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De-Facto Science Policy in the Making: How Scientists Shape Science Policy and Why it Matters (or, Why STS and STP Scholars Should Socialize)

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Abstract Science and technology (S&T) policy studies has explored the relationship between the structure of scientific research and the attainment of desired outcomes. Due to the difficulty of measuring them directly, S&T policy scholars have traditionally equated "outcomes" with several proxies for evaluation, including economic impact, and academic output such as papers published and citations received. More recently, scholars have evaluated science policies through the lens of Public Value Mapping, which assesses scientific programs against societal values. Missing from these approaches is an examination of the social activities within the scientific enterprise that affect research outputs and outcomes. We contend that activities that significantly affect research trajectories take place at the levels of individual researchers and their communities, and that S&T policy scholars must take heed of this activity in their work in order to better inform policy. Based on primary research of two scientific communities—ecologists and sustainability scientists—we demonstrate that research agendas are actively shaped by parochial epistemic and normative concerns of the scientists and their disciplines. S&T policy scholarship that explores how scientists balance these concerns, alongside more formal science policies and incentive structures, will enhance understanding of why certain science policies fail or succeed and how to more effectively link science to beneficial social outcomes.

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Introduction

Central to science and technology (S&T) policy scholarship since the outset of this journal has been a contest over the optimal organization of science. In the first issue of *Minerva*, Michael Polanyi (1962) articulated a view that individual scientists following their individual curiosities aggregate into a scientific system that operates as if guided by an invisible hand. Any attempt to guide scientific effort toward particular problems, he felt, would stifle overall productivity. Scientists and their collective institutions and norms, argued Polanyi and his allies, are best positioned to steer the scientific enterprise. As Barke (2003) recounts, various other authors have argued that social and economic goals must be a part of science policy making. In this vision, non-scientists play a key role in identifying research priorities. As Barke (2003) notes, neither side of this debate has emerged as an obvious victor in the intellectual debate; scientists retain a large degree of autonomy and regularly act as science policy-makers themselves, and innumerable policies offer incentives that systematically steer scientific effort whether they were intended for that purpose or not (Barke 1998; Jasanoff 1990).

The field of S&T policy studies, intellectually spurred on by *Minerva*, has developed to explore these policies surrounding science and technology that affect the structure of scientific research and the attainment of desired social outcomes (Marburger 2005; Shils 1968). In part due to a lack of other well-developed tools, the academic literature has typically used economic impact as a proxy for the scientific enterprise's contribution to societal goals (e.g., Jones and Williams 1998) or has otherwise relied on academic outputs such as the number of papers published, patents received, or citations received (Borner et al. 2003). None of these proxies account for the breadth of expectations that society has for science, and thus they are of limited utility in evaluating scientific policies. Recognizing these shortcomings, a group of scholars has begun examining scientific programs through the lens of Public Value Mapping—evaluating science against language (i.e., public values) in sponsoring legislation, funding agency documents, and other sources (Bozeman and Sarewitz 2005, 2011). While these various approaches can provide valuable insights into the effectiveness of science policies, they for the most part treat scientific programs as black boxes with only inputs and outputs. In so doing, they do not account for the social processes by which policies are constructed and translated into scientific products and to outcomes of some kind and the myriad policies at other levels of organization which systematically steer scientific efforts but were not consciously designed with that goal in mind. There are, however, important exceptions as Meyer's (2011) analysis of climate science illustrates.

Though individual scientists are subject to various institutional constraints, including tenure and promotion guidelines and constraints that may come with funding, they retain a substantial degree of autonomy in much of their work, including their selection of research problems (Rip 1985; Hackett 2005).

Disciplinary research portfolios then reflect, to some degree, the aggregated–yet not necessarily coordinated–choices that individual scientists make as they seek to balance numerous competing influences alongside their own normative considerations. Simultaneously, in other settings, groups of scientists with varying levels of coordination work to build new fields and research agendas they view as responding to gaps in existing knowledge, combining knowledge sets in new, interdisciplinary ways or, increasingly, responding to the perceived knowledge needs of society and decision-makers (Bocking 2004; Parker and Hackett 2011). In other words, both the social and scientific outcomes of science policies are shaped in large part by the social actions of scientists; scientists respond to, interpret, implement and actively co-produce S&T policy. These insights are not necessarily novel, as work in other fields such as the sociology of science and science and technology studies (STS; e.g., Gieryn 1995; Latour 1987; Jasanoff 1990; Kinchy and Kleinman 2003; Shackley 2000) has illustrated. Such work is, however, rarely done with an eye toward engaging S&T policy or S&T policy studies (Nowotny 2007). Similarly, as we have noted, S&T policy scholars rarely engage with STS. We argue that in order to evaluate the efficacy of science policies, and, more importantly, construct policies and research agendas that more effectively link scientific research to beneficial social outcomes, S&T policy scholars need to understand scientists and their communities as actors in shaping disciplinary research trajectories, and establishing norms and disciplinary cultures that serve as informal science policies. S&T policy studies has much to gain through continued interaction with the science studies community and the utilization of the knowledge they generate just as a more engaged STS scholarship has the potential to put its insights to work by grounding it in the S&T policy world.

Supported by primary research on two scientific communities—ecologists (Neff 2011) and sustainability scientists (Miller 2013)—we demonstrate that while scientists are often concerned with providing knowledge that will be linked to social outcomes, research priorities and questions are defined according to the epistemic and normative frames of scientists and their disciplines. The perception of the relationship between scientific knowledge and broader social and environmental outcomes by scientists shapes how they attempt to address science policy goals and speak to social values. Out of these empirical observations, a normative dilemma then emerges: How should S&T policy-makers incorporate such insights to enhance the capacity to align science with beneficial social outcomes? Many authors (with whom we generally agree) have called for more open, democratic and deliberative models for the setting of S&T policy and research agendas (e.g., Fischer 1999, 2000; Rayner 2003; Guston 2004). We argue that a more process-oriented approach (as opposed to outcome-oriented) to S&T policy studies would both contribute to the understanding of and serve to inform these models. We suggest a need for S&T policy scholars to "wade into the weeds" and engage in a two-way dialogue with scientists and their communities. Scientists and their communities are actors in science policy. Thus, in addition to studying how policies are made, interpreted, and implemented at that level, S&T policy scholars need to engage with those stakeholders in policy discussions by publishing in relevant scientific journals and attending relevant professional meetings. Before turning to the case studies and these arguments, we begin by establishing the context and need for a research pathway in S&T policy studies that explore the social processes and practices of science and science policy.

Shaping Science Policy: From Social Outcomes to Social Processes

Governments and other sponsors of S&T justify their expenditures on the premise that S&T hold promise to better the human condition, either by solving problems or yielding intangible benefits associated with better understanding our world. Documenting contributions toward those goals is notoriously difficult in part because most social and environmental problems are wicked, in the sense that they are complex, nested, continually evolving, and wrapped in layers of value considerations (Rittel and Webber 1973). Policy problems are rarely—if ever—reducible to uncontested technical considerations (Sarewitz 2004; Sarewitz and Nelson 2008). As such, S&T's contributions toward solutions to public policy problems are frequently not direct and transformative; rather, they are incremental, dispersed, and result from the collective activities of communities of researchers and technologists interacting in complex and diverse ways with the rest of society (Bozeman 2003; Toulmin 1964). They are, therefore, difficult to quantify.

Nevertheless, out of both scholarly interest and institutional mandates, S&T policy researchers have attempted to quantify various aspects of those enterprises. Beginning with Price's classic work *Little Science, Big Science* (1971, 1986), the discipline of scientometrics has spent significant time evaluating the comparatively quantifiable aspects of science, such as scientific funding (e.g., Roco 2005; Siegel 1999); the size, productivity, and growth of scientific workforce (e.g., Bliziotis et al. 2005; Cameron 2005; Hicks et al 2004; Kyvik 2003); and evaluating the training and availability of future scientists (e.g., Committee on Prospering in the Global Economy of the 21st Century 2007). Others have sought to characterize social networks, collaborations, and sub-disciplinary communities within the scientific enterprise by tracking citation and co-authorship patterns (e.g., Borner et al. 2003; White and McCain 1998). Still others have developed approaches to track the development of scientific disciplines and their focal areas over time (e.g., Neff and Corley 2009; White and McCain 1998).

Within these broad efforts to document the size, shape, and activities of scientific and technological work, a subset of research has focused on attempting to document S&T's contributions to broader social and policy realms. Scholars with that intent have often equated outcomes with one of two proxies for quantification purposes: economic impacts and scientific outputs, such as patents and publications. Both of these proxy measurements have spawned numerous quantitative productivity measures that have been used to quantify and compare outputs of individual scientists and groups of scientists operating under different conditions (Bonaccorsi and Daraio 2003; Bonaccorsi et al. 2006; Kretschmer 2004; Mauleón and Bordons 2006; Prpić 2002). The impact of an individual output (e.g., a patent or paper) can be further evaluated by equating impact with reference by subsequent patents and scholarly works. With the intent of using the information to facilitate technological innovation and its putative economic impacts, others have sought to understand the geographic, social, policy, political, and other factors that contribute to centers of innovation (Shapira and Youtie 2006; Wilson and Markusova 2004).

The above measures of science are compelling for those who seek quantifiable evidence that scientists are active and productive—as defined by the various aforementioned metrics—and provide insights about the conditions that optimize that productivity. They do not, however, adequately allow assessment of S&T's contributions to societal goals. Under pressure from the US Congress to document the impacts of science, beginning in 1997 the US National Science Foundation instituted a requirement that all grant applicants enumerate the likely broader impacts of their proposed work when they submit grant proposals (Holbrook 2005), a requirement commonly dubbed "Criterion 2." Asking researchers to predict the impacts of their work is problematic because any given scientific project is likely to yield incremental knowledge advances; yet, in reporting their broader impacts, aspiring grantees are likely to invoke the potential impacts of the broader quest to which they envision their particular project contributing (Gieryn 1983; Latour 1987; Mervis 2006). The structure of that requirement is currently in the process of being reconsidered, but the intent remains the same, as do many of the underlying challenges (Sarewitz 2011).

Probably in part because of the inherent messiness of the inner-workings of scientific communities and their settings, most S&T policy scholars have focused primarily on evaluating the inputs and outputs of science. A group of S&T policy scholars—recognizing that societies fund science based upon expectations of outcomes (e.g., improved health, solutions to environmental and social problems) rather than outputs (publications, patents, and citations), and that economic impacts represent but a small set of those expected outcomes—have developed Public Value Mapping (PVM) as an alternative framework to evaluate S&T's contributions (Bozeman 2003; Bozeman and Sarewitz 2005, 2011). They suggest that scientific programs should be evaluated by their contribution or potential contribution to "public values," which they define to be "those that embody the prerogatives, normative standards, social supports, rights and procedural guarantees that a given society aspires to provide to all citizens" (Bozeman and Sarewitz 2005: 122). Public values can be identified from a number of sources, including the legislation allocating research funding, public policy statements, public opinion poles, and other sources (Bozeman and Sarewitz 2011). A recent special issue of *Minerva* (Volume 49, Number 1) focused on applying PVM to a variety of branches of S&T, including climate science, nanotechnology, hurricane and earthquake research, and green chemistry. PVM improves on the approaches discussed above by more directly examining the effectiveness of S&T in meeting the goals we ascribe to it.

Taken together, these scientometric, self-reporting, and PVM approaches provide S&T policy scholars with useful tools to evaluate outputs, and to a lesser degree, the outcomes of S&T. PVM has made notable inroads in exploring the inner workings of science and the extent to which they are conducive to the achievement of desired outcomes. PVM studies have, for example, explored the assumptions, values and perspectives that influence how scientific and policy actors view the relationship between S&T research and social outcomes (Logar 2011; Maricle 2011; Meyer

2011). We suggest that S&T policy scholars continue along the trajectory initiated by PVM scholars and work to include analysis of social processes and incentives that shape scientific efforts at the level of individual scientists and their communities. These are important sites of science policy activity, yet S&T policy scholars have traditionally left exploration of these processes to other disciplinary approaches. Relevant work exists within science and technology studies, history of science and technology, and other fields, but those scholars have rarely conducted their research with an eye toward engaging with S&T policy. Because those groups have not actively engaged with S&T policy, and policy scholars have not adequately interacted with those disciplines, the social processes that comprise significant sites of science policy have largely been left out of relevant scholarship.

Despite some notable exceptions [see, e.g., Rip (1981) for a discussion of the social and cognitive aspects of science policy and a summary of the Starnberg-Bielefeld group's work in the 1970s], S&T policy scholarship has under-appreciated the social and behavioral elements that help to shape scientific research. The social process orientation proposed here fills this gap by exploring, at a more micro-scale, how research agendas are constructed to meet S&T policy goals and public values. Policy awareness of how social processes at the level of scientists contribute to scientific outcomes is particularly important in light of increased calls for public participation in the steering of S&T (Jasanoff 2011). More specifically, this approach enables S&T policy scholars to focus on empirical analysis of the tensions between the social norms and epistemic concerns guiding scientific research within scientific communities, the expectations and hopes of broader constituencies, and the normative and political goals embedded in broader S&T policy.

Though not historically universal, many contemporary scientists are motivated by the goal of contributing to disciplinary knowledge—not necessarily generating a larger suite of potential social outcomes (Cartwright 1999; Longino 1990; Stokes 1997). In fact, just as Polanyi (1962) argued, many scientists assume that the pursuit of disciplinary knowledge will inevitably lead to positive social outcomes (see also Meyer 2011). This tension is also driven by the desire on the part of scientists to maintain a value-free ideal of science (Douglas 2009; Proctor 1991). As Latour (2004: 95) notes, "The tempting aspect of the distinction between facts and values lies in its seeming modesty, its innocence, even: scientists define facts, only facts: they leave to politicians and moralists the even more daunting task of defining values." The reality, as scholars in science studies and STS have shown, is that scientists interpret science policy goals and social values and apply their own value systems and assumptions in a variety of ways during the course of selecting scientific problems, generating research questions, conducting their research and interpreting their findings (Longino 1990; Toulmin 1964). These scientific framings of social and environmental problems are embedded in and co-produce broader societal understandings of public policy problems and desirable policy goals (Jasanoff 2004; Latour 1993, 2004).

This point becomes particularly salient when considering the areas in which it seems scientists and science policy-makers agree on the desired outcomes. For example, many scientists have identified climate change as a critical social and environmental problem that should be a focus of research. There has been a significant investment of public funds in the US and elsewhere to advance climate science and contribute to the ability of decision-makers to address the causes and effects of climate change. Much of the research has focused on classifying the uncertainties around global average temperature predictions and specifying potential consequences (Rayner 2000). Yet, decades of scientific research and investment have resulted in little progress in social and political arenas on substantive climate policy (Pielke 2010). As Meyer (2011) has shown, US climate scientists often equate advances in basic knowledge to a public good. The underlying assumption of many scientists is that rational action ought to flow from scientific understanding (Sarewitz 2004). The scientific framing of climate change as a global problem that science can predict and even manage is also a social and political framing that has made it more difficult for alternative understandings and normative concerns to enter into the policy discourse (Hulme et al. 2009; Jasanoff 2001; Miller 2004). This has come at the expense of an expanded discussion that includes local (rather than just global) risks and vulnerabilities, adaption and technological solutions (Hulme et al. 2009; Pielke 2007; Rayner and Malone 1998).

Science and science policy often fail to adequately meet science policy goals and address public values even when there is widespread agreement on those goals and values (e.g., Maricle 2011; Meyer 2011), and PVM research reminds us that this synchronicity of scientists' goals with public values cannot be taken for granted (Bozeman and Sarewitz 2005). That scientific research programs can fail to achieve public values, even in cases where scientists' values correspond to those values, suggests that science policy scholars need to unpack the social processes that contribute to scientific research agendas, as well as the processes by which research products contribute to outcomes. Of critical importance to science policy is how scientists integrate the myriad influences provided by science policies, disciplinary epistemic norms, and normative goals—whether personal or shared by a broader community—into decisions about research. A more nuanced understanding of the interaction between science policies and scientists' interpretations of those policies and conduct of research will enable policy-makers to construct improved science policies.

S&T policy studies focused on social processes in science and S&T policy and are especially relevant today due to several trends in the relationship between science, technology and society (Funtowicz and Ravetz 1993; Nowotny et al. 2001). First, scientists are increasingly motivated to conduct use-inspired research and engage with public policy problems (Stokes 1997). For example, while serving as President of the American Association for the Advancement of Science, Jane Lubchenco (1998) called for a new social contract for science. Lubchenco argued that science has led to incalculable benefits for society while seeking knowledge that is largely divorced from considerations of societal benefit. However, society now faces a set of challenges that require scientists to shift their research priorities and translate knowledge to policy-makers and the public more effectively. Many fields have embraced this use-inspired, problem-driven approach, including areas related to biodiversity conservation (Lackey 2007), ecology (Palmer et al. 2004) and sustainability (Clark 2007). Examining how scientists negotiate boundaries between science and politics (Gieryn 1995) and navigate the tension between normative aspirations (e.g., informing decisions related to social and environmental problems) and the epistemic commitments and social norms of science (e.g., contributing to disciplinary knowledge and maintain purity of scientific research) is essential to understanding how and why science policies are effective (or not) and informing S&T policy-making in these areas and others.

Second, as many scholars have noted in recent years, the effects of S&T are ubiquitous in modern society (Allenby and Sarewitz 2011; Beck 1992; Nowotny et al. 2001). S&T controversies (e.g., Fortun 2001; Wynne 1989, 2001) and emerging fields such as nanotechnology (Guston 2010; Swierstra and Rip 2007), synthetic biology (Parens et al. 2009) and geoengineering (Rayner 2010), have led to a conversation about how to best steer S&T and manage their effects on society and the environment (Guston and Sarewitz 2002; Jasanoff 2003; Rip and van der Meulen 1996). Many scientists, scholars and policy-makers have argued that in order to more closely align research with desirable social outcomes, stakeholders and the public, more broadly, must be engaged and integrated into the setting of research priorities and the development and deployment of S&T (e.g., European Commission 2009; Fisher 2011; Jasanoff 2011; Kitcher 2001; Stirling 2008). This is a fundamental issue for the future of S&T policy studies; yet, a focus on the evaluation of inputs and outcomes fails to provide an understanding of how scientists and other social actors operate to successful engage S&T policy and research to ensure that public values are met. We do not discuss the potential models of public engagement here (see, e.g., Fischer 2000; Hagendijk and Irwin 2006; Irwin 2006; Tlili and Dawson 2010). However, S&T policy studies that recognize the roles individual scientists, their communities, and broader publics play in coproducing S&T policy and governance can enhance our understanding of how more open, democratic and deliberative processes can be more effective.

These issues are evidence of the complexities encountered on the road from science policy goals, to research questions, the performance of that research, scientific output and back to social outcomes. Yet, as discussed, S&T policy studies tend to treat scientists and their communities as black boxes that respond to top-down science policies to produce outputs and/or outcomes. Studies that span science policy, sociology of science, and STS can highlight previously unexplored yet important processes in the construction of research agendas and social outcomes. In the following sections, we present two case studies—ecology and sustainability science—that illustrate how research on scientists' perceptions of the relationship between knowledge and social outcomes can enrich our understanding of the effectiveness of science policy and the tension between scientific practice and normative aspirations.

Ecology

The scientific discipline of ecology is relatively young and is rapidly evolving, characteristics that make it accessible to studies of social processes within science. The field of ecology has gradually taken shape over the past 150 years and in the United States was only institutionalized in the form of university departments awarding degrees bearing the name ‘ecology’ beginning in the 1970s (Kwa 1987). As is the case in many scientific fields, the methods and subjects of ecological research have changed dramatically over the past century and a half (Kohler 2002). Darwin, a naturalist who utilized inductive logic and did not follow any strict scientific method (May 1981), is often seen as the father of modern ecology (Worster 1994). As the science developed, disciplines as disparate as atomic physics, chemistry, and laboratory branches of biology have influenced the development of the field (Keller and Golley 2000; Kingsland 2005). Throughout its history there has been tension between proponents of naturalist and laboratory methods in ecology, with the former emphasizing the importance of context, and the latter favoring the precision and prestige of reductionist laboratory methods (Kohler 2002; Odum 1977; Schoener 1986). Other biologists have at times been quite hostile to ecologists, whose work they considered insufficiently rigorous to be legitimate science (Kwa 1987). When viewed as a discrete entity, the discipline of ecology has continuously re-negotiated its borders in response to these and other pressures (Kohler 2002). As a result, the subject matter and problem areas investigated by ecologists, as well as the methods used, have undergone continuous change through the decades. In the United States, naturalist methods of long-term immersion in small scale systems, observation, narrative description and inductive techniques—used, for example, by Darwin—have given way to controlled experimentation, remote sensing, modeling, and other ‘modern’ techniques (Cooper 2003; Kohler 2002; Neff and Corley 2009; Worster 1994).

Examining some of the social processes that contributed to this evolution, Kinchy and Kleinman (2003) describe ecologists and their US professional society, the Ecological Society of America, as constantly negotiating the perceived contradictory pressures of being relevant to social and political concerns and retaining the authority of an objective, value-free, and rigorous science. The field has to be responsive to social concerns or risks becoming irrelevant, and a science seen to be irrelevant risks decreased funding and prestige. The flip side of that coin, however, is that scientists whose work is seen as too relevant to political movements risk their science being called into question by those with differing beliefs (c.f. the common conflation of the scientific field of ecology with environmentalism). Ecology as a science is prone to that kind of criticism in part because of the multiple meanings and contradictory worldviews connoted by the word.

Treating the discipline of ecology as an entity unto itself—subject to external social pressures, funding opportunities, policy interventions, and other influences—yields important insights for S&T policy. For example, it is possible to track disciplinary research agendas over time (Neff and Corley 2009) and then in retrospect correlate any changes to social pressures (Kinchy and Kleinman 2003), technological innovations (e.g., Leimgruber et al. 2005), or policy interventions that preceded them (e.g., Picard-Aitken et al. 2011). What studies at this level of aggregation fail to provide, however, is an understanding of *how* S&T policies precipitate altered research outcomes.

High-quality historical research highlights the roles of particularly entrepreneurial scientists in developing new areas of scholarship (e.g., Mitman 1992; Takacs 1996; Worster 1994), but there has been relatively little focus on rank-and-file scientists as science policy actors. Unpacking social processes at these lower levels of aggregation can yield valuable insights for those seeking to understand the evolution of scientific research, and such understanding is a prerequisite for designing informed S&T policies. Individual scientists coproduce the science policies and structures of science that influence them (c.f. Giddens 1984). They frequently populate and advise the institutions that allocate research funding; and they serve as editors, peer reviewers, and authors who collectively create, fill the pages of, and serve as gatekeepers to scientific journals. Therefore, S&T policy scholars need both to be aware of individuals as actors in science policy, and as one of the several levels at which science policies have impacts.

With the intent of understanding what considerations go into individual ecologists' evaluations of the merit of potential research topics, a recent study revealed that participants consider not only the norms of their discipline, but also their individual policy preferences, desired environmental and social futures, and understandings of how policy change can come about as justifications for their preferences (Neff 2011). These various considerations were so intimately interwoven that participants in this study saw many of their policy preferences as following directly from their science and therefore as scientific rather than normative. Other scholarship has indicated that alongside these considerations, scientists choose research problems in part based upon their strategies to secure funding and produce adequate publications for their professional development while pushing disciplinary boundaries to open up new areas of research (Gieryn 1978; Ziman 1987; Zuckerman 1978, 1989).

Science policy scholarship focused at the level of individual scientists also reveals that scientists who seek to generate useful information as they balance these simultaneous considerations can face particular difficulties in balancing competing pressures as they select research topics. In a recent study, numerous natural scientists indicated that over the course of their careers they came to learn that improvements to coral reef ecosystems–the goal that motivates their research—is more likely to result from research that they were personally not trained to conduct. They expressed frustration that, were they to advocate that others pursue their preferred research topics or lobby for resources for that branch of research, it would undercut their own ability to publish and successfully generate grant funding. A similar concern, several scientists reported, occurs at the institutional level and prevented the Coral Reef Targeted Research group at the Global Environment Facility from advocating for social science research, which they felt to be critical, because their funding was tied to natural science by external mandate (Neff In review; see also Ziman 1987). Dynamics such as these shape disciplinary research portfolios, and thus deserve attention from S&T policy scholars.

How scientists navigate these myriad considerations is of critical importance to science policy scholars because similar judgments of scientific merit occur throughout the scientific enterprise, including in peer review for funding and publication decisions and in the merit evaluations that are part of credentialing, hiring, tenure and promotion decisions. The choices that scientists make as they navigate these various considerations yield, in aggregate, disciplinary research portfolios. Traditional S&T policy, however, has not paid adequate attention to influences on individuals' selection of research problems. Ecology, perhaps because many scientists buy into Polanyi's idea that individual researchers acting in their own best interest yields optimal research portfolios, lacks institutions and procedures that might help the discipline self-consciously orient itself toward the most worthwhile research, however defined. Not only is the lack of scholarly attention on these phenomena a problem for S&T policy scholars and policy-makers, but it also constitutes a problem for scientists who are motivated by a desire to make a difference in the world. Amongst ecologists, the lack of open discussion of what constitutes worthwhile research precludes opportunities for this community to learn from other academic disciplines, which might provide insights about how ecological knowledge acts in the world, as well as from the broader public, which have a strong interest in contributing to definitions of desired futures (Neff 2011).

Sustainability Science

Many scientists have argued that the urgency and complexity of sustainability problems require an urgent effort on the part of the scientific community to conduct research on the issues that matter most to society (e.g., Lubchenco 1998). From climate change and biodiversity loss to agricultural systems and land use change, scientists have stressed the need to harness S&T as a means for developing solutions to many of the problems of sustainability (e.g., Clark and Dickson 2003; Kates et al. 2001; Hardin 1993; Leshner 2002; Reid et al. 2010). The rapidly emerging field of sustainability science has been positioned as providing sorely needed knowledge for decision-makers to move society toward sustainability goals. For example, the National Research Council (NRC 1999: 7) Board on Sustainable Development's report, *Our Common Journey*, states that "significant advances in basic knowledge, in social capacity and technological capabilities to use it, and political will to turn this…into action" are necessary for transitioning to sustainability.

The NRC report concluded with the argument for a new field of research—sustainability science—in which scientists should conduct problem-driven research on pressing social and environmental issues. As Cash et al. (2003: 8089) argue, without drastically increasing the contribution of science and technology to efforts to solve sustainability problems, "…it seems unlikely that the transition to sustainability will be either fast enough or far enough to prevent significant degradation of human life or the earth system." A major developmental point for the field was the publication of "Sustainability Science" by Kates et al. (2001) in the journal *Science*. The authors of that paper define sustainability science as an interdisciplinary field that aims to understand the "fundamental character of interactions between nature and society" and enhance "society's capacity to guide those interactions along more sustainable trajectories" (Kates et al. 2001: 641). Over the last decade, sustainability science has emerged as a rapidly growing, interdisciplinary field with significant institutional momentum, particularly in North America, Europe and Japan, including the establishment of peer-reviewed journals, research and education programs and funding agency initiatives[1] (Bettencourt and Kaur 2011; Kates 2011; Miller 2011; Schoolman et al. 2011).

Sustainability science is a particularly interesting field to use as a case study to explore how scientists might shape science policy for two reasons (Miller 2013).[2] The first is the field's normative focus on social and environmental outcomes—i.e., to contribute to the resolution of pressing sustainability problems. As Clark (2010: 82) states, "[sustainability science] is ultimately a project that seeks to understand what is, can be, and ought to be the human use of the earth." Second, sustainability science maintains a core epistemic commitment to advancing fundamental research on coupled human-natural systems. Carpenter et al. (2009: 1305) note that sustainability science "is motivated by fundamental questions about interactions of nature and society as well as compelling and urgent social needs." Carpenter et al. (2009: 1305) go on to stress "the urgency and importance of an accelerated effort to understand the dynamics of coupled human-natural systems."

It is this pursuit of normative and epistemic goals, and the tension between them, that make sustainability science an interesting analog to the broader science policy challenge—how to align the normative goals for science policy (i.e., the public values we would like S&T to serve) and the epistemic commitments of science. Analyzing how sustainability scientists set research agendas and attempt to link the knowledge they produce to social outcomes provides an opportunity to understand how sustainability scientists' broader goals (i.e., contributing to sustainability transitions) are perceived and translated into research amidst epistemic commitments and the social and institutional norms of scientific practice.

Sustainability scientists are actively interested in working to contribute to positive social outcomes by linking knowledge they generate to social action and decision-making. The Friiberg Workshop on Sustainability Science (Friiberg 2000: 1), for instance, concluded that "the goal of sustainability requires the emergence and conduct of the new field of sustainability science," which must be more applied and interdisciplinary in order to produce the knowledge that is required for decision-making. As Cash et al. (2003: 8086) argue, "A capacity for mobilizing and using science and technology is increasingly recognized as an essential component of strategies for promoting sustainable development." A lack of scientific knowledge is viewed as a factor limiting the ability of society to take action relative to sustainability goals. Sustainability science—and, more specifically, the focus on fundamental questions in coupled human-natural system dynamics (Turner et al. 2003)—is positioned as providing knowledge that is essential to the ability of society to take action toward more sustainable outcomes. As Cash et al. (2003) and others (Clark et al. 2011; McCullough and Matson 2012) have frequently discussed, the knowledge generated by sustainability scientists must also be viewed as credible, salient and legitimate by its users.

[1] The NSF has, for example, established a program-wide investment area in Science, Engineering and Education for Sustainability (SEES).

[2] While this research did not focus specifically on science policy goals for sustainability science, it does illustrate the need to understand how scientists interpret public values and perceive the link between knowledge and social outcomes.

Sustainability scientists' normative commitments to sustainability goals and problem-solving are matched with epistemic obligations and social norms guiding scientific research and practice to produce fundamental knowledge about human-environment interactions. Mooney and Sala (1993: 566), for instance, contend that better science will lead to more sustainable use of natural resources—"We conclude that sustainable use of resources is feasible, but the only way to achieve this goal is by improving our understanding of ecological systems." The normative goals of sustainability are met through the analysis of coupled human-natural system dynamics.

In the course of constructing sustainability science, these commitments and obligations are often viewed as mutually reinforcing by scientists; however, as STS scholars (Gieryn 1995; Jasanoff 1987) and others have argued, these elements are often in tension. This echoes Kinchy and Kleinman's (2003) analysis of ecology as seeking a balance between utility and purity—i.e., balancing the aspiration to provide useful knowledge to decision-makers about pressing social and environmental problems while remaining committed to the value-free ideal of science (Douglas 2009). If navigated poorly, this tension can result in either the scientization of politics, wherein scientific arguments stand in for what are in fact value debates (Sarewitz 2004), or the politicization of science, in which values and politics infiltrate and influence scientific practice and conclusions (Pielke 2006).

This tension is particularly acute when it comes to sustainability problems as they can be particularly wicked (Norton 2005; Thompson and Whyte 2011). This wickedness challenges the goals and practice of sustainability science in several important ways. First, wicked problems are highly complex and carry with them (often) irreducible uncertainty. The ability of scientists to interpret such complexity and reduce uncertainty is questionable (Stirling 2010). Second, though there may be a subset of problems wherein additional knowledge about coupled human-natural systems is a limiting factor, there are often far more proximate factors limiting the ability to pursue sustainable solutions. In framing such problems as requiring additional knowledge in order to move forward, sustainability science can limit the exploration of alternative social, political or technological actions (Sagoff 2008). Finally, wicked problems are characterized by value disputes. Additional scientific knowledge will do little to help resolve such debates and may in fact serve to exacerbate them by revealing further uncertainties (Sarewitz 2004).

The result is that sustainability science—and many similar use-inspired, problem-driven approaches—are at risk of falling into what Sarewitz et al. (2010: 3) refer to as the knowledge-first trap "where rational action is viewed as deriving from factually correct assessments of the causes of a problem." The knowledge-first trap can lead to a spiral of endless research and technical debates (Collingridge and Reeve 1986; Nelson 2003). Collingridge and Reeve (1986: 5), for example, argue that there is a fundamental mismatch "between the needs of policy and the requirements for efficient research within science which forbids science any real influence on decision-making." In effect, sustainability science could potentially make the realization of its normative goals more difficult through its focus on fundamental questions about human-environment interactions.

The point here is not to be overly critical of sustainability science or any other use-inspired field. Such efforts are important and worthwhile attempts to link science to beneficial social outcomes. Instead, the point is to show how despite agreement on social and environmental goals for sustainability science, scientists are constrained by social and disciplinary norms as well as epistemic obligations to conduct fundamental research that may not help to create the desired outcomes. S&T policy studies that provide an analysis of the social processes that might help to either foster or inhibit the ability of science to generate positive outcomes can contribute to the efforts of fields like sustainability science that are focused on contributing to specific social and environmental outcomes. Furthermore, a process-oriented approach provides an empirical foundation for a reflexive analysis for science and science policy—in this case, for sustainability. For example, for the normative goals of sustainability science to be met, a more broadly interdisciplinary perspective that focuses not just on coupled human-natural systems, but on the social and political processes that might foster social, ecological and technological innovations for sustainability might be necessary (Loorbach 2010; Rip and Kemp 1998; Smith et al. 2005; Stirling 2009). Further research on sustainability science will explore how such alternative approaches might enrich the ability of the field to link knowledge with social action and also inform how more democratic and inclusive approaches to constructing research agendas can be informed by a process-oriented S&T policy studies agenda.

Conclusion: Scientists as Social Actors

Focusing on the links between scientific outputs and societal and policy outcomes, public policy scholars have long noted that the interface between scientific knowledge and policy outcomes is fraught with complexity (e.g., Collingridge and Reeve 1986). Focusing its lens on the production of science in laboratories and other settings, scholarship in the sociology and anthropology of science and technology has made it clear that science is a social process (e.g., Jasanoff 2004; Latour 1987, 2004). In this paper, we argue that *science policy scholarship will benefit from treating science policy as a social process operating at several scales*, including, as we hope we have illustrated here, those of individual scientists and their communities as they set research agendas.

The cases we present illustrate that despite the scholarly attention at macro-scale science policies, scientists and their communities are active players in coproducing science policy. Regardless of the intentions of science policy makers and many scientists to contribute to social outcomes, they encounter difficulties for four primary reasons. First, individual scientists and their communities integrate formalized science policies and funding opportunities with myriad other considerations in developing research agendas and in interacting with policy processes. Scientists actively manage epistemic commitments, normative goals and career ambitions and associated mandates alongside formalized science policies in selecting research topics, as individuals, and in coproducing science policies, both as individuals and communities. Second, the social and institutional norms of science can be in tension with normative aspirations and the needs of decision-makers (Collingridge and Reeve 1986; Kinzig et al. 2003). Third, scientists often view the achievement of desirable outcomes as flowing from advances in scientific understanding (Neff 2011; Meyer 2011; Miller 2011). Finally, scientists may have a particular public policy solution that they view as desirable. For example, as Pielke (2007) notes, many climate scientists believe that a Kyoto-like cap-and-trade policy is the best option to combat climate change and attempt to build the scientific case for taking action.

Traditional approaches to science policy scholarship allow scholars to assess the outputs, and to a lesser degree the outcomes, of formal science policies. Public Value Mapping allows scholars to identify when this focus leads to failure of scientific efforts to achieve the goals we ascribe to them. While the evaluation of outcomes is a critical theme in S&T policy studies, it fails to provide an analysis of the social and scientific practices that encourage or inhibit the ability of scientific research to align with social outcomes. Significant science policy action takes place in this neglected space, and thus it constitutes a fruitful location for future science policy scholarship. Scientists are prime actors in science policy in that they, in responding to their contexts, play significant roles in shaping disciplines and research agendas. Scholarship that explores scientists' epistemic and normative commitments demonstrates that Polanyi's (1962) "invisible hand" is an inadequate metaphor by which to understand these processes. Science policies and policy evaluations that lack awareness of the dynamics that occur within this neglected terrain hamper the ability of science to contribute to the outcomes societies would like to see and that form the basis of support for science. Thus, scholarship on scientists' interactions with their contexts constitutes fruitful empirical space for future S&T policy scholarship with support from sociology of science and STS. Attention to the processes of science—from research agenda setting to models of how the knowledge generated will be useful in decision-making—will help enable S&T policy scholars and policy-makers to design incentive structures that can adequately steer science toward the topics that most profitably serve societal goals.

Because scientists and their communities are actors in science policy and create many of the incentive structures that shape disciplinary research trajectories, S&T policy scholars who "wade into the weeds" to engage with those communities in a two-way dialogue stand to have improved leverage in helping science to meet those goals ascribed to it by the societies that fund it. In many current scientific systems, individual scientists and their communities have significant autonomy, and thus top-down policies always take place in the context of bottom-up social processes. We can better understand that interface by more directly engaging with scientific communities. As S&T policy scholars, we need to engage scientists as actors in science policy by publishing findings in scientific journals (e.g., Miller 2013; Neff 2011) and presenting at scientific meetings. Doing so will benefit S&T scholarship by better understanding scientific communities, and it will support the ability of scientists to be more deliberate in their activities as inevitable actors in science policy.

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