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ORIGINAL ARTICLE

Risk communication and sustainability science: lessons from the field

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Abstract Sustainability science aims to help societies across the globe address the increased environmental and health crises and risks that range from poverty to climate change to health pandemics. With the increased magnitude and frequency of these large-scale risks to different societies, scientists and institutions have increasingly recognized the need for improved communication and collaboration among researchers, governments, businesses, and communities. This article argues that risk communication has fundamentally important contributions to make to sustainability science's mission to create use-inspired, "actionable science" that can lead to solutions. Risk communication research can advance the mission of sustainability science to engage a wide range of stakeholders. This kind of engagement is especially important in the context of addressing sustainability problems that are characterized by high levels of uncertainty and complexity. We introduce three core tenets of risk communication research that are fundamental to advancing sustainability science. Risk communication specifically offers an increased understanding of how system feedbacks, human perceptions, and levels of uncertainty influence the study and design of solutions within social ecological systems.

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Introduction

As a field, sustainability science aims to help societies across the globe address the environmental and health crises and risks that range from poverty to climate change to health pandemics (Clark and Dickson 2003; Komiyama and Takeuchi 2006; Turner et al. 2003). Given the magnitude and frequency of these large-scale risks to different societies, scientists and institutions have increasingly recognized the need for improved communication and collaboration among researchers, governments, businesses, and communities (Lindenfeld et al. 2012; Moser and Dilling 2007; Peterson et al. 2007; van Kerkhoff and Lebel 2006; Welp et al. 2006). Sustainability science acknowledges that we must utilize science to improve decision making and reconceptualize how researchers, stakeholders, and communities can work together to ensure a more sustainable planet for future generations (Cash et al. 2006a; Clark and Dickson 2003; Kates et al. 2001; Kauffman 2009; McNie 2007; Vogel et al. 2007). This move toward creating "useable knowledge" (Cash et al. 2006a, b; McNie 2007; Pielke 2007) requires research and research-based strategies on more effective ways to communicate across a wide range of institutions. Improved communication depends on a deeper, more comprehensive understanding of behavior change and decision making. Fundamental to improving our understanding of this context is our ability to understand perceptions of risk and how these influence decision making and behavior (Beer et al. 2003; Cash et al. 2006a, b; Fischhoff 2012; Fischhoff and Kadvany 2011).

Academic disciplines ranging from risk science to communication to social psychology attempt to understand more about the causes, amplifications, and consequences of different types of risks, but they have yet to address these issues sufficiently. As Cox describes it, this is a "moment of conjunctural crisis, defined in not insignificant ways by human-caused threats to both biological systems and human communities, and also by the continuing failure of societal institutions to sufficiently engage these pressures" (2007, p. 7). This "moment in crisis" is not something new; it has developed in tangent with the industrialization of contemporary society. The future consequences of these risks and social changes will likely be to "dehumanize and stratify society and to create catastrophic instabilities" and call for a broader systems approach to understanding and response (Weinstein et al. 2012). Attending to intergenerational responsibility and management of social and natural resources is an important area to which sustainability science contributes in its aim to create use-inspired science that can help manage environmental and human risks (Kates et al. 2001, p. 641).

Risk communication researchers and practitioners have been working through these future-focused issues across a range of scales for years. Risk communication started as a subfield of risk analysis in the late 1960s and early 1970s, with a focus on clarifying public misconceptions of risk. The field has evolved into a more participatory area of research within communication studies, and it focuses on social dimensions of conflicts, decision making, and political processes related to risk (Boholm 2009). The inclusion of stakeholder values into risk assessment and communication aligns with sustainability science's call for the "co-production" of research questions and knowledge (Aeberhard and Rist 2009; Cash et al. 2006a, b; Lemos and Morehouse 2005; Pohl 2008).

While risk science and risk communication have overlapping areas of focus, there are some fundamental differences. The National Research Council defines risk communication as an "interactive process of exchange of information and opinion among individuals, groups, and institutions" (National Academies 1989). Risk communication as a field is "dominated by the practical and normative sociotechnical aim of improving communication on risk" (Boholm 2009, p. 335). Risk science and analysis, in contrast, is grounded in probability and decision theory, focusing on reducing uncertainty by providing information. While there are blurry areas of overlap between the two fields, risk communication is focused more on the social dimensions of risk experiences, while risk science is more attuned to the statistical probability of risks and hazards.

We maintain that risk communication has fundamentally important contributions to make to sustainability science's mission to create use-inspired, "actionable science" that can lead to solutions (Palmer 2012). Risk communication research can advance the mission of sustainability science to engage a wide range of stakeholders. This kind of engagement is especially important in the context of addressing sustainability problems, which are characterized by high levels of uncertainty and complexity (Clark and Dickson 2003). The intersections among risks, society, and sustainability are inherently complex and provide a rich space for exploring the interactions among individual behaviors, collective decisions, and ecological thresholds. In this essay, we lay out three core tenets of risk communication research that are fundamental to advancing sustainability science. Below, we provide a brief summary of the most relevant contributions from risk communication to set the stage for our analysis of where sustainability science and risk communication should find greater overlap.

Risk communication and sustainability science

As sustainability sciences grapples with ways to preserve resources for future generations, risk communication can help illuminate how individuals and societies are using information to adopt or reject scientific information about sustainability decisions. Some researchers in sustainability science are working to integrate the concepts we describe in this essay, such as perceptions and the mental models framework, into their work (Bang et al. 2007; Weinstein et al. 2012). This integration of social variables is an important step in the right direction, yet there are still areas where risk communication can offer a more nuanced understanding of key practical and theoretical insights into the problems that sustainability science addresses. Notable advancements, especially in Europe, provide models for integrating risk communication frameworks into sustainability science. Organizations like the STEPS Centre (STEPS Centre 2013; Seyfang and Smith 2007; Rammel et al. 2007), Euroscience (Beer et al. 2003), and the Stockholm Environment Institute (Kasperson and Kasperson 2001; Forrester et al. 2009), for example, engage in interdisciplinary approaches focused on how to support science that emphasizes moving beyond traditional hazard and risk management to involving communities and decision-makers in "extensive campaigns of knowledge exchange and communication" (Beer et al. 2003, p. xvi) that will lead to practical solutions for communities. Several other projects have integrated risk communication through vulnerability analyses (Turner et al. 2003a, b), and through interdisciplinary approaches, like the risk governance framework, that aim to understand how to deal with public risks (Renn and Klinke 2013). Characteristic of these models is that they tend to see risk communication as something that becomes implemented at the end of risk analysis. We argue that risk communication should be interwoven throughout the entire research process. In particular, risk communication can play an important role in helping to frame sustainability science research projects in early stages, as this can help to create a deeper understanding of the societal context. This understanding is key to advancing strategies for developing research aligned with societal needs, which bolsters efforts to link the production of scientific knowledge with societal action.

Sustainability science has tended to approach the concept of risk through the lens of vulnerability and resilience (Perrings 2006), that is, how society adapts or bounces back from varying scales of ecological pressures and change (Pimm 1984), or crosses thresholds and moves into a new domain of stability (Holling 1973). While resilience literature focuses on the adaptation of systems to change, the concept would benefit from a more fully developed understanding of human perceptions, social uncertainty, and decision-making dynamics in the systematic analysis of balance and change. Resilience literature embraces the interconnectedness of people and nature and aspires to explain the adaptability and transformability of the earth's system with a focus on social change (Folke et al. 2010). Risk communication can support this effort by bridging some of these concepts, as this area offers an increased understanding of how system feedbacks, human perceptions, and levels of uncertainty influence the study and design of solutions within sustainability science. Risk communication can help with practical and conceptual considerations within sustainability science research. As Fischhoff and Kadvany (2011) note, risk communication offers pathways for society to learn about causes of new dangers, give weight to their demands, and give meaning to the choices that follow. Research in risk communication ranges from the study of micro- to macro-level dimensions of human communication, and it envelopes various models of human communication. Risk communication dynamics complement sustainability science in its ability to assess human dynamics as tightly coupled to natural resource management. In the following section, we argue that risk communication provides three core conceptual contributions (see Table 1) that are central to sustainability science.

Table 1 Conceptual contributions of risk communication to sustainability science

Risk concept	Guiding framework
Risk and societal systems	Focus on a whole system approach that includes consideration of intended and unintended feedbacks
Risk and perceptions	Elevate assessment of beliefs and perceptions
Risk and uncertainty	Conceptualize uncertainty as a diverse communication dynamic that operates in different sustainability contexts

Concept 1: risk and societal systems

Focusing on risk and its relationship to societal systems raises an important shift in thinking about sustainability problems and solutions. By approaching sustainability and risk from a systems perspective, we shift from thinking about a single risk factor and single causal chains, for example, the relationship of climate change to drier conditions, to consider complex, interdependent chains of interaction that include both intended and unintended feedbacks (Meadows and Wright 2008). This involves reorienting sustainability science away from a single risk context toward an interdependent chain of hazards and consequences. This framework parallels and complements sustainability science's aim to understand complex interacting social ecological systems (SES) and treats risk as complex adaptive systems that occur within particular temporal and spatial contexts.

Contemporary societal risks exist in part because of the unintended consequences of economic, industrial, and scientific progress (Beck 1992; Zinn 2008). Analyzing these risks means accounting for consequences that current actions create for current and future generations. This lens is important for understanding how actions within one geographic area may affect other regions across the globe. This shift means that we must operate with greater levels of scientific uncertainty and manage resources with less-than-perfect understandings of how institutions, politics, and biophysical dynamics interact. This is not to suggest that we do away with rigorous analysis of sustainable use of resources, but rather that risk communication perspectives can help us create more careful considerations of the complexity of SES and how we are achieve higher levels of sustainability given this complexity and uncertainty (Collins et al. 2011). As Weinstein et al. (2012) highlight, sustainability science often focuses on macroscopic interactions between humans and their environment, yet a more complete and systemic understanding of behavior is critical to unraveling how a deeper understanding of SES can promote sustainable development. This more complex science will surely involve multiple spatial and temporal feedback loops among indicators and considerations of how human, economic, and ecological interactions can lead to both intended and unintended consequences. Assessing this larger societal system scale requires more dialogue among economists, psychologists, stakeholders, and biophysical researchers. This blended expertise on social and biophysical systems that interact in specific places but have broader social consequences is essential to understanding systems at multiple different scales. While this approach is essential, it also requires innovations in interdisciplinary methods. This approach also means working across temporal and geographical scales, which increases complexity given the practical and political restraints that scientific and political institutions frequently encounter.

Given the issue of scale, a systems approach may also encourage sustainability scientists to reconsider the variables deemed important for assessing sustainability among communities in place-based contexts. Van Kerkoff and Lebel (2006) note the need for assessing implications at multiple scales and for groups beyond the stakeholders immediately involved in a particular problem (van Kerkhoff and Lebel 2006, p. 470). As Turner et al. (2003) emphasize, vulnerability of systems, even when they are similar, can vary greatly by locale. Sustainability science must address the complexity of working with both global scales and place-based contexts. The capacity of science to help solve societal problems depends on factors other than biophysical findings and must include a greater understanding of cultural, economic, and social barriers to change. This shift heightens the need for understanding how place-based solutions can create ripples in the larger social fabric. Understanding the complexities of scale, problems, and solutions is clearly not an easy task, yet the interactions along this spectrum need to be considered to advance solutions to sustainability issues.

Integrating risk communication into sustainability science offers an important framework for addressing the relationship of challenges across diverse scales, from the place-based to the global, and foregrounds a perspective that conceptually binds human behavior, economics, and ecological capacity in a systemic way. To embrace this perspective effectively, we must assess how people utilize scientific information in their daily lives (López-Marrero and Yarnal 2010). This, in turn, necessitates more systematic attention to the perceptions held by those publics.

Risk as perceptions

Sustainability problems can only be adequately addressed when science integrates diverse, often conflicting beliefs, attitudes, values, and perceptions. Cultural studies researcher Benhabib emphasizes that society "presents itself through narratively contested accounts," and cultures themselves emerge through "contested practices" (2002, p. viii). For sustainability science to achieve its goals, assessment of belief, values, and perceptions held and maintained by different segments of the population needs to be granted greater priority. Risk communication encourages this focus. As mentioned above, some scientists working from an SES framework have integrated social variables related to culture and perception into their work (Bang et al. 2007), yet those studies are few in comparison to the amount of work that focuses purely on quantitative modeling and predictions.

Perceptions are critical in sustainability science, as many of the sustainability hazards facing the world are not, strictly speaking, biophysical in nature. Problems of water resource management, fishery populations, species and habitat management, and climate variability and change (Leiserowitz et al. 2009) are driven by human actions, which in turn are driven by and made sense of through perceptions (Morgan 1992). As researchers work collaboratively to design studies and advance sustainability science, we must recognize the need to converge social and scientific rationality claims in our approaches to SES. Risk communication science and practice are driven by the core principle that perceptions are meaningful because they play a significant role in how people respond to crises and hazards. At the core of communication theory rests the concept that communication is constitutive, that is, it constitutes our sense of the world rather than simply reflecting some fundamental, objective reality that can be accessed directly through language. Communication researchers Cantrill and Oravec describe language as a process by which we "reify what we take to be real" (1996, p. 2). If sustainability aims to create solutions to existing problems, we must remember that problems themselves are socially constructed creatures. From this perspective, communication is a process that shapes our relationships with each other and the natural environment (Cox 2010), and sustainability problems and solutions are socially constructed through communication and our daily practices of living. Understanding that cultures fundamentally have conflicts is of paramount importance to advancing solutions.

This perspective holds true across the various conceptual camps within risk communication (Morgan 1992). The old adage "perception is reality" does not mean that subjective perceptions substantiate objectively true data. People react "illogically" to hazards all the time. For example, some people are unconcerned about the impacts of climate change because they perceive such changes to be natural and not connected to anthropogenic forces (Norton et al. 2011). The objectivity and soundness of the biophysical evidence indicating the risks of climate change hold little sway with these publics, in part because it is inconsistent with their fundamental perceptions. In this way, there is an analog with health literature such that increased uncertainty and incongruence of science with perceptions might well lead to either inaction or seemingly counter-logical behavior (Sandman 2003). What is more, this gap between perception and reality reveals core social dynamics directly pertinent to how we communicate and manage hazards in collaboration with different stakeholder groups.

We do not want to suggest that perceptions define reality in the sense of objective, verified data. Rather, we emphasize that perceptions drive human behavior, including collective action problems that can lead to unsustainable resource use. Indeed, risk and risk perception "converge, condition each other, strengthen each other, and because risks are risk in knowledge, perceptions of risk and risks are not different things, but one and the same" (Beck 1992, p. 55). Sustainability science approaches that want to create meaningful impacts should conceptualize risk and risk perception together.

Risk scholars have developed several conceptual frameworks to understand stakeholder perceptions of hazards. We outline these briefly to provide an overview of some of the core tenets that define this field. The risk = hazard + outrage approach (Corvello and Sandman 2001; Sandman 2003) is probably the best known and accessible approach for practitioners. Sandman, in particular, demands technical assessments to acknowledge the important role of human perceptual processes and the various dynamics that impact and drive those perceptions. The framework serves as a useful outline of components of outrage rather than as a wellspring of testable hypotheses. Similarly, the Social Amplification of Risk Framework (SARF) offers a complementary approach to the Outrage model. Revolutionary in its time, SARF (Pidgeon and Kasperson 2003) demanded that risk communicators consider the way perceptions were attenuated or amplified through various message channel options and message designs. The framing of risks (Hom et al. 2011) follows a parallel line of analysis with an emphasis on message design as fundamental to the sorts of risks and ways that people think about them. This approach is useful as it looks to the availability and nature of risk messages and perceptions manifested in a population.

Offering a similar view of human perceptions, but a much more detailed methodology to asses them, the mental models approach to risks (Morgan et al. 2001; Morgan 1992) has provided both a conceptual platform and specific set of processes for researchers and practitioners to assess baseline understanding of hazards and message design. Researchers using the mental models approach engage in a process to better understand the gaps between expert and audience knowledge, and design how to bridge the two most effectively. Morgan et al. (2001) lay out five basic steps most mental models scholars follow to work through this process. What makes the mental models approach different from other approaches is its iterative nature. There is continual refinement of models and messages through communication between experts and audiences. As Weinstein et al. (2012) demonstrate, this iterative process enables sustainability science to benefit from risk communication methods and frameworks to significant advantage. While we understand the inherent fluidity of perception as a variable and the difficulties of assessing it, we argue that the inclusion of perception into sustainability science will lead to more usable and socially valid scientific results.

Risk and uncertainty

Similar to how risk communication is driven by human perceptions and responses, *uncertainty* as a communicative dynamic has the capacity to operate under a variety of informative conditions and at different stages of ecological and human systems processes. Uncertainty plays an important role in the context of data, modeling, and predictions in both the natural and social sciences. Many of the so-called "hard sciences" view uncertainty as a probabilistic issue of data: whether or not an identified phenomenon is actually occurring, has precise and replicable methods, soundness, and fit of modeling parameters, etc. In contrast, a growing body of research from the social sciences views uncertainty as a perceptual process that involves a complex suite of assessments and actions by people. *Uncertainty* refers to the aspects of situations that are characterized as "ambiguous, complex, unpredictable, or probabilistic; when information is unavailable or inconsistent; and when people feel insecure in their own state of knowledge or the state of knowledge in general" (Brashers 2001, p. 478). From a risk communication perspective, managing risk involves making decisions under conditions of uncertainty with ubiquitous consequences (Lorenzoni and Pidgeon 2006). While sustainability science already embraces the concept of uncertainty in its approach to SES, risk communication approaches encourage sustainability science to consider uncertainty at a variety of different scales. Similarly, risk communication offers key points of entrance for scientists to understand how uncertainty plays into decision-making on a variety of scales. We outline these scales and their implications for sustainability science briefly.

At a basic level, uncertainty needs to be addressed as it relates to the data used in sustainability science. Data uncertainty refers to the uncertainty that arises "from several sources, including limitations in current data, imperfect understanding of physical processes, and the inherent unpredictability of economic activity, technological innovation, and many aspects of the interacting components" (Shackleton et al. 2009). Often, competing scientific claims, predictions, and models offer stakeholders different understandings of sustainability problems. Acknowledging the uncertainty of data is paramount to working effectively to produce sustainability solutions. Over the last decade, methods have been developed in response to the need to incorporate variability and uncertainty into probabilistic risk assessments due to the lack of empirical information (Slavin et al. 2008, p. 63). Here, different knowledge claims accompany uncertainty in data. Stakeholders may have differing perspectives on what constitutes legitimate data, and perceptions will vary on how to work within these dynamics. While the natural sciences sometimes do not emphasize degrees of uncertainty in modeling and predictions (Rey et al. 2004), risk communication brings into view the importance of highlighting and communicating about those uncertainties for moving forward toward sustainability solutions.

Uncertainty research within the social sciences has predominately focused on uncertainty at the individual, interpersonal, and group levels (Babrow and Kline 2000; Ellis and Shpielberg 2003). Of equal importance is how sustainability science integrates uncertainty at an organizational level and how that uncertainty impacts decision making at institutional and policy levels. What is of particular importance here is how uncertainty scales up from reasonably simple systems (e.g., a person's availability for collaborating) to complex systems with public policy implications (Norton et al. 2011). How the science community depicts uncertainty in semi-public and policy contexts facilitates the interactions, translations, and cooperation between the science community and the policy community (Shackley and Wynne 1996). Therefore, communication regarding the uncertainty of risks should address the uncertainties of the future, while planning directly for uncertainty by minimizing these risks through the development of multiple courses of action (Millar et al. 2007). This comes into context when dealing with risks that have irreversible consequences. When dealing with sustainability thresholds that may lead to irreversible damage, the communication of uncertainty becomes key. Scientists must communicate about how (un)certain it is that society will cross a specific threshold so decision-makers and political institutions can put into place policies and practices that keep the system within a balanced domain. Risk communication encourages the scientific community to communicate uncertainty about the future in such a way that emphasizes strategic flexibility, risk taking (which includes decisions of no action), and the willingness to change direction as sustainability conditions change. Incorporating this flexibility into scientific work and political decision making can be challenging, as institutional and social barriers such as time, expectations, and professional incentives can inhibit the possibility of engaging in these longitudinally focused studies that incorporate uncertainty and change. However, understanding societal roles of uncertainty is key to making more sustainable decisions in the future.

Concluding thoughts, future directions

Conceptualizing risk and sustainability science as complementary and overlapping fields can help account for the unintended consequences of place-based work, with a focus on feedback, perceptions, and uncertainty. Adopting a wider systems approach to risk within sustainability science brings into direct view the larger consequences of our work. Within the realm of science, taking this approach means addressing sustainability problems with some level of responsibility to think about the dynamics of institutions, politics, and science at different scales and in diverse contexts. Of course science cannot hold all of the answers, nor should it attempt to make itself the sole responsible party for what happens socially with scientific results. Yet, this idea does imply that science "should accept reports that come back on threats and risks as empirical challenges to its self-concept and for the reorganization of its work" (Beck 1992, p. 174). As Perrings (2006) notes, "Understanding system dynamics is important to sustainability because it enables decision-makers to choose between actions that involve adaptation to future changes, and action that mitigate those changes" (p. 423). These dynamics highlight that the ability of science to solve societal problems depends critically on factors other than just science itself (Sarewitz and Pielke 2007). We suggest that perceptions and uncertainty are two of those most critical factors.

Risk communication frameworks offer sustainability science numerous methods and tools for understanding better perceptions of stakeholders and how we might incorporate those perceptions into scientific assessments. For example, adopting Morgan et al.'s (2001) mental models approach helps us clearly understand how important perception is when dealing with risks or sustainability problems. This approach provides us with a tool to assess and bridge different models of belief and perception. Sustainability science as a field often emphasizes the co-production of knowledge, yet there is rarely a discussion of how perceptions play into that co-production and resulting action. Similarly, trust has been shown to play a key role in collaboration (Smith et al. 2013), and this is particularly important when considering the risk associated with making decisions that affect communities, ecosystems, the economy, and other domains that are centrally linked to sustainability. Risk communication helps us understand perceptions of distrust that might derail otherwise effective efforts to create effective linkages between scientific knowledge and action.

As researchers and stakeholders work collaboratively to design studies and further the field of sustainability science, we must recognize that we need to study SES, while also considering social and scientific rationality claims alongside each other. Both are essential for a more holistic and systems-based approach for adaptation to emerging risk. This means taking cultural practices seriously as we consider what people think the problems are and which solutions would be acceptable to them. Beck reminds us that "scientific rationality without social rationality remains *empty,* but social rationality without scientific rationality remains *blind*" (Beck 1992, p. 30). Understanding beliefs, history, and perceptions is important in the study of risk communication as the "understandings of risks, like other experiential phenomena, are informed by socially and culturally structured and historically conditioned conceptions and evaluations of the world, what it is like, what it should or should not be like" (Boholm 2009, p. 340). Sustainability science's ability to balance these different concepts is clearly essential to the field's ability to achieve the impact required to avoid irreversible changes within SES. Risk communication is ripe with methodological tools that can aid us in communicating about sustainability issues in ways that influence behavior enough to keep society from crossing certain ecological thresholds.

Another important lesson from risk communication is the need to study audiences and do empirical testing of scientific messages (Nisbet and Mooney 2007; Nisbet 2009; Nisbet et al. 2011). Even when mental models about perceptions have been completed and knowledge gaps identified, messages can be drastically misinterpreted. This line of risk communication work shows us that when we engage in sustainability science, we should think about how to format and share results, so that our communication is interpreted in ways that foster trust, multidirectional flows of information, and iterative understanding among groups. It is easy to forget that as sustainability researchers working to understand complex systems we are not just communicating about science: We need to understand communication as a science, that, to be done well, demands the same levels of scientific attention and support that other disciplines receive. Fortunately, funding agencies like the National Science Foundation, the National Oceanic and Atmospheric Administration, and others are increasingly recognizing the important roles that communication research can help to address in collaborative, interdisciplinary research aimed at creating solutions.

Lastly, we have argued that a better understanding and explicit inclusion of uncertainty needs to be incorporated into sustainability science work. As uncertainty runs through every level of science and decision-making, sustainability science needs to address it as a fundamental social variable that will influence acceptance of scientific or social claims, and decision making at both individual and institutional levels. The inclusion of uncertainty in scientific work calls for a need to communicate more effectively how uncertainty works in tandem with stakeholders' knowledge claims. Empirical communication research can help to assess perceptual, experiential, and scientific uncertainty in support of more collaborative, informed, and effective decision-making. Much can be gained from communicating the uncertainties that are inherent in sustainability models and predictions. Integrating risk communication into sustainability science offers important opportunities for advancing the aims of both fields.

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