with the basic stock of common knowledge and techniques for the area concerned*" [OECD, 2002 p. 34; emphasis added]. Such a definition eliminates even the possibility of incorporating the influence of knowledge use and knowledge on research processes by limiting research activities to those involving only technical subject area experts (i.e., scientific researchers).

Today, basic and applied research approaches have become epistemic norms in the science community, and as a result, most research types can be classified as basic or applied. These approaches are defined mostly by only two qualities: the motivation for research (fundamental discovery vs. application of knowledge) and temporal delay to application of research results.

Many practitioners and scholars of science policy have come to recognize that the basic/applied dichotomy may conceal as much as it reveals. For example, in Stokes' well-known conception of use-inspired research, he added to the standard dichotomy a new dimension (Pasteur's Quadrant) that accommodated the recognition that research, whether basic or applied, is commonly influenced by considerations of use (1997). Little to no progress has been made in translating such insights into criteria for research design, which is an ongoing and iterative process that implies not only the design of particular science study, project, or program, but its ongoing management and evaluation. Even Stokes failed to consider the role of users themselves. The character of scientific knowledge, the intended use of science, and the role of users in the research process are all pertinent to appropriate research design.

Moreover, public investments in science have always been significantly justified by the promise and expectation that more research—both basic and applied—would respond to problems

Table 1
Standard research approaches.

Ad hoc	Curiosity-driven	Jeffersonian	Pure-basic
Applied	Curiosity-oriented	Mode 1	Purposive-basic
Background	Development	Mission-oriented	Strategic
Baconian	Directed	Newtonian	Tactical
Basic	Experimental	Normal science	Translational
Clinical	Free basic	Oriented-basic	Uncommitted
Committed	Fundamental	Pure	Use-inspired

Table 2
Alternative research approaches.

Action	Participatory	Sustainability science
Mode 2	Post-normal science	Transdisciplinary
Operations	Problem-oriented	

articulated by policy makers and citizens, even if the role of users was explicitly ruled out or simply not acknowledged (Bozeman and Sarewitz, 2011). Mission-oriented research in fields such as agriculture, biomedicine, and engineering have of course typically been focused on end-users, as Stokes (1997), Rosenberg and Nelson (1994) and others have long emphasized. Lacking, however, has been any formal conception of research that acknowledges and fully integrates the role of use and users in knowledge production as part of its basic definitions and conceptualizations.

Perceived limitations of the standard research approaches to respond to society's information needs have led to new thinking about how research should be conducted. Many science-policy researchers have contributed to the ontological landscape of what constitutes knowledge generation and validity in a 'post normal' age (e.g. 'Sustainability Science' by Clark and Dickson, 2003; 'Post-Normal Science' Funtowicz and Ravetz, 1993; 'Mode-2' research by Gibbons et al., 1994; and 'Socially Robust Knowledge' by Nowotny et al., 2002). Some of the research approaches identified in Table 2 have addressed the shortcomings of the basic/applied approach to research by demonstrating the value of situated knowledge and improving linkages between science and society. While informative about ontological issues, the types identified in Table 2 lack adequate detail or explanation on how to shape and operationalize the research process, specifically, they lack clear explanation of the variables that should inform organizational and institutional design considerations in support of their respective research approaches. It is worth noting, however, that this goal was not necessarily a motivation for the aforementioned work.

Understanding the characteristics of, and processes related to, any research approach requires that we break each approach into its constitutive parts. The typology introduced here serves this purpose. The authors conducted an extensive literature review aimed at understanding the full array of research qualities and characteristics. Key word searches were done using, for example, phrases such as: science policy, basic research, applied research, science-policy interfaces, use-inspired research, knowledge generation, etc. The activities and attributes introduced here were then developed through inductive reasoning based on the literature review. Findings from the literature review are embedded throughout the text. The authors also worked with science-policy decision makers one-on-one and in two separate workshops to fine-tune the typology as it is presented here. The authors also have experience as science-policy decision makers and are now using the typology in their own work.

1.3. Role of the user

One variable that runs throughout the typology is that of the user. It is a broad category that includes people or organizations that use the results of research to better inform decisions and influence outcomes. Users are the ones with whom researchers must engage to produce useful information. Users may be individuals, program managers, science translators, educators, policy makers or elected officials among many. Users may also be other researchers or technologists. Another category of users are those people and program managers who will use this typology to inform decisions related to science policy and research design. Identifying users' information needs involves a process of direct engagement between researchers and users, in which information and ideas are shared jointly between them (Lemos and Morehouse, 2005). Research agendas are shaped collaboratively to best address the needs of the users and capabilities of the researchers. Underlying this entire discussion of users is the question of influence, that is, who gets to influence, and to what extent, the design and implementation of research. The distribution of influence among unique users is not uniform and varies by social, political, economic, intellectual and cultural dimensions.

One important question relating to users is that of representation, specifically, whose interests are represented in the shaping of research agendas? Power and representation may be concentrated in a few hands, namely, in the funding agencies, principal investigators, researchers, and may also extend to the research institutes, centers and universities in which research takes place. In these circumstances, autonomy of research by researchers is sought and maintained. Society, especially politically marginalized populations, has little or no voice in research. Power and representation may also be shared by users. Engaging users to help shape research agendas results in power being transferred, at least to some extent, from science to society. To improve the use of information, those most effected by the decisions it informs need to be included in the creation of knowledge (Fischer, 2000). This may require the inclusion of indigenous knowledge and involvement by politically-marginalized populations who may not otherwise participate unless sought out as part of the agenda-setting process (Berkes, 2009). Inclusion and representation of users is particularly important in the development and implementation of policies, and in integrating knowledge into socio-cultural and organizational contexts.

Some question whether science can be shaped, let alone shaped by users. Extensive research has shown that science is a social process influenced by societal and individual values and norms (Jasanoff, 2004; Latour, 1987; van den Hove, 2007) and is therefore amenable to being shaped and informed by users. Others may suggest that directing research toward specific outcomes is unproductive, may limit scientists' exploration of possible alternative solutions (Merton, 1945), may lead to concerns over scientific accountability (Lövbrand, 2011), and may even be harmful to science (Bush, 1945). Yet directing research toward practical ends has always been a part of our scientific enterprise, and doing so does not necessarily drive out fundamental and novel discoveries (Logar, 2009; McNie, 2008; Stokes, 1997).

Changing or expanding on the basic/applied dichotomy will be difficult. First, the phrase 'basic' research has become a political symbol used in science-policy debates and decisions, and has meaning that goes well beyond what it describes about research (Pielke, 2012). Second, despite limitations in the basic/applied dichotomy, the phrase 'basic research' provides a "flexible repertoire of characteristics" to be used by scientists and policy makers alike in order to protect their respective interests (Calvert, 2006, p. 199). In this sense, the heterogeneity of 'basic research' enables it to remain resilient to epistemic and political challenges. Third, research metrics, as well as the statistical tools used to evaluate them, have become so institutionalized over the years that adding to the research approaches used in science policy would require overcoming significant inertia (Godin, 2005).

2. Activities and attributes of research

The typology is divided into three broad activities. The **knowledge production** activity describes the nature of expertise, goals of research and treatment of uncertainty. The **learning and engagement** activity describes what is learned, how knowledge is exchanged with users, who participates in the exchange network, and the role of social capital in transferring knowledge. The

organizational and institutional processes activity describes research outputs, human capital, institutional accessibility, organizational flexibility, boundary work and approaches for evaluation, which together help inform how resources can be identified and deployed to support research. Each activity is further clarified by a suite of attributes. These activities and attributes are idealized, and each one is expressed in terms of a spectrum of opposing variables (see Fig. 2). The left side of each spectrum represents a variable of an attribute in which the focus is science values (Meyer, 2011). This research tends to be more disconnected from explicit consideration of the context of use and involvement of users, that is, science is treated as a closed system. The right side represents an attribute in which the focus is user values where research activity is open to engagement with stakeholders, and devoted to providing information and knowledge for specific users and uses. A research activity is characterized in full by assessing where it lies on the spectrum of attributes for the entire suite of criteria. Of course most research activities lie between the extremes. The typology allows this intermediate domain to be explored and characterized with attention to each of the criteria. The typology is a heuristic device that can help inform and improve science-policy decisions. In reality the boundaries between different activities and attributes are fuzzy, with substantial 'gray areas' between them. Clarifying and characterizing types of research is important because such definitions can 'stabilize expectations' and support 'unquestioned assumptions', that influence science-policy funding and support (Calvert, 2006; Gieryn, 1999; Pielke, 2012).

2.1. Knowledge

This section addresses what knowledge is credible, who is credible and what ways of creating knowledge are credible (Epstein, 1995). Knowledge consists not just of facts but is inclusive of lived experiences and acknowledges the fact that knowledge is not purely objective or free from social influence (Jasanoff, 2004; Latour, 1987; Latour and Woolgar, 1979).

2.1.1. Expertise

Who has the credibility to produce knowledge?

Research approaches view and deploy expertise differently. Experts are needed to help inform all phases of decision making but the kind of expertise needed varies depending on whether policies need to be designed and implemented.

Epistemic: Experts are typically the researchers who have specific training, norms and behaviors consistent with their epistemic communities (Knorr Cetina, 2009). Their expertise lies in a particular discipline or sub-discipline consistent with those in academia. They are considered experts in their field and usually by society due to their academic degree (e.g. PhD) and location of work (e.g. laboratory or university).

Experiential: Expertise also includes economic, policy, bureaucratic, community, lay and indigenous expertise, each of which comes with its own norms and criteria for quality (Edelenbos et al., 2011; Pohl, 2008; van Enst et al., 2014). Expertise is not just a result of degree achieved or focused effort of investigation, but also of lived experiences and proximity to the problem. Other forms of expertise are necessary to inform problems in which 'academic' expertise alone cannot inform solutions (Epstein, 1995). Designing and implementing policies requires the broadest array of expertise in order to ensure knowledge integration.

2.1.2. Relevance

How is the research relevant to solving the specific problem?

General: Research is oriented toward developing and testing hypotheses with the aim of informing theories (NSB, 2010; OECD, 2002). Consequently, outputs from research tend toward global instead of local scales and are broadly relevant.

Contextual: Research must be context sensitive and consider the appropriate physical, social, temporal and natural scales in order to be relevant (Cash et al., 2002; McNie, 2007).

2.1.3. Disciplinary focus

How discipline-driven are the knowledge production activities?

Intellectual inquiry is divided into different disciplines, each with its own accepted norms and processes that guide and validate research activities.

Singular, Narrow: Research is largely guided by single or sub-disciplines. Knowledge is characterized by a reductionist worldview in which systems are divided into smaller parts and analyzed in isolation, "studied by ever more esoteric specialism" (Funtowicz and Ravetz, 1993). Interdisciplinary research may also occur, but is still informed by a reductionist worldview.

Activity	Attribute	Spectra of Research Criteria: Science Values ←	→ User Values
Knowledge Production	Expertise	Epistemic	Experiential
	Relevance	General	Contextual
	Disciplinary Focus	Singular, Narrow	Transdisciplinary, Diverse
	Uncertainty	Reduce Uncertainty	Manage Uncertainty
	Goals for Research	Exploratory	Outcome Oriented
Learning & Engagement	Learning	Theoretical	Social, Practical
	Knowledge Exchange	Narrow	Iterative, Influential
	Network Participation	Homogeneous	Heterogeneous
	Social Capital	Negligible	Significant
Organizational & Institutional Processes	Accessibility	Constrained	High
	Outputs	Narrow	Diverse
	Evaluation & Effectiveness	Science-Centric	Public-Value Oriented
	Flexibility	Constrained	Responsive
	Human Capital	Narrow	Broad
	Boundary Management	Limited	Broad

Fig. 2. Typology of research activities and attributes.

Transdisciplinary, Diverse: Research is transdisciplinary and is organized around problems that are defined by the context of use, and will often incorporate social, physical, and natural sciences. Such an approach is necessary when knowledge is sought to inform decisions related to coupled, human–environmental systems (Berkes, 2009; Clark and Dickson, 2003; Ziegler and Ott, 2011).

2.1.4. Uncertainty

How do researchers understand and address the problem of uncertainty in knowledge production?

Researchers strive to reduce epistemic uncertainty but how they manage uncertainty varies by research approach.

Reduce: Uncertainty and statistical errors are to be reduced as much as possible, while simultaneously ensuring the highest degree of accuracy and precision. Some exceptions to the treatment of uncertainty can be found in more theoretical fields.

Manage: In some problems uncertainty is irreducible and must be managed as an accepted condition of more complex and interconnected realities (Funtowicz and Ravetz, 1993; van den Hove, 2007). More information does not necessarily reduce uncertainty and can in fact increase it (Sarewitz, 2004). Reducing uncertainties, often considered essential for policy, is not necessarily a precondition for making robust decisions that reduce vulnerabilities (Lempert et al., 2004). Formulating and implementing decisions may not need information produced with the same level of precision that is expected in assuring quality in the production of more fundamental knowledge.

2.1.5. Goals for research

What are the epistemic goals of research?

Exploratory: Research is driven by curiosity and not constrained by specific goals (NSB, 2010; OECD, 2002).

Outcomes-Oriented: Research is shaped by those people who will use the knowledge. Use may involve expanding understanding of a discrete problem or may feed into specific decisions, policies, plans, etc.

2.2. Learning and engagement

One can think of knowledge as having two dimensions: declarative and procedural (Alic, 2011). This category focuses on the procedural dimension of knowledge, specifically, how researchers and users learn, how they engage with each other, and how knowledge is exchanged between all participants. Overall, learning requires information and a process of transformation in which behavior, knowledge, skills, etc. are developed or changed (Knowles et al., 1998; Mezirow, 1997). There are multiple theories of individual, group and organizational learning (Armitage et al., 2008). Not all knowledge leads to learning. Many researchers believe their research, and knowledge outputs will lead to learning although it is not inevitable (Kropp and Wagner, 2010). Social learning is contextual, iterative (Pahl-Wostl, 2009), requiring systems thinking, communication and negotiation (Keen and Mahatny, 2006). Learning becomes more difficult as problems become less structured and more complex (Argyris, 1976).

2.2.1. Learning

In what ways do the research outputs change the knowledge system?

Theoretical: Learning is focused on understanding theories and focuses on the absorption of explicit knowledge that can be easily transferred between people through documents, patents and procedures.

Social, practical: Learning is also about understanding new things, and is also focused on developing new techniques, better approaches, and developing new policies, plans and changing behavior by exchanging tacit knowledge which is difficult to codify, takes time to explain and learn, and is embedded in relationships (Nonaka, 1994).

2.2.2. Knowledge exchange

To what extent, and how, is knowledge exchanged?

Knowledge exchange is an important concept in understanding how to reconcile the supply of scientific information with users' demands and increase the impact of social, economic, and environmental research (Fazey et al., 2013). Knowledge exchange is a process of "generating, sharing, and/or using knowledge through various methods appropriate to the context, purpose, and participants involved" (Fazey et al., 2013, p. 19). Methods can include knowledge brokering, informing, consulting, collaborating, mediating and negotiating among others (Lemos et al., 2012; Michaels, 2009) and leads to more "novel forms of the contextualization of knowledge" (Nowotny et al., 2002, p. 206). Communication can be one-way, from science to society, or vice versa, but two-way, iterative or 'multi-way' communication is needed for the production of useful information to inform decisions (Kirchhoff et al., 2013; Lemos and Morehouse, 2005). Scientists may need to develop language to speak to users, while at times the users may need to become versed in the language of science to improve dialog (Epstein, 1995). Knowledge exchange activities may need to be facilitated by intermediaries. In some cases brokering is done by organizations that are designed to do this work. Brokering is fundamentally about building relationships between the different actors (hence the need for social capital) and leveraging knowledge networks. Brokering requires training in 'soft-system skills' such as group dynamics, participation and relationship building (van Rooyen, 1998). Brokers also do 'boundary work' aimed at linking science with society while simultaneously maintaining the credibility of science (see Section 2.3). Boundary work involves convening relevant stakeholders, translating knowledge, and mediating between research and users (Cash and Moser, 2000). While we are still developing a better understanding about what kind of engagement solves what kind of challenges (van Enst et al., 2014), we do know that designing engagement activities with clear outcomes in mind increases their effectiveness (Fazey et al., 2014) and leads to the production of more useful information (Spaapen and van Drooge, 2011). Knowledge exchange also involves the collaborative production of knowledge aimed at informing decisions (van den Hove, 2007).

Restricted, linear: Knowledge exchanges between researchers and users are limited or non-existent. If knowledge exchange does occur it typically involves one-way communication from science to society through peer-review publications, press-releases and annual reports. Researchers usually communicate in ways that are consistent with, and understood by, their shared epistemic communities and not with the general public (McNie, 2007). Knowledge brokers tend to be the scientists themselves. Brokers, in the form of media or public affairs agents, may be used in some occasions to publicize recent research findings. Brokering supports one-way communication from science to society.

Iterative, influential: Communication must occur early in the research process, be iterative (Lemos and Morehouse, 2005), and be conducted in a language understood by researchers and users alike. Mediation and negotiation strategies may be needed to manage debates about what constitutes knowledge, what is credible, and who decides, in addition to debates about policy alternatives and decisions. Supporting productive interactions and engagement between researchers and users is "near vital to achieve social impact" (Spaapen and van Drooge, 2011, p. 214). As the complexity of the problem increases, for example in coupled human–environmental problems, the need for knowledge brokers increases. If the potential for political, cultural or epistemological conflict is high, then using brokers becomes more important to help mediate conflict.

2.2.3. Network participation

Who participates in the knowledge network?

Networks are structures of relationships and connections between different individuals or organizations through which information and resources are exchanged. Networks are flexible and efficient, enabling "participants to accomplish something collectively" that they could not accomplish individually, facilitating knowledge sharing and learning (Weber and Khademian, 2008, p. 334). Leveraging networks helps to improve research coordination, translation, and integration of knowledge to support decisions (Best and Holmes, 2010; Klerkx and Leeuwis, 2009; Molas-Gallart et al., 2014). Strong ties between actors in networks can increase the ease in which information is identified, shared and learned while leveraging weak ties may yield more novel information (Levin and Cross, 2004; Tsai and Ghoshal, 1998). Maintaining ties within a network requires time and resources. Networks can help to explain different conditions of relationships between individuals and organizations, for example by proximity, cognitive, social, organizational, institutional and geographic dimensions (Boschma, 2005).

Homogeneous: Networks are more homogenous and usually constrained within the researchers' epistemic communities. The network may be diffuse geographically but tends to be limited regarding the kinds of institutions that are in network, for example, a network of astrophysicists may be globally dispersed, yet all of whom are based in research centers or universities.

Heterogeneous: Networks are more heterogeneous from the outset in that they involve both researchers and users. Networks may include a wider variety of institutions including research, policy, business, community, and advocacy groups. Networks may also be more vertically integrated by connecting global and local actors, as well as scientific knowledge with indigenous knowledge. The disparateness of actors in these networks makes it more difficult to build and maintain the networks and thus takes more resources to do so. More heterogeneous networks, however, also have the potential to yield a greater variety of knowledge.

2.2.4. Social capital

How important is the development and deployment of social capital?

Social capital describes the relationships and "goodwill that others have toward us", the effects of which flow from the "information, influence and solidarity such goodwill makes available" (Adler and Kwon, 2002, p. 18). Social capital, trust, and relationships are necessary to create and share knowledge (Levin and Cross, 2004). People are more willing to share useful information, listen and absorb knowledge when the relationship is grounded in trust (Lemos et al., 2012; Levin and Cross, 2004). Leveraging social capital can result in the availability of more resources and power. While stronger relationships in an actor's social network are more difficult to maintain, such relationships lead to more social capital and hence greater exchange of knowledge and other resources.

Negligible: Social capital and trust aids in the development of research collaborations. Trust between researchers who do not know each other, or between researchers and the public, is mediated through rigorous methods and norms of conducting research. The need for creating or deploying social capital may be non-existent or exist only within the researchers' epistemic community.

Significant: Social capital, trust, and relationships are necessary to create and share knowledge (Levin and Cross, 2004). People are more willing to share useful information, listen, and absorb knowledge when the relationship is grounded in trust (Levin and Cross, 2004; Lemos et al., 2012). Communication between researchers and users is dependent on adequate social capital. As decision stakes increase, or if users are socially or politically marginalized, social capital and trust become even more important (McNie, 2013), and require more time to develop such relations. Social capital is particularly important in building capacity to apply knowledge in actual decisions and policies.

2.3. Organizational and institutional processes

Socio-technical systems describe the interrelatedness of social systems and technological systems (both material and procedural) in work groups, organizations and larger networks. The organization of work, research, incentives, and both formal and informal rules, among many, all shape the process of work, knowledge production and interactions between groups (Geels, 2004; Trist, 1981). Research processes and organizations are also subject to the same socio-technical considerations as other forms of work, albeit with different characteristics, norms, identities and processes (Jasanoff, 2004). Research over several decades has examined the optimal way to organize research, whether through large institutions or through more heterogeneous networks (Hellström and Jacob, 2000), and has posited different variables and metrics to describe research (America COMPETES, 2007; NRC, 2011; OECD, 2002; see also the National Science Foundation SciSip program). This section describes the variables that need to be considered in organizational and institutional design in order to support research, including the role of human capital, institutional setting, research outputs and outcomes, evaluation and effectiveness.

2.3.1. Accessibility

How accessible to users are the researchers and their organizations or institutions?

The proximity of an organization to others, its institutional settings, and other conditions, are factors that influence access (Boschma, 2005) between users and researchers.

Constrained: Research organizations and researchers are often difficult to access due to physical constrains (location of researchers or their organization) or institutional constraints (placement of the research organization within other organizations, centers or institutions), making it difficult for users to gain access. Within universities, research activities are situated in departments, centers, schools, colleges or institutes, each of which has its own barriers to access both for users and other researchers.

High: Researchers and their organizations are located proximate to the user and problem. Organizations are often designed to facilitate easy access to researchers and knowledge resources. Access by users is prioritized in organizational activities. A state or university-run extension office is more accessible than 'ivory tower' research facilities.

2.3.2. Outputs and outcomes

How various are the research outputs and outcomes?

Outputs can be thought of as material or experiential phenomena including reports, patents, peer-reviewed publications, workshops, trainings, lectures, proposals, meetings, etc. Outputs tend to be easily quantifiable. What constitutes relevant outputs varies between different research approaches. Outcomes occur when knowledge is gained or changed, or when decisions are made that effect policy, public or individual health, the economy, society, environmental well-being, culture, and even such things as cooperation and respect, among others (Lasswell, 1971; Penfield et al., 2014). Outcomes may be considered beneficial or harmful, may take years to manifest, and may be very difficult to measure. Achieving a particular outcome may require that other outcomes be achieved first.

Narrow: Outputs are directed toward a limited audience. The most common output is the peer-reviewed publication, followed by reports, patents, conference attendance, new methods and processes, workshops, etc. The primary outcome is new knowledge and the improved understanding of phenomena. Additional outcomes may be several years or decades away.

Diverse: These approaches yield similar outputs to research disconnected from users' needs, but also include trainings, public outreach activities, educational materials, press releases, meetings, plans, and expanded social networks. Outcomes include the production of knowledge, but also, for example, greater efficiency of solar cells, increased high-school graduation rates, or improved skill in seasonal climate forecasts. Some outcomes are critical in producing useful information for decision support such as the creation of social capital, stronger relationships with users, and changes in decision makers' understanding of phenomena. Many of these outcomes are necessary before decisions related to other outcomes can be made (Lasswell and McDougal, 1992).

2.3.3. Evaluation and effectiveness

What factors shape the evaluation of research?

Society and policy makers are calling for better methods to assess how linking science with society can lead to greater social impact (NRC, 2011; Spaapen and van Drooge, 2011). Publically-funded programs should be evaluated to determine their effectiveness and identify opportunities for improvement. Such evaluations should be designed so that their results can be useful to planners and policy makers (Patton, 2000). Evaluation activities and even the choice of metrics can inform research practice and design (Mahieu et al., 2014; Molas-Gallart et al., 2014; Rafols et al., 2012). Evaluation methods include quantitative (e.g. bibliometric analysis, patents, network analysis, other statistical methods, citations external to academia, number and type of outputs) and qualitative (e.g. peer-review, interview, survey, case study, narrative, public values mapping) approaches.

Science-centric: Quantitative and statistical approaches are used to evaluate outputs and are consistent with a linear, 'knowledge transfer', framework (Best and Holmes, 2010; Godin, 2005). Evaluation is most commonly performed through bibliometric analysis by quantifying the number of peer-reviewed publications, the impact factor of the journals where the papers are published, and the number of times the papers are cited. Newer methods and indices include the 'h-index' and network analysis of research collaborations, however these are not widely used by funding agencies to evaluate research productivity. Outcomes are not typically evaluated.

Public-value oriented: Evaluation includes the aforementioned approaches but also includes an "extended peer community" beyond the world of researchers (Funtowicz and Ravetz, 1993). Using traditional bibliometric analyses alone limits our evaluation of these approaches and may even deter interdisciplinary research (Penfield et al., 2014; Rafols et al., 2012). Evaluating research productivity needs to include qualitative approaches using network and systems approaches to describe how knowledge is used in policy and the impacts it has on social values and preferences (Best and Holmes, 2010; Bozeman and Sarewitz, 2011; Cozzens and Snoek, 2010; Donovan, 2011; Meyer, 2011). Producing, exchanging and integrating knowledge to support decisions is a complex process, thus the widest array of outcomes should be evaluated, including outcomes oriented to process and interactions between researchers and users (Fazey et al., 2014; Molas-Gallart et al., 2014; Moser, 2009). Evaluating outcomes related to social capital, knowledge exchange, and influence is best served by the use of qualitative methods. Evaluating outcomes remains challenging due to long temporal delays between knowledge production, integration and application, and because the effects of some decisions may not be able to be assessed for years to come (e.g. flood mitigation planning).

2.3.4. Organizational flexibility

How easy is it to alter research to better respond to users' needs, and changes in those needs?

Organizational flexibility describes the ability of an organization to respond to emerging opportunities or threats by allocating resources (human, financial, etc.) in strategic ways. Overcoming organizational inertia is essential to enable organizational flexibility.

Constrained: Research organizations are relatively inflexible with formal rules of operations. The inflexibility is not a problem given the rather predictable forms of research conduct and applications.

Responsive: Responding to users' needs, developing problems, and emerging research windows of opportunities requires higher degrees of organizational flexibility (McNie, 2013).

2.3.5. Human capital

What kinds of skills and training are needed to do the work?

This describes the formal training and education required for doing research. Calls for improving the training, social diversity and capacity in the scientific workforce are not uncommon (e.g. Alic, 2011; America Competes Act, 2007; OECD, 2002), although little attention has been given to the skills necessary for research aimed at users' information needs.

Hard skills: Researchers are trained almost exclusively as PhDs and have gone through rigorous training in specialized skills of which the abilities to formulate hypotheses, develop research protocols, undertake research, and publish articles are the most important. Hard skills are rules-based and encompass scientific, technical and engineering activities.

Soft skills: In addition to a PhD, other terminal degrees (such as a JD), or Masters' level degrees may be more relevant. People engaged in integrating research and capacity building may only hold a bachelor's degree. Soft skills are experienced-based skills and focus on behavior and relationships. Effective communication, translation and mediation skills are such examples. Leadership skills and experience in managing more complex research-policy interfaces is also a desirable trait (McNie, 2013).

2.3.6. Boundary management

To what extent must efforts be made to actively manage the boundary?

Whenever the two distinct worlds of science and society move closer to each other, the risk of science becoming politicized, or policy and decisions becoming 'scientized', becomes more acute (Guston, 1999, 2000; Sarewitz, 2004). The boundary between science and society needs to be managed, by doing boundary work, in order to accomplish two mutual goals: ensuring that research responds to the needs of users while assuring the credibility of science. Boundary work involves communicating between science and society, translating information, and mediating and negotiating across the boundary. When done effectively (either by individuals or by 'boundary' organizations whose function is to operate at the boundary between science and society, (Guston, 2000; Clark et al., 2011), the credibility, relevance and legitimacy of the knowledge created increases (Cash et al., 2002). As political stakes increase, so too does the need for more deliberate and intentional boundary work.

Low: The risk of politicization of science is low, although varies by discipline, but increases somewhat with more applied research. Less attention needs to be paid toward boundary management.

High: Active involvement of users in shaping research brings science and society closer together, inevitably increasing the risks

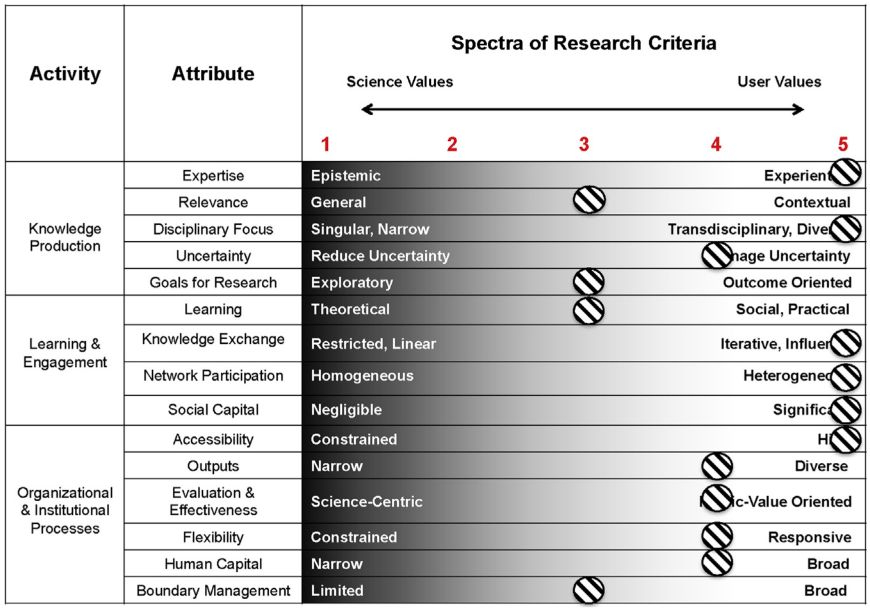

Fig. 3. Southwest fire monsoon decision support.

of science's credibility being impugned or of science becoming politicized. It may be necessary to employ skilled individuals or organizations whose purpose it is to manage the boundary.

3. Using the typology

The typology provides a framework to visualize the range of activities of a science project or several projects across a program or institution at both fixed points in time and over a succession of years. To operationalize the use of the typology, one might allow the spectra to vary on a scale of one (science-centric values are dominant) to five (user-oriented values are dominant). Expert judgments, including those of program managers, researchers and more sophisticated users and practitioners, can be applied to classify the full menu of attributes for a given project or set of projects or programs. A research program might receive two different scores by two different people. This is to be expected given that scoring is a subjective activity. However, the different scores will inevitably lead to more discussion and deliberation about the program, which is one of the goals of the typology. We demonstrate how the typology can be used with two examples. The assignment of specific scores (from one to five) along each of the spectra is based on our direct experience[1] with these specific projects. Users were not consulted for the scoring in these examples.

3.1. Southwest monsoon fire decision support

Wildfire suppression in the United States is built on a three-tiered system of geographic support: a local area, one of the 11 regional areas, and finally, the national level. When a fire is reported, the local agency and its firefighting partners respond. If the fire continues to grow, the agency can ask for help from its geographic area. When a geographic area has exhausted all its resources, it can turn to the National Interagency Coordination Center (NICC) at the National Interagency Fire Center (NIFC) for help in locating what is needed, from air tankers to radios to firefighting crews to incident management teams. The Predictive Services group was developed to provide decision-support information needed to be more proactive in anticipating significant fire activity and determining resource allocation needs. Predictive Services consists of three primary functions: fire weather, fire danger/fuels, and intelligence/resource status information. Predictive Services involves participation from representatives of the Bureau of Land Management, Bureau of Indian Affairs, National Park Service, Forest Service, U.S. Fish and Wildlife Service, Federal Emergency Management Administration, and the National Association of State Foresters. In this project, researchers from the Desert Research Institute (Reno, NV) and the University of Arizona identified needs within the Southwest Area, Rocky Mountain, and Great Basin Predictive Services information in relation to the Southwest Monsoon to better understand the physical relationships between monsoon atmospheric processes and fire activity. The results of the project provide operational fire staff and managers with information and products to improve prediction of monsoon impacts on fire, and climatological information on monsoon-fire relationships for assessments and planning. Fig. 3 represents our classification of this research for each attribute, based on elements of the project description above and extensive interaction with the researchers on the project.

While the activities described in the typology may be idealized, the example in Fig. 3 illustrates how research projects are not idealized. If the Spectra of Research Criteria vary on a generic scale of 1–5, then a science manager could assign a score of 3 to Relevance, given that the monsoon information may not fit the decisions of both the Southwest and Great Basin. Similarly, a science manager could assign a score of 5 to Expertise, since the experience of fire managers and agency personnel help shape the decision support information. Moreover, this example illustrates how research directed toward satisfying the needs of decision makers need not have every attribute scored as a 5, which adequately reflects the complexity of research design and implementation. We emphasize, however, that these scores are not inherently evaluative; rather, they are meant to characterize the many attributes of the project that are potentially relevant to the achievement of the project's stipulated goals. This process of characterization allows the project to be viewed and discussed that may then allow project managers and participants (scientists and users) to relate the performance of the program to its constituent attributes.

[1] Parris for the first example and McNie for the second.

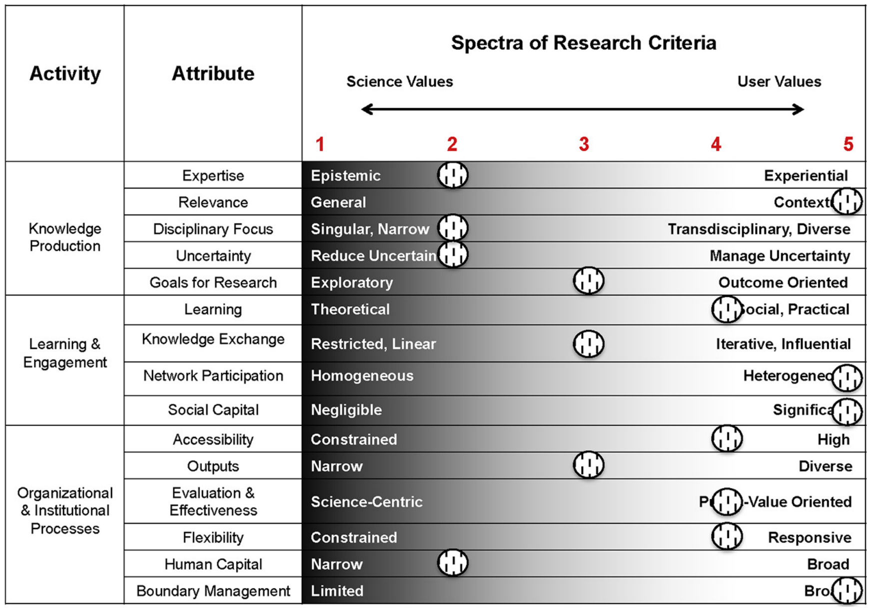

Fig. 4. Indonesian agroforestry.

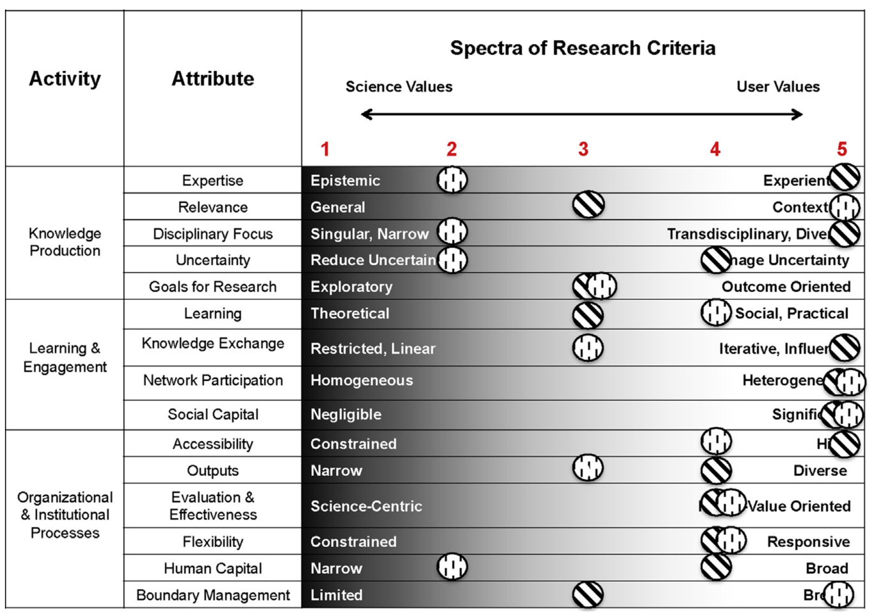

Fig. 5. Combined SW monsoon and Indonesian agroforestry.

3.2. Indonesian agroforestry

On the island of Sumatra, "protection forests" provide several economic and ecosystem services including erosion control, water filtration, and timber production. Agroforestry practices, such as coffee cultivation, were not allowed in protection forests limiting the opportunity for people to improve their livelihoods. The Ministry of Forestry believed that coffee trees were not "trees" in that they could not provide the same ecosystem services as timber species. In the interest of improving livelihoods for impoverished farmers living in the protection forests, the World Agroforestry Centre sought to determine if coffee trees were in fact trees in terms of providing similar ecosystem services as timber species (e.g. Leimona et al., 2015). From a disciplinary perspective the research was fairly narrow, so it scored a 2 on the spectra (see Fig. 4). Research determined that coffee trees did in fact provide similar ecosystem services as timber varietals. This research was complex for many reasons. One is that findings from the research had implications in how protection forests were managed that could result in transferring some power for land management from the government to local tenant farmers. The World Agroforestry Centre was largely seen as a trusted broker of information, but significant mistrust existed between the government and farmers, consequently increasing the need for the research to be both credible and legitimate, and for managing the boundary between science and society thus scoring a 5 on the spectra.

In both examples, producing scientific information to inform decision making and improve societal outcomes was the goal. Yet each project had different characteristics including users, role of expertise and disciplinary foci, knowledge exchange, and others. Differences between approaches in these examples do not directly indicate if one is better than the other, but rather, that the projects were pursued in different ways. Fig. 5 provides a side-by-side comparison of the two projects.

For the science manager, the most important element of putting the typology into practice through such graphical tools is in bringing to the fore aspects of the research process that are often unexamined, assumed, or excluded. Using the typology will create a process of developing and visualizing empirical evidence and expert judgments about the internal coherence of science projects, programs, and institutions. It will also allow deeper understanding of how they are evolving over time. It will allow comparison of different projects and inform consideration about why one project might have been more (or less) effective than another one. For a program or institution, this exercise could be done for any number of projects to yield an aggregated sense of the type of research being performed. This process would allow science managers to: (a) form mental models about mechanisms that might support different attributes and activities over time, (b) dispel bias about whether or not the research is complementing mission and goals that support user-driven science, and (c) link observed changes in the character and conduct of science to observations of contextual factors (e.g. a decrease in knowledge exchange resulting from a different project or program leader). The typology can aid in the development of proposal solicitations, in allocation decisions about resources to support research, and in devising more valuable grant-reporting processes. We emphasize that, by itself, the typology is not meant to be directly evaluative. A given score or set of scores only has meaning in the context of program (or project) goals, program evolution, comparison between programs, and so on.

4. Conclusions

The typology is a heuristic that enables science policy practitioners and researchers to investigate, understand, assess, and plan research projects and programs based on three broad activities and numerous attributes. It is intended primarily to be a heuristic that can promote greater understanding, and thus more effective deliberation and planning, about research activities and practices, far beyond the two prevailing attributes used today to describe basic and applied research: motivation for research and temporal delay to application. Examples provided in this paper illustrate that specific projects and programs may pursue user-inspired research along significantly different pathways. As with the problems they seek to solve, user-inspired research activities are similarly complex and nuanced and research priorities should reflect the unique context in which a given program or project is situated.

The typology can be used both for descriptive purposes and prescriptive purposes. As a descriptive tool, the typology represents the first comprehensive attempt to identify and characterize the major activities and attributes of research in terms that give equal weight to the consideration of “science values” and “user values” in characterizing research activities. Use of the typology thus gives science policy practitioners and researchers a more holistic vision of what a given research program or project entails and whether or not it is aligned with project or programmatic goals. The typology may also be used prescriptively as a planning tool to design research. After a comprehensive assessment of the identified problem, available research capabilities, and the needs of the intended users, science-policy decision makers may then determine how science-centric or user-oriented certain attributes should be, given the context of the research problem. The typology is not, however, explicitly normative in that it does not favor one value over another as a matter of course. However, given desired program or project goals, the typology could be used over time to see if or how changes in various attributes influence the alignment of research with identified goals, in a manner not dissimilar from adaptive management strategies (e.g. Holling, 1978; Lee, 1993, 1999). Mapping program or project attributes onto the spectra could be done through a collaborative process among science managers, project researchers, and those users for whom the research is intended. Periodic assessments of progress on research should also be done collaboratively.

The typology provides a richer depiction of the character and conduct of science than permitted by terms like “basic” and “applied.” Such terms are often semantic, used with vague and varied definitions, often for political purposes in the competition for resources. Moreover, individual science projects, programs, and institutions change over time in response to many of the contextual factors mentioned in the attributes. For example, leaders of science institutions can have a dramatic effect, shifting the focus of an institution to or from particular goals or societal needs. Also, federally funded, national scale programs are being designed with the goal of building capacity to connect science with societal needs. But science managers lack methods to empirically portray, let alone assess whether this capacity is actually being achieved, a wholly different process than that of evaluation of impact, outcomes, or public value of an individual effort.

For the science policy community as a whole, putting the typology to use over time can help bring the expert judgment of science managers to bear on understanding the relations among the complex attributes of research activities, for example, in understanding how the need for adequate social capital may inform the types of outputs and outcomes generated by the research. The typology is also an important tool for evaluating the expectations for, and promises, about the goals of science. It aids in identifying when problems are best addressed through basic and applied research approaches and when alternative approaches are preferable. Additionally, the typology helps to overcome the barriers between science and society by informing the assessment and analysis of the factors that enhance or inhibit closer linkages between the two cultures. Finally, the typology helps to identify the extent to which research activities actually are appropriately structured to advance desired societal outcomes, thus serving an evaluative function. Using the typology also aids in identifying the ways in which users of research can and should be involved in the research given the specific context of the research problem. Applying the typology, or other rigorous methods of science policy assessment, across broad portfolios of science can support responsible decision making about science that is justified by, and aimed at, the achievement of public values in addition to simple knowledge creation. This typology represents an important step in that direction.

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References

Adler, P.S., Kwon, S.W., 2002. Social capital: prospects for a new concept. Acad. Manag. Rev. 27 (1), 17–40.
Alic, J.A., 2011. Everyone an innovator. In: Block, F., Keller, M.R. (Eds.), State of Innovation: The U.S Government's Role in Technology Development. Paradigm Publishers, London.
America COMPETES Act, 2007. H.R. 2272, 100th Congress, 2007–2009. Signed August 9, 2007.
Argyris, C., 1976. Single-loop and double-loop models in research on decision making. Admin. Sci. Q. 21 (3), 363.
Armitage, D., Marschke, M., Plummer, R., 2008. Adaptive co-management and the paradox of learning. Global Environ. Change 18, 86–98, http://dx.doi.org/10.1016/j.gloenvcha.2007.07.002.
Berkes, F., 2009. Evolution of co-management: role of knowledge generation, bridging organizations and social learning. J. Environ. Manag. 90 (5), 1692–1702.
Best, A., Holmes, B., 2010. Systems thinking, knowledge and action: towards better models and methods. Evid. Policy: J. Res. Debate Pract. 6 (2), 145–159.

Boschma, R., 2005. Proximity and innovation: a critical assessment. Reg. Stud. 39, 61–74, http://dx.doi.org/10.1080/0034340052000320887.

Bozeman, B., Sarewitz, D., 2011. Public value mapping and science policy evaluation. Minerva 49 (1), 1–23.

Bush, V., 1945. Science: The Endless Frontier. Office of Scientific Research and Development, Washington, DC.

Calvert, J., 2006. What's special about basic research? Sci. Technol. Hum. Values 31 (2), 199–220.

Cash, D., Clark, W., Alcock, F., Dickson, N., Eckley, N., Jager, J., 2002. Salience, Credibility Legitimacy and Boundaries: Linking Research, Assessment and Decision Making. RWP02-046 Kennedy School of Government. Harvard University, pp. 25.

Cash, D.W., Moser, S.C., 2000. Linking global and local scales: designing dynamic assessment and management processes. Global Environ. Change 10 (2), 109–120.

Clark, W.C., Tomich, T.P., van Noordwijk, M., Guston, D., Catacutan, D., Dickson, N.M., McNie, E., 2011. Boundary work for sustainable development: natural resource management at the Consultative Group on International Agricultural Research (CGIAR). Proc. Natl. Acad. Sci. U.S.A. (August), http://dx.doi.org/10.1073/pnas.0900231108.

Clark, W.C., Dickson, N.M., 2003. Sustainability science: the emerging research program. Proc. Natl. Acad. Sci. U.S.A. 100 (14), 8059–8061.

Cozzens, S., Snoek, M., 2010. Knowledge to Policy: Contributing to the Measurement of Social, Health, and Environmental Benefits. White paper prepared for the "Workshop on the Science of Science Measurement", Washington D.C. December 2–3, 39 pp.

Dilling, L., Lemos, M.C., 2011. Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy. Global Environ. Change 21, 680–689.

Dilling, L., Lackstrom, K., Haywood, B., Dow, K., Lemos, M.C., Berggren, J., 2015. What stakeholder needs tell us about enabling adaptive capacity: the intersection of context and information provision across regions in the United States. Weather Clim. Soc. 6, 238–252.

Donovan, C., 2011. State of the art in assessing research impact: introduction to a special issue. Res. Eval. 20 (3), 175–179.

Donovan, S., Holdren, J., 2015. Memorandum for the Heads of Executive Departments and Agencies. Executive Office of the President of the United States of America.

Edelenbos, J., van Buuren, A., van Schie, N., 2011. Co-producing knowledge: joint knowledge production between experts, bureaucrats and stakeholders in Dutch water management projects. Environ. Sci. Policy 14, 675–684, http://dx.doi.org/10.1016/j.envsci.2011.04.004.

Eden, S., 2011. Lessons on the generation of usable science from an assessment of decision support practices. Environ. Sci. Policy 14, 11–19.

Epstein, S., 1995. The construction of lay expertise: AIDS activism and the forging of credibility in the reform of clinical trials. Sci. Technol. Hum. Values 20 (4), 408–437.

Fazey, I., Bunse, L., Msika, J., Pinke, M., Preedy, K., Evely, A.C., Lambert, E., Hastings, E., Morris, S., Reed, M.S., 2014. Evaluating knowledge exchange in interdisciplinary and multi-stakeholder research. Global Environ. Change 25 (March), 204–220.

Fazey, I., Evely, A.C., Reed, M.S., Stringer, L.C., Kruijsen, J., White, P.C.L., Newsham, A., Jin, L., Cortazzi, M., Phillipson, J., Blackstock, K., Entwistle, N., Sheate, W., Armstrong, F., Blackmore, C., Fazey, J., Ingram, J., Gregson, J., Lowe, P., Morton, S., Trevitt, C., 2013. Knowledge exchange: a review and research agenda for environmental management. Environ. Conserv. 40, 19–36, http://dx.doi.org/10.1017/S037689291200029X.

Fischer, F., 2000. Citizens, Experts, and the Environment: The Politics of Local Knowledge. Duke University Press, Durham, NC.

Funtowicz, S.O., Ravetz, J.R., 1993. Science for the post-normal age. Futures 25 (7), 739–755.

Geels, F.W., 2004. From sectoral systems of innovation to socio-technical systems. Res. Policy 33 (6–7), 897–920.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., Trow, M., 1994. The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies. Sage, London.

Gieryn, T.F., 1999. Cultural Boundaries of Science: Credibility on the Line. University of Chicago Press, Chicago.

Godin, B., 2005. The Linear Model of Innovation: The Historical Construction of an Analytical Framework. Project on the History and Sociology of S&T Statistics. Working Paper No. 30, 36 pp.

Guston, D.H., 2000. Between Politics and Science: Assuring the Integrity and Productivity of Research. Cambridge University Press, Cambridge, UK.

Guston, D.H., 1999. Stabilizing the boundary between U.S. politics and science: the role of the office of technology transfer as a boundary organization. Soc. Stud. Sci. 29 (1), 87–111.

Hellström, T., Jacob, M., 2000. Scientification of politics or politicization of science? Traditionalist science-policy discourse and its quarrels with mode 2 epistemology. Soc. Epistemol. 14, 69–77.

Holling, C.S., 1978. Adaptive Environmental Assessment and Management. John Wiley & Sons, New York.

Jasanoff, S., 2004. The idiom of co-production. In: Jasanoff, S. (Ed.), States of Knowledge: The Co-Production of Science and Social Order. Routledge, London, pp. 1–12.

Keen, M., Mahatny, S., 2006. Learning in sustainable natural resource management: challenges and opportunities in the Pacific. Soc. Nat. Resour. 19 (6), 497–513.

Kirchhoff, C.J., Lemos, M.C., Dessai, S., 2013. Actionable knowledge for environmental decision making: broadening the usability of climate science. Annu. Rev. Environ. Resour. 38 (1), 393–414.

Kitcher, P., 2001. Science, Truth and Democracy. Oxford, London.

Klerkx, L., Leeuwis, C., 2009. Establishment and embedding of innovation brokers at different innovation system levels: insights from the Dutch agricultural sector. Technol. Forecast. Soc. 76, 849–860, http://dx.doi.org/10.1016/j.techfore.2008.10.001.

Knorr Cetina, K., 2009. Epistemic Cultures: How Sciences Make Knowledge. Harvard University Press, Cambridge.

Knowles, M.S., Holton III, E.F., Swanson, R.A., 1998. The Adult Learner. Routledge, New York.

Kropp, C., Wagner, J., 2010. Knowledge on stage: scientific policy advice. Sci. Technol. Hum. Values 35, 812–838, http://dx.doi.org/10.1177/0162243909357912.

Lackstrom, K., Kettle, N., Haywood, B., Dow, K., 2014. Climate sensitive decisions and time frames: a cross-sectoral analysis of information pathways in the Carolines. Weather Clim. Soc. 6, 238–252.

Lasswell, H.D., 1971. A Pre-view of Policy Sciences. Elsevier, New York.

Lasswell, H.D., McDougal, M.S., 1992. Jurisprudence for a Free Society: Studies in Law, Science and Society. New Haven Press, New Haven, CT.

Latour, B., 1987. Science in Action: How to Follow Scientists and Engineers Through Society. Harvard University Press, Cambridge.

Latour, B., Woolgar, S., 1979. Laboratory Life: The Construction of Science. Princeton University Press, Princeton, NJ.

Lee, K.N., 1993. Compass and Gyroscope: Integrating Science and Politics for the Environment. Island Press, Washington, DC.

Lee, K.N., 1999. Appraising adaptive management. Conserv. Ecol. 3 (2), Available from: http://www.ecologyandsociety.org/vol3/iss2/art3/.

Leimona, B., van Noordwijk, M., de Groot, R., Leemans, R., 2015. Fairly efficient, efficiently fair: lessons from designing and testing payment schemes for ecosystem services in Asia. Ecosyst. Serv. 12, 16–28.

Lemos, M.C., Kirchhoff, C.J., Ramprasad, V., 2012. Narrowing the climate information usability gap. Nat. Clim. Change 2, 789–794.

Lemos, M.C., Morehouse, B.J., 2005. The co-production of science and policy in integrated climate assessments. Global Environ. Change 15, 57–68.

Lempert, R., Nakicenovic, N., Sarewitz, D., Schlesinger, M., 2004. Characterizing climate-change uncertainties for decision-makers. An editorial essay. Clim. Change 65 (1), 1–9.

Levin, D.Z., Cross, R., 2004. The strength of weak ties you can trust: the mediating role of trust in effective knowledge transfer. Manag. Sci. 50 (11), 1477–1490.

Logar, N., 2009. Towards a culture of application: science and decision making at the National Institute of Standards & Technology. Minerva 47 (4), 345–366.

Lövbrand, E., 2011. Co-producing European climate science and policy: a cautionary note on the making of useful knowledge. Sci. Public Policy 38 (2), 225–236.

Mahieu, B., Arnold, E., Kolarz, P., 2014. Measuring Scientific Performance of Improved Policy Making. Science and Technology Options Assessment. European Parliamentary Research Service. PE 527.383, 132 pp.

McNie, E.C., 2013. Delivering climate services: organizational strategies and approaches for producing useful climate-science information. Weather Clim. Soc. 5, 14–26.

McNie, E.C., 2008. Co-Producing Useful Climate Science for Policy: Lessons from the RISA Program. Monograph. University of Colorado, Boulder.

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, http://dx.doi.org/10.1016/j.envsci.2006.10.004.

Merton, R.K., 1945. Role of the intellectual in public bureaucracy. Soc. Forces 23 (4), 405–415.

Meyer, R., 2011. The public values failures of climate science in the U.S. Minerva 49 (1), 47–70.

Mezirow, J., 1997. Transformative learning: theory and practice. New Dir. Adult Contin. Educ. 74, 5–12.

Michaels, S., 2009. Matching knowledge brokering strategies to environmental policy problems and settings. Environ. Sci. Policy 12 (7), 994–1011.

Molas-Gallart, J., D'Este, P., Llopis, Ó., Rafols, I., 2014. Towards an Alternative Framework for the Evaluation of Translational Research Initiatives. INGENIO (CSIC-UPV) http://www.ingenio.upv.es/sites/default/files/working-paper/2014-03.pdf.

Moser, S., 2009. Making a difference on the ground: the challenge of demonstrating the effectiveness of decision support. Clim. Change 95 (1–2), 11–21.

NRC – National Research Council, 2006. Linking Knowledge With Action for Sustainable Development: The Role of Program Management – Summary of a Workshop. National Academies Press, Washington, DC.

NRC – National Research Council, 2009. Informing Decisions in a Changing Climate, Panel on Strategies and Methods for Climate-Related Decision Support. National Academies Press, Washington, DC.

NRC – National Research Council, 2011. Measuring the Impact of Federal Investments in Research, Workshop Summary. National Academies Press, Washington, DC.

NSB – National Science Board, 2010. Key science and engineering indicators: 2010 digest. In: Roesel, C. (Ed.), NSB 10-02. National Science Foundation, Washington, DC.

Nonaka, I., 1994. A dynamic theory of organizational knowledge creation. Organ. Sci. 5 (1), 14–37.
Nowotny, H., Scott, P., Gibbons, M., 2002. Re-Thinking Science: Knowledge and the Public in an Age of Uncertainty. Polity Press, London.
OECD, 2002. Frascati Manual 2002: Proposed Standard Practice for Surveys on Research and Experimental Development, The Measurement of Scientific and Technological Activities. OECD Publishing, Paris.
Pahl-Wostl, C., 2009. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. Global Environ. Change 19 (3), 354–365.
Patton, M.Q., 2000. Utilization-Focused Evaluation. Sage, Netherlands/Los Angeles.
Penfield, T., Baker, M.J., Scoble, R., Wykes, M.C., 2014. Assessment, evaluations, and definitions of research impact: a review. Res. Eval. 23 (1), 21–32.
Pielke Jr., R., 2012. Basic research as a political symbol. Minerva (Spring), 23, http://dx.doi.org/10.1007/s11024-012-9207-5.
Pohl, C., 2008. From science to policy through transdisciplinary research. Environ. Sci. Policy 11 (1), 46–53.
Rafols, I., Leydesdorff, L., O'Hare, A., Nightingale, P., Stirling, A., 2012. How journal rankings can suppress interdisciplinarity: the case of innovation studies and business and management. Res. Policy 41 (7), 1262–1282.
Rosenberg, N., Nelson, R., 1994. American universities and technical advance in industry. Res. Policy 23, 323–348.
Sarewitz, D., 2004. How science makes environmental controversies worse. Environ. Sci. Policy 7 (5), 385–403.
Sarewitz, D., Pielke, R.A., 2007. The neglected heart of science policy: reconciling supply of and demand for science. Environ. Sci. Policy 10 (1), 5–16.
Sarkki, S., Tinch, R., Niemelä, J., Heink, R., Waylen, K., Timaeus, J., Young, J., Watt, A., Nibhöver, C., van den Hove, S., 2015. Adding 'iterativity' to the credibility, relevance, legitimacy: a novel scheme to highlight dynamic aspects of science-policy interfaces. Environ. Sci. Policy, http://dx.doi.org/10.1016/j.envsci.2015.02.01.
Simpson, C., Dilling, L., Dow, K., Lackstrom, K.J., Lemos, M.C., Riley, M.C., 2016. Assessing needs and decision contexts: RISA approaches to engagement research. In: Parris, A., Garfin, G., Dow, K., Meyer, R., Close, S.L. (Eds.), Climate in Context: Science and Society Partnering for Adaptation. Wiley & Sons, London (in press).
Spaapen, J., van Drooge, L., 2011. Introducing "productive interactions" in social impact assessment. Res. Eval. 20, 211–218.
Stokes, D.E., 1997. Pasteur's Quadrant: Basic Science and Technological Innovation. Brookings Institution Press, Washington, DC.
Trist, E., 1981. The Evolution of Socio-Technical Systems: A Conceptual Framework and an Action Research Program, Occasional Paper No. 2. June. York University, Toronto, 67 pp.
Tsai, W., Ghoshal, S., 1998. Social capital and value creation: the role of intrafirm networks. Acad. Manag. J. 4 (14), 464–476.
van den Hove, S., 2007. A rationale for science-policy interfaces. Futures 39 (7), 807–826.
van Enst, W.I., Driessen, P.P.J., Runhaar, H.A.C., 2014. Towards productive science-policy interfaces: a research agenda. J. Environ. Assess. Policy Manag. 16, 1450007, http://dx.doi.org/10.1142/S1464333214500070.
van Rooyen, A.F., 1998. Combating desertification in the southern Kalahari: connecting science with community action in South Africa. J. Arid Environ. 39 (2), 285–297.
Weber, E.P., Khademian, A.M., 2008. Wicked problems, knowledge challenges, and collaborative capacity builders in network settings. Public Admin. Rev. 68, 334–349.
Ziegler, R., Ott, K., 2011. The quality of sustainability science: a philosophical perspective. Sustain.: Sci. Pract. Policy 7 (1), 31–44.