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ARTICLE

The quality of sustainability science: a philosophical perspective

Rafael Ziegler[1] & Konrad Ott[2]

[1] GETIDOS, Institute of Botany and Landscape Ecology–Institute of Philosophy, Ernst-Moritz-Arndt University, Soldmannstrasse 23, 17487 Germany (email: rziegler@uni-greifswald.de)

[2] Institute of Botany Landscape Ecology–Institute of Philosophy, University of Greifswald, Grimmer Strasse 88, Greifswald 17487 Germany (email: ott@uni-greifswald.de)

Sustainability science does not fit easily with established criteria of the quality of science. Making explicit and justifying four features of sustainability science—normativity, inclusion of nonscientists, urgency, and cooperation of natural and social scientists—can promote deep and comprehensive questioning. In particular, because the inclusion of nonscientists into sustainability science has become a dogma, re-examining the epistemic, normative, and political reasons for inclusion is important for the quality of sustainability science. These reasons include providing a range of perspectives and helping to craft and implement policy in real-world social and ethical situations. To be included effectively, nonscientists must be understood within this demanding context rather than employed merely to satisfy a dogma. We situate our discussion in this article against a foundational controversy of sustainability science: the weak versus strong sustainability debate. According to our analysis, comprehensive consideration of the features of normativity, inclusion of nonscientists, urgency, and cooperation of natural and social scientists suggests a convincing case for strong sustainability.

KEYWORDS*:* sustainable development, interdisciplinary research, evaluation, participatory planning, culture (human)

Introduction

Sustainability science has become a recognizable domain for scientific funding. Two notable examples are the program *Forschung für Nachhaltigkeit* (Research for Sustainability) organized by the German Ministry of Education and Research and the Science and Technology for Sustainability Program of the National Academies in the United States. Funding by itself does not legitimize sustainability science. Rather, it calls for reflection on such scientific activities, their key features, and the reasons for them. There is also sustainability science in the sense that there are scientists who regard themselves as sustainability scientists and who claim to do such science. However, neither funding nor a mere presumption to do science is sufficient to establish a scientific field. Sustainability science must continuously reflect on its practice and its key features if dogmatism is to be avoided. To this end, we raise from a philosophical perspective four questions regarding key features of sustainability science. How these questions are dealt with strongly influences the quality of sustainability science. The respective choices and positions should be made explicit so as to avoid confusion and to improve understanding of the concept "sustainability science."

This article examines key features of the projects and research activities of sustainability science—these features define our working concept of "sustainability science" or "science for sustainable development."[1] These elements are normativity, the temporal character (urgency) of the research, the inclusion of nonscientists into sustainability science, and the task of understanding social and environmental interrelations. Put briefly, these four factors concern the explication and articulation of values and principles (normativity), addressing the temporal relation of the research to what is at stake (urgency), the justified inclusion of nonscientists (participation), and the joint research of natural and social scientists (interdisciplinarity).

[1] In addition to this journal, contributions to sustainability science are regularly published in a special section of the *Proceedings of the National Academy of Sciences of the United States of America* as well as a numerous other journals (for a current list, as well as further resources, see http://sustainabilityscience.org/document.html?type=journal). Important, frequently overlapping research communities contributing to sustainability science include resilience research, common-pool research, socioecological research, transitions research, and vulnerability research. For the discussion in this article, the ecological economics community is particularly important, as one of the cofounders of the field, Herman Daly, made major contributions to the weak versus strong sustainability debate (see, e.g., Daly, 1996).

These features make sustainability science difficult to evaluate according to the standards of disciplinary science, especially of the natural sciences. The overall field of sustainability science, with its explicit inclusion of normative considerations, seems to rest on shaky ground by the standards of customary disciplinary approaches. However, since the challenges of sustainability are real and unresolved, and a high quality of scientific inquiry desirable, a deeper understanding of these features matters. Philosophical considerations, in particular from philosophy of science, can contribute to this task.[2] For the investigation of the quality of sustainability science, it is of primary importance to ask methodological questions and to examine ways of defining a problem. As important as the development of indicators and tool sets for evaluation is the philosophical task of examining major presuppositions of sustainability science and their justifications. Our approach aims at deep and comprehensive questioning in sustainability science: depth with respect to each feature, comprehensiveness as covering all major features.

We first introduce a famous example to demonstrate that philosophy of science plays a role by co-structuring the debate in sustainability science. Our illustration is the ongoing dispute between weak and strong sustainability. We show how Popperian and Kuhnian philosophy of science costructure Neumayer's (2010) classic contribution to the debate. In addition, we demonstrate this to be an uptake of philosophy of science that leads to a conceptually problematic way of framing the debate.[3] The article then discusses how a critical re-examination of the Kuhnian and Popperian views can inform an analysis of the four key features mentioned above—and with it shed a different light on the debate between strong and weak sustainability. Philosophy of science so conceived is enabling and its attempt to pose the relevant questions is one contribution to a critical self-understanding for sustainability scientists. Rather than uncritically stating certain features, we re-examine why and under what conditions features are justified, thereby improving the quality of the research. Finally, we draw some tentative conclusions for the emerging culture of sustainability science.

Framing Issues—the Difficult Heritage of Philosophy of Science

The relevance of philosophy of science for the way questions are asked in sustainability science can be demonstrated via the discussion of weak and strong sustainability. This key debate revolves around the question of whether natural capital, in particular natural resources and natural sinks, should be regarded in principle as substitutable ("if we run out of coal or oil it does not matter, for we will be able to substitute another energy source")—weak sustainability—or as complementary ("if we destroy or deplete natural capital such as the world freshwater supplies, there is no alternative for this essential service")—strong sustainability. Here we focus on Eric Neumayer's (2010) seminal contribution to this debate.

Weak sustainability (WS) in Neumayer's definition requires "keeping total net investment [or total savings], suitably defined to encompass all relevant forms of capital, above zero." In contrast, *strong sustainability* (SS) "calls for the preservation of the physical stock of those forms of natural capital that are regarded as nonsubstitutable (so-called critical natural capital)." Neumayer states his goal as follows: "It will be argued here that both paradigms are non-falsifiable under scientific standards. Therefore, there can be no unambiguous support for either weak sustainability or strong sustainability." At the end of his extended debate, he states: "the contest between WS and SS cannot be settled by theoretical inquiry. Nor can it be settled by empirical inquiry." For the present purpose, we need to pay attention to the way Neumayer frames the question: *Can the paradigms of WS or SS be falsified*? This question (as Neumayer indicates via his references) points directly to two seminal contributors to philosophy of science: Karl Popper and Thomas Kuhn. We will therefore very briefly introduce a few essential points pertaining to these respective philosophers so as to highlight the philosophical structure of Neumayer's question.[4]

Karl Popper and Scientific Method

Karl Popper (1963) influentially argued for the idea that science is distinguished by a scientific method consisting of an evolutionary process of conjectures and refutations. Popper's work has been doubly influential: with respect to reinforcing the meta idea that science is distinguished by a method

[2] It is in this respect that we hope to contribute to the discussion of the quality of sustainability science and thus pragmatically to its evaluation. We deliberately say "contribute" as we do not claim that philosophy of science somehow delivers "the" method of sustainability science. In our view, sustainability benefits from a diversity of methods. One contribution of philosophy of science is to make explicit and discuss the presuppositions about science that costructure fundamental disputes such as the one between strong and weak sustainability.

[3] There is probably a link here to the French tradition of epistemology and its examination of the role of philosophy of science as in Lecourt's (1969) account of a historical epistemology.

[4] The secondary literature on Popper and Kuhn is enormous. Here we cannot discuss the many critical points that have been raised with respect to these philosophies, amendments, and refinements. Our only goal is to delineate as clearly as possible how they influence the way the question is posed in our case study.

and his specific idea of falsification, which has been endorsed by numerous scientists, as well as—suitably for a discussion of sustainability science—a wider public.

The specification of this scientific method, Popper argues, allows science to be distinguished from pseudoscience (the so-called demarcation problem). Popper believed fields such as psychoanalysis or scientific socialism belong in the domain of pseudoscience because they do not follow the scientific method. Popper did not describe how the fabric of science works in its day-to-day routines. His philosophy of science is prescriptive, since it tells courageous scientists how they should proceed, a method, Popper believed, that would bring about scientific progress in the long run. On the one hand, scientists (should) advance bold and risky hypotheses and, on the other hand, they (should) attempt to derive empirical predictions from these conjectures and seek to refute them. This process of conjectures and refutations is (or should be) in Popper's view at the core of the scientific method. A proposition is only scientific if it is possible to falsify it. Thus, if neither WS nor SS can be properly falsified, both concepts would not belong to the realm of scientific knowledge. If key approaches in sustainability science turned out to be nonfalsifiable pseudoscience, then this way of framing the problem could have serious consequences in general for sustainability science well beyond the focus of Neumayer's claim.

The situation looks less painful for sustainability science if empirical falsification is perceived as a special case of refutation. There are many controversies that cannot be settled by empirical falsification of risky predications derived from a theory. For example, ethicists may refute specific claims by means of analysis of the concepts and the internal coherence of a theory (Neumayer himself engages in this kind of logical argumentation). Here, nonempirical shortcomings such as circularity, nonsequitur, self contradiction, absurd implications, and so forth count as counterarguments. There are thus plausible refutations beyond empirical falsification.

Thomas Kuhn and Scientific Community

Only Kuhn's (1996) paradigm account of science has been similar in scientific and popular influence in the twentieth century. Paradigms, in one key meaning of the definitive term in Kuhn's work,[5] offer a vision of what scientific work ("puzzle solving") is worth performing in terms of theory articulation, empirical experimentation, and measurement, and which scientific work is secondary or even illegitimate. A paradigm in this sense includes generalizations along with preferred instruments and methods. It is furthermore structured by ontological commitments about elements and concepts and powered by the faith that nature can be fit into the box of the paradigm via puzzle solving (such as the often brilliant work of more elegant theory formulation and extension or more precise measurements).

Kuhn describes the social structure of science as one of particular scientific communities that are constituted by a shared faith in a paradigm. In his view, the scientific community is the supreme authority for validating and assessing scientific claims. Scientific claims are adopted and rejected according to criteria that stem from the paradigm itself. Students are initiated into the scientific community via textbooks, academic study programs, and laboratory training and they adopt basic axioms, concepts, and mindsets. Specialized conferences and peer-reviewed journals make it possible to assure the quality of research done within the community. In such ways, normal science becomes established.

The Problematic Structure of Neumayer's Question

In light of Popper's and Kuhn's views on science, the philosophical structure of Neumayer's question emerges—and is puzzling! From a Popperian perspective, the structural process of science is one of conjecture and refutation with falsification as the selection, or rather elimination, criterion. From a Kuhnian perspective, scientific work mostly takes place in paradigm-based normal science. There will be scientific revolutions and new paradigms will emerge and take hold according to Kuhn, but the selection criterion for the new paradigm is *not* one of falsification. Moreover, falsification plays little role for (faith-based) normal science. We thus face the following dilemma: either WS or SS really are genuine paradigms—but then we should not expect any attempts at falsification, rather "puzzle solving" (much of such puzzle solving is in evidence in the materials Neumayer cites)—or WS and SS are falsifiable. Paradigms are not falsifiable according to Kuhn's rich account of the history of science and arguably also for conceptual reasons (for example,

[5] Kuhn (1996) notably also uses the term in the sense of a scientific achievement: "research firmly based upon one or more past scientific achievements, achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice". It is not clear that WS and SS are "paradigms" in this sense. Rather, they seem to depend on a wider dispute between the neoclassical growth model and ecological economics. Underpinning these we have, respectively, Solow's growth model (1956) and Georgescu-Roegen's (1971) work on the entropy law and the economic process as scientific achievements on which other scientists built. We would like to thank an anonymous reviewer for identifying the need to clarify these different meanings of "paradigm."

the holism of paradigms makes it unclear what would have to be rejected if an experiment is to be falsified). In short, viewed in terms of these philosophies of science, Neumayer's guiding question is indeed a difficult one, not only because of empirical problems (missing or incomplete data on resource availability, substitution elasticities, and so forth), but because conceptually the question—can paradigms be falsified?—is problematically stated. That paradigms cannot be falsified is a conceptual truth and Neumayer's thesis is in this sense correct—but this of course is hardly what he meant to show.[6] No case studies or secondary literature are required for this result.

Moreover, this uptake of philosophy of science has further problematic implications. "Normative positions are nonrefutable," according to Neumayer. There are two readings of this claim. First, it can be justified in the sense that a person's violation of a normative proposition does not refute the proposition's validity. A corrupt politician does not falsify the validity of anticorruption legislation. Instead, he demonstrates the difficulty of its effective implementation. The Popperian language of risky predictions and falsifications, and its classic example (relativity theory), tempts us to exclude or ignore genuine ethical methods of refutation. An example is John Rawls' (1999) classic method of reaching a reflective equilibrium, which draws on ethical convictions as well as a procedural method ("the veil of ignorance") to reach an outcome motivated by a coherentist epistemology (see also Scanlon, 2003).[7] In a second reading, Neumayer seems to endorse some variant of metaethical noncognitivism. His claim that there might be a "persuasive case" in favor of a specific concept of sustainability could be informed by emotivism that regards normative statements as mere expressions of emotive attitudes. Emotivism is by no means an uncontested metaethical theory, as it cannot distinguish between the convincing force of reason and the persuasive force of rhetoric (Ott, 1997). Under emotivist premises, the question of how the quality of ethical reflection within sustainability science might be assessed becomes somewhat pointless or must be replaced by interviews about how well and badly people feel within a given project. If the project were performed in a good mood, the ethical quality would be high. Given this consequence, we would not like to adopt an emotive approach to assess quality in the ethical dimension of sustainability science.[8]

If normative statements are not refutable in laboratories or on scientific expeditions, it does not follow that they are necessarily unscientific. But it would be unscientific not to use the methods proper to ethics. Because the debate between WS and SS depends strongly on ethical arguments about our responsibility to future generations, about precautionary motives, and about our relationship to the natural environment, excluding normative propositions from method-based investigation amounts to a problematic, and more precisely, to an insufficiently comprehensive way of posing the question.

This analysis of the structure of Neumayer's argument demonstrates that philosophical questions play a role in the analysis of sustainability science and the self-understanding of sustainability scientists. One might abstract them away in the routines of individual projects, but one should not overlook them in basic debates. If sustainability science is to stand for a distinctive way of doing science, the philosophical dimensions of this mode need to be considered. We submit that both Kuhn's focus on the scientific community and Popper's call for a scientific method continue to raise important questions. The point, however, is not to uncritically accept their philosophies, but to reconsider them in their respective contexts. In the next sections, we therefore discuss their utility for thinking about key features of sustainability science. By doing so, we follow the route Neumayer has opened, but add that there are different viable pathways for framing questions in sustainability science.

Sustainability Science

In this section, we wish to deepen the understanding of our four key features of sustainability science that its practitioners have identified as distin-

[6] Note that Neumayer is well aware of the problem that any simple view of falsification is implausible and we therefore by no means want to charge him with this mistake. Rather, our goal is to draw the conclusion from this insight. If "simple falsification" is implausible, what is the implication for theory choice in sustainability science (or for a decision on "correctness" as Neumayer puts it)? Our response to these questions is the discussion of the four features of sustainability science and their justification.

[7] Rawls' method of reflective equilibrium is based on a) a hypothetical situation of choice ("the original position") that allows the comparison of various approaches to justice (Kantian, utilitarian, intuitionist, and so forth), and b) a consideration of our considered ethical judgments (for example: "racist discrimination is wrong"). Reflective equilibrium is a state of coherence between the conclusions arrived at in the original position and one's considered judgments. Achieving reflective equilibrium requires adjustments both in the formal reasoning of the original position and of (some) considered judgments or basic intuitions about justice.

[8] Also note that Neumayer relies on a Kantian approach to make the case why we should care about future generations. A Kantian perspective is not only inconsistent with emotivism, it also shows that performatively it is not possible to conceptually introduce the debate without drawing on ethical arguments (Neumayer's own skepticism elsewhere notwithstanding).

guishing the nascent field in a particular, and even peculiar, way.[9]

Normativity: Sustainability science explicitly acknowledges a normative context, that of sustainability or sustainable development (Clark & Dickinson, 2003). As "sustainability" and "sustainable development" are contested concepts, many definitions and approaches have been argued for. However, it seems fair to say that the so-called Brundtland definition—"sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"—defines a vague space of global intergenerational and intragenerational justice and development that, nevertheless, no specific or more rigorous definition can ignore (Jacobs, 1999). If so, any concept of sustainability must clarify notions and theories of justice with respect to development. This clarification is by no means an easy task and we will return to it below.

Urgency: A commitment to the fulfillment of human needs in a world where even the basic requirements of a large part of the human population are often not met implies a dimension of urgency. How can science and technology help move society toward a more sustainable future (Clark & Dickinson, 2003)? There is an ethical supposition in claims of urgency: as moral persons, we are not neutral to whether a specific problem might be addressed now, in some decades, or even in centuries. Fermat stated a theorem in the seventeenth century, but did not disclose the proof. It took three centuries until Andrew Wiles and Richard Taylor did so; in the intermediary time those interested simply had to wait and/or puzzle. The patience of the puzzle solver is a virtue. In puzzle-solving science, one might trust that all major problems will be solved in the longer run and that science will, in the end, discover some ultimate truth (Peirce's "final opinion") about how the universe is. Meanwhile, down on earth, there is suffering, injustice, and devastation of the biosphere. The puzzle-solving scientific attitude can abstract away from such pressing concerns, transforming them into private opinions a scientist may (or may not) hold. However, in the case of sustainability science these moral concerns are intrinsic. Those whose needs are to be met may simply no longer be alive in the long run. There is still another aspect of urgency: in the case of climate change the risks associated with waiting for better science might simply be judged too high. A purely scientific attitude can become a source of risk in sustainability science. As Hiroshi Komiyama & Kazuhiko Takeuchi (2006) put it, "the search for solutions cannot wait."

Inclusion of nonscientists: Sustainability science typically endorses a commitment to the inclusion of nonscientists in the process of research itself. Funding bodies might even require the satisfaction of this condition. As Kates et al. (2001) observe, "Combining different ways of knowing and learning will permit different social actors to work in concert, even with much uncertainty and limited information." Sustainability science thus supposes that nonscientists can contribute to projects in the field in ways that the scientists involved cannot substitute for. The inclusion of nonscientists and its justification is further discussed below.

Interrelation of environment and society: Sustainability science seeks to "understand the fundamental character of interactions between nature and society" (Kates et al. 2001; see also Renn, 2008), to find joint ways in which natural and social scientists can improve the understanding of environment-society relations. Typical tools for such attempts are scenario techniques that depend on information and causal mechanisms from natural and social sciences. Another example might be coupled models that shed light on the interactions between human and natural systems.

In the subsequent sections, we discuss the questions raised by these features and their contribution to the quality of sustainability science. In doing so, we further engage with the weak and strong sustainability debate and its framing in our attempt to contribute to a critical and enabling philosophy of science.

Why Include Nonscientists?

An important contribution, explicitly informed by philosophy of science, is the post-normal science proposed by Silvio Funtowicz, Jerome Ravetz, and others (Funtowicz & Ravetz, 1991; 1993; van der Sluijs & Funtowicz, 2008). This approach specifically focuses on the inclusion of nonscientists (as a matter of extended peer review). Post-normal science is explicitly situated in a sustainability context:

> The new global environmental issues…are global in scale and long term in their impact.

[9] There are very close family ties between sustainability science and other research programs including integrative and transdisciplinary environmental research (Renn, 2008) or respectively social-ecological research (Jahn, 2008). This article does not compare these approaches. However, we believe that our conclusions regarding the quality of sustainability science by and large also pertain to these other "family members."

> Data are … radically inadequate. Science … can frequently only achieve at best mathematical models and computer simulations, which are essentially untestable. On the basis of such uncertain inputs, decisions must be made (Funtowicz & Ravetz, 1991).

This context of sustainability science calls for a revision of the organization of science;[10] the scientific community, in the context of sustainability issues, must open itself to extended peer review and the extended facts it might offer. Put differently, the Kuhnian community structure, which gives the scientific community supreme authority, no longer applies. As Funtowicz & Ravetz (1991) note, this can be observed as a simple matter of external pressure. To the extent that scientists are "manifestly incapable of providing effective conclusive answers to the many problems they confront," administrators, politicians, and others are able to "force" their way into the dialogue. However, there is also a separate series of arguments for the inclusion of nonscientists in sustainability science.[11] We discuss first five epistemological, then three political, and finally one ethical argument for the inclusion of nonscientists in project-based sustainability science.

1. Local Knowledge: The inclusion of nonscientists opens sustainability science to local knowledge and tacit knowledge considerations. Ravetz & Funtowicz (1991) assert that "[k]nowledge of local conditions may not merely shape the policy problem, it can also determine which data is strong and relevant" (see also Renn, 2008). Thus, the inclusion of nonscientists might be relevant for both problem formulation and for contextual knowledge application. Local knowledge is found in laypersons and it may also be stored in literature that does not count as scientific. According to contemporary standards of peer-reviewed journals, such literature is very often "dark grey." Local knowledge often comes in "thick" narratives that are not "stored" in the same way as disciplinary knowledge.

2. Bias: Funtowicz & Ravetz (1991) contend that "[e]xperts lack practical knowledge and have their own forms of bias." Normal science involves a process of initiation; assumptions have to be internalized, methods learned—in short, a paradigmatic view acquired. The result is a certain way of seeing the world; we see evidence of this, when, for example, laypersons strongly react to the economists' point of view. Because biases need to be unnoticed to be biases, the antidote against biases tends to come from outside. The inclusion of nonscientists can serve as an antidote against specialization and can help expose the limits of science. For instance, scientists are often ignorant about history, while history plays an important role for local people.

3. Self-criticism and normal science: Precisely because academic science has a strong institutional character that involves hierarchies, careers, and hence people's life prospects, internal criticism may be difficult or even rare (Betz, 2006). Again, outside perspectives not so constrained can be helpful in engaging in such criticism. Laypersons do not have blind faith in science and often challenge scientific claims. In this way, the scientific virtue of a critical attitude is turned against science from the outside.

4. Alertness: Normal science can be compared to a large tanker. It is the tanker of science at sea and it is difficult to change its course once it has picked up speed. Research programs involve significant human and monetary investments and paradigm work on measuring and theory articulation is likely to have a long-term perspective. As a result, scientists as a community may have difficulty being alert to novel challenges that do not easily fit into their prevailing theoretical outlook. Nonscientists are not so constrained; hence, they can serve the function of communicating novel issues, thereby possibly making the ship of science more responsive.

5. Conjectures: Conjectures require imagination. Imagination is, like prudence or even wisdom, not only found among scientists. The inclusion of nonscientists may open the scientific communities to new conjectures: wild ideas, naïve questions, and unexpected observations that the scientific community has the resources to state rigorously, refine, or refute.

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[10] Funtowicz & Ravetz (1991) put much weight on the distinction of quality and certainty (as logically independent attributes of knowledge). However, we are not sure that this argument succeeds and, moreover, whether it does not unnecessarily overstate the role of certainty for science. For example, neither Popper's risky predictions nor Kuhn's normal science put fundamental weight on certainty.

[11] These arguments are not directly stated as such by Funtowicz & Ravetz (1991) but are, where indicated, inspired by them and others. In the following paragraphs, we use the language of inclusion of nonscientists rather than extended peer review because it is *prima facie* unclear in what sense a nonscientist is a "peer." As the discussion will show, there is more than one reason for the inclusion of nonscientists and even for their equal standing in a scientific project. However, whether this makes them peers is debatable and possibly obscures the point that the relationship between scientists and nonscientists is by no means trivial, but is rather multifold and contextual. In their discussion of research evaluation, Bergmann & Schramm (2008) speak of "expert review." The need for the inclusion of nonscientists has been widely recognized in sustainability science. For a review of major problems associated with the idea of sustainability scientists as "separate" researchers offering society the facts, see van Kerkhoff & Lebel (2006).

6. Care and Concern: Funtowicz & Ravetz (1991) write that "[t]hose whose lives and livelihood depend on solutions of the problems will have a keen awareness of how general principles are realized in their 'back yards.'" Science that aims to have a practical influence must be especially cautious with respect to the real-world impacts it may have. To the extent that people most affected by environmental issues are not generally scientists, the care argument is sociologically plausible: those most affected are likely to care the most, and hence care that the policy instrument (or similar) is appropriate. In medicine, it is the patient who must live with the consequences of a physician's recommendation for surgery. Because of this, the ultimate decision is up to her (informed consent). In similar ways, local stakeholders have to cope with the consequences of projects designed by scientific experts.

7. Timing: If sustainability science seeks to contribute to practical problem solving, then generally timing will be one component of successful science. For example, if a scientific report, however brilliant, misses the window of opportunity provided by an election cycle, it might be practically useless. Here, too, the inclusion of nonscientists may offer insight. Such inclusion also gives scientists a better understanding of the affected people's perception of the pressure and urgency of a given problem (for example, a problem could be less urgent for local people than the scientists believe!)

8. Power: Nonscientists may not only offer insight, but they can also generate the power to help advance a proposal resulting from sustainability science. Nonscientists who are informed and have the necessary influence can help effectively communicate or even implement a policy proposal (Bergman, 2008).

9. Normativity: A normative science needs to take care with respect to the social values it seeks to achieve or promote. However, as Funtowicz & Ravetz (1991) note, values are in dispute. Precisely for this reason, it seems important to make this dispute public and not to leave science with the decision of which values to prioritize (Renn, 2008). The inclusion of nonscientists can contribute to this end. Scientists as such are not experts in value judgments. Ethicists may offer skills for the investigation of normative intuitions and their implications, historians may offer insight into the contexts of such intuitions, and so forth. However, here, too, bias and limited self criticism can pertain. Scientists should not have ultimate authority in moral matters.

These various arguments partly complement one another and may also be in many contexts quasi-independent. It is conceivable that in a context concerning basic needs, the value dimension is trivial and uncontroversial. This does not mean that there is no value dimension in this context, but only that it may justifiably fade into the background as far as the possible inclusion of nonscientists is concerned. More generally, it seems that some set of these arguments ought to be made explicit for the specific context of the sustainability project at hand. Put differently, for each sustainability science research project that includes nonscientists, the various epistemological, political, and normative relationships between the scientists and nonscientists ought in principle be made explicit. They are not always the same; they may not always have the same weight and the design consequences (the question of *how* nonscientists are included or participate) are accordingly also likely to vary.

These reasons indicate that one criterion for the quality of sustainability science is an explicit rationale for the inclusion of nonscientists in a given project. In terms of the evaluation of sustainability science projects, this point concerns especially *ex ante* and intermediary evaluations. That there are reasons for the inclusion of nonscientists is here not in doubt, but what is required is that these reasons are made explicit and are specified according to the design of a given project. In his discussion, Neumayer does not explicitly take this feature into account for his problem formulation, but where he implicitly notes it, it suggests a tendency in favor of strong sustainability. For example, discussing climate change, he notes that "voters and politicians who favour decisive and urgent action…are concerned that climate change is like no other and that its sheer scale and extent of damage threatens to create a new-biophysical world that either leaves the future worse off or violates the inalienable right to enjoy natural capital" (Neumayer, 2010).

The Dogma of Participation

As noted above, the establishment of sustainability science has meant that some funders mandate the participation of nonscientists. In such cases, inclusion does not need to be justified, but becomes an expectation or simply a dogma of sustainability science. However, one can endorse the nine reasons just mentioned and remain critical of dogmatic ways to perform participation for the sake of funding requirements. We may face such dogma if participation and inclusion seem to be mere add-ons to a given project, are disconnected to the scientific objectives, or do not rely on a sound concept.

For this reason, Wolfgang Zierhofer & Paul Burger (2007) have a valid point when they question whether the inclusion of nonscientists in transdisciplinary research always serves epistemic ends. They define transdisciplinary research formally by interdisciplinarity and participation (of nonscientists), and they view problem-oriented research as its main epistemic end. Problem-oriented research in their understanding aims to reduce knowledge gaps that "hinder some stakeholders or institution to pursue certain actions." Based on a survey of sixteen transdisciplinary research projects, they found that few projects really investigate goals or knowledge objectives. They conclude that transdisciplinary research should not be regarded as a distinct mode of knowledge production. Instead, it "should be considered rather a class of epistemically and methodologically heterogeneous research activities which are only formally unified by the two general properties 'interdisciplinary' and 'participatory.'"

Skepticism as to the inclusion of nonscientists is reasonable in view of participation as dogma. However, Zierhofer & Burger's (2007) conclusion that transdisciplinary research is "not a distinct mode of knowledge production" does not logically follow from the observation of a sample of empirical examples. Moreover, their conclusion seems to be the consequence of a formal description of transdisciplinary research that does not specify a domain of investigation, which could be numbers as in mathematics, life as in biology, the commitment to sustainability as in sustainability science, and so forth. These domains of investigation stand for distinct epistemic ends (What is number? What is life? What is sustainability?). Once we have stated these domains, we can ask whether transdisciplinary research contributes to the respective ends. For example, sustainability science focuses on the promotion of normative sustainability goals and to this end on an improved understanding of nature-society relations. The inclusion of nonscientists can serve this end (see the list of arguments above). Therefore, transdisciplinary research in conjunction with a domain of investigation does seem to yield distinct modes of knowledge production.

As Zierhofer & Burger's (2007) survey of research projects shows, many of them relied in practice on nonscientists only for strategic reasons. They benefit from a dogma of participation and here the inclusion of nonscientists may not serve epistemic ends. But sustainability scientists should examine what relationships between scientists and nonscientists may promote the issue at hand. Therefore, in our view a criterion for the quality of sustainability science is an explicit statement why nonscientists are included and a clear concept of how participation should be performed and how the results should contribute to the overall results.

Why the Pathos of Urgency? The Temporal Horizon

We tend to think that whether a geometric proof is valid is independent from its discovery by Greek, Indian, or other mathematicians. The context of discovery is distinct from the context of justification. According to this view, it is the reasoning for a scientific claim that counts, not its timing. We say that a scientific claim is valid if it can be shown to be a condition of the world, according to a specific observation or laboratory method that verifies or confirms the claim (this method usually involves a specific community structure for confirmation and testimony of experiments and observations). Such conditions of the world can have a temporal reference. For example, the passenger pigeon—once an abundant species in North America—is supposed to have become extinct in the early twentieth century. A scientific claim (or entire set of claims) can involve a reference to a specific time or temporal dynamic (such as the once abundant passenger pigeon becoming extinct). However, such temporal references are irrelevant with respect to the validity of the scientific claims.

Many events and temporal dynamics are relevant within sustainability science. "Urgency" is determined by temporal considerations (how much time do we have?) as well as ethical stakes (how important is the event/dynamic?). For example, predictions and forecasts regarding single events and dynamics of stocks are frequently related to human options. If global temperature is likely to increase by two degrees within the next generation, this can affect environmental security (for example, shelter due to increased risks of floods). Accordingly, there can be questions of mitigation (fight temperature increase) and adaptation (improve shelter). As the adaptation example shows, the relevance of scientific claims is not dependent on the human capacity to influence the occurrence of an event or the pattern of a dynamic. In any case, sustainability science is interested in the dynamics of specific stocks and flows over time. These dynamics (Aristotles' *kinesis*) are perceived from the normative perspective: in sustainability science one must, *ceteris paribus*, engage oneself against stocks of pollutants, declining stocks of resources, increasing stocks of greenhouse gases, and so forth. As in the case of atmospheric greenhouse gases, the dynamics of increase give reason to claim that mitigation is urgent. If a lake is close to collapse or a species is near extinction, action is urgent. Many stocks are goods that are components of the overall fair bequest package we owe to future generations. If so, sustainability science must schedule the relationship between stocks and time. A normative approach to the kinetics of stocks is required. Quite often, there will be a window of opportunity. We can call this the *kairos*, the opportunity to act.

The quality of sustainability science is codependent on an explicit way of dealing with urgency: How do stocks change over time? What are the temporal windows? How can long-term objectives be combined prudently with first steps and a transition period? In our view, these questions do not necessitate a departure from sound scientific standards, but augment them. The pathos of urgency as such clearly does not make any claim a scientific one. Scenarios being presented in a context of urgency must *in principle* be open to disciplinary scrutiny and critique. Even the claims of urgency themselves must be open for refutation. What is required is the explicit contextualization of scientific claims (and practices) in a temporal framing of dynamics and events. Whether a scientific claim is considered as evidence and reason for action is ultimately an ethical question. (This establishes a double link to the inclusion of nonscientists: Who decides on ethical stakes? Who has knowledge of and influence on windows of opportunity for action?)

These questions, we submit, also need to be asked for the weak versus strong sustainability debate. Consider the example of energy substitution, such as the substitution of nonrenewable oil with renewable solar energy that Neumeyer discusses. There are optimistic scenarios that suggest substitution is possible and there are pessimistic scenarios that put the possibility of substitution into doubt. As Neumeyer notes, “Which of the two projections will be closer to reality we do not know.” Again, we need to pay attention to the formulation of the question. No doubt, there are energy optimists and energy pessimists, but what, in this context, is the meaning of “closer to reality?” The discussion above suggests that for a sustainability evaluation of these scenarios we would have to ask whose needs are likely to be affected and how and when they will be affected (with respect to the question of substituting oil with solar power). With regard to urgency, WS would likely rely on economic wisdom about how depreciation of a resource motivates the search for substitutes, while SS would recommend political measures to speed up such substitution. In such matters, there is no such thing as empirical “closeness to reality.” “Closeness to reality,” we submit, requires an account of these questions of needs and urgency without which a dimension of sustainability science is missing. Only with these questions addressed can we discuss and compare energy scenarios on which to base our decision. Ethicotemporal urgency is a condition of asking the question.

Why Must Various Disciplines Work Together?

Sustainability science, it will be recalled, seeks to understand the “interactions between nature and society,” and it is in principle plausible that it needs to draw on the knowledge of both natural and social scientists, as well as the humanities and vocational disciplines (such as engineering, law, and medicine) to advance this understanding. As a minimum question of quality, the various scientists working on the respective issue should be included (Jahn, 2008). For example, research on a problem pertaining to floods requires hydrological (and possibly climatological) knowledge, but also political knowledge regarding the societal actors and their coalitions.

A closely related second question of quality is the hierarchy of the disciplines involved. Does one discipline define the problem and simply add the other disciplines so that the basic perspective on the problem is essentially disciplinary (compare the example below)? If there is a hierarchy, what is the reason? One nonhierarchical approach is to start from the societal problem (rather than the scientific puzzle of a discipline).[12] Working together is then a process of joint problem analysis (Wätzold, 2009). Scenario techniques and models can serve as tools for joint work in this sense. Scenario techniques are one example of a family of models, which suggests a joint method for various sciences. Moreover, scenarios and others tools can themselves be included in integrated sustainability approaches, such as the embedded case-study approach for sustainability learning (Scholz et al. 2006).

In light of the discussion of urgency and scientific validity, we need to recall that problem-oriented science is not something different from scientific practice (and its methods, data, observations, and so forth). In establishing a knowledge base, sustainability science consumes the results of scientific research. It frequently relies on normal science. Therefore, sustainability science is hard to reconcile with philosophies of science that are highly critical of modern science. A third question of quality in this category is whether sustainability science produces results that are communicable or translatable into specific disciplines and open to the critique and scru-

[12] “Problem solving” will only acquire a social meaning if nonscientists are included in problem formulation. This is another instance of the codependence of the four features of sustainability science discussed here.

tiny of disciplinary science and its systems of peer review.

Again, the debate of weak versus strong sustainability can serve as an instructive illustration of this feature of sustainability science. Both paradigms presuppose some ideas of how humans and natural systems are related. We here make three observations with respect to nature-society relationships:

1. The definitions of weak sustainability, strong sustainability (see above), and natural capital[13] and their terminology originate in economic thought about investments, substitutes, complements, capital, and so forth. Thus, it is already a challenge to translate the weak versus strong debate into a genuine debate of social *and* natural science.

2. The debate issues from another debate between much wider paradigms: those of neoclassical economics and ecological economics.[14] Roughly put, the first paradigm conceives of the economy as an autonomous entity in which economic growth can be examined and explained without reference to exogenous variables. Endogenous growth is in principle unlimited. The second paradigm conceives of the economy as a subset of the biosphere and claims that economic growth cannot be explained without reference to the enveloping biophysical system that also limits economic growth. The anomaly in the Kuhnian sense is the problem of substitution (the old neoclassical paradigm is pushed to defend the increasingly contested claim that natural resources and services are substitutable). *Prima facie*, the paradigm of ecological economists necessitates nature-society integration due to its image of the economy as a subset of the biosphere. Its paradigmatic image is one that fits well with respect to sustainability science, whereas the same cannot be said, at least at first sight, with respect to neoclassical economics.

3. Precisely because the debate is in the first place one between economic paradigms, we need to pay attention to the structure of the argument and to the burden of proof. Here we find the following structure in Neumayer's discussion of the debate. He subjects the four premises of weak sustainability to the logical and empirical objections of opponents,[15] concluding that SS proponents cannot decisively refute WS because their objections are inconclusive or logically flawed. But there is no complementary examination of the premises of strong sustainability.[16] In short, Neumayer does not ask whether proponents of WS have good arguments to put the SS premises into doubt. Therefore, the burden of proof is not applied in an even-handed manner.

We submit that the normative considerations, along with the observation that this very debate has a disciplinary bias (it is in the first place posited as an economic debate, in which ecologists do not really have a say), suggest a reasonable argument in favor of strong sustainability. The evidence is that ecologists clearly tend toward the nonsubstitution view (see, e.g., MEA, 2005). Indeed, some of them might not accept the terms of the debate as meaningful to begin with. How could life-supporting ecosystems possibly be substitutable? Even minute artificial biosphere projects have failed.

Why Do Ethical Considerations Matter?

Even for Popperians, as we noted above, the scientific method is not reduced to empirical falsification. It is all the more important not to simply ignore normative questions because they are not falsifiable via risky predictions. Normativity is a key feature of sustainability science. Under a broad conception of science (as in the continental tradition of *Wissenschaft*) this is not as problematic as under a narrow conception of science. Many disciplines are intrinsically related to and connected with ethical questions (e.g., medicine, technology, ecology, architecture, economics, psychology, history). Scientists might abstract away such ethical questions, but they should not be ignorant about the closeness of their discipline to ethics. It might be beneficial for specific research (experiments) to abstract away all social concerns; however, from this premise it cannot be inferred that such a move would be beneficial for whole disciplines. This rejection of value-free dogmatism often has been stated in critical theory of science and it can be supported even by Max Weber's critical analysis of the fact-value distinction (Ott, 1997).

Because sustainability science incorporates members of different disciplines, its general ethical

[13] Neumayer defines natural capital as "[t]he totality of nature—resources, plants, species and ecosystems—that is capable of providing human beings with material and nonmaterial utility."

[14] See also Footnote 5.

[15] As noted by Neumayer, natural resources can be substituted with other natural resources: price signals overcome resource constraints; man-made capital will substitute for natural resources; technical progress eases resource constraints.

[16] Neumayer himself notes the following key reasons (based on Spash, 2002): we are largely uncertain/ignorant about the detrimental consequences of depleting natural capital, natural capital loss is often irreversible, some forms of natural capital provide basic life-support functions, and individuals are highly adverse to losses in natural capital.

framework—with all its pitfalls—must become transparent. How can there be sound ethics within the realm of science and, especially, within the field of sustainability science? We define ethics as being a critical reflection and analysis of prescriptive claims of different kinds (e.g., metaethical, moral, axiological, prudential, legal-political). Ethical inquiry investigates how prescriptive claims (How should we act?) can be substantiated by means of argument. Given this definition, we would like to propose the following considerations regarding the quality of sustainability science with respect to normativity.

1. If science, in general, often comes close to ethics and implicitly has a normative dimension, then it is a minimum requirement to make norms and values explicit to both scientists and nonscientists. Clearly, this is not easy, since humans are always engaged in moral affairs and often the borderline between facts and values is passed unnoticed. This is simply human, but in science it is "all-too-human." High quality in the ethical dimension of sustainability science implies a sharp awareness of the *haarfeine Linie* (Max Weber's "capillary line") between facts and values. Scrutiny and honesty in dealing with the fact-value distinction are required in sustainability science. Very often, sustainability science projects make use of specific concepts and measures (e.g., ecological footprint, ecosystem approach, safe biological limits, critical loads, environmental impact analysis, integrated water management) that entail values and objectives. The obligation of transparency applies to them as well. It also applies to hybrid concepts such as biodiversity (Potthast, 2006). This obligation is not specific to sustainability science, but is certainly very important for it.

2. An account of the various values at stake is also a matter of a more comprehensive theoretical articulation. On the general and vague level of sustainable development as a contested concept there are certain essential ethical questions regarding what to sustain and why to sustain (Dobson, 1998). These questions need to be substantiated and this quickly leads to difficult nontrivial questions. Does moral obligation diminish with temporal (and physical) distance and does it come close to zero after three generations? Do future persons hold rights in the present? Would strong care for posterity imply an individual duty for procreation? Moreover, values are in dispute—there are conflicting intuitions within the domain of sustainable development. In addition, sustainable development stands for value considerations among other value considerations. These difficult questions and challenges suggest that at least large-scale sustainability projects will need to draw on the tools of ethics for the work of theoretical articulation and clarity (so important where there are activist urges)—with the above-noted qualification that professional ethicists and other scientists do not have ultimate moral authority. No doubt, in practice a tightrope walk.

3. Given a commonly shared vague commitment to sustainable development, how can we specify it according to concepts, temporal and spatial scales, guiding visions, objectives, measures, and implementation schemes? The underlying problem is that there are norms and values to be addressed all the way down from sophisticated ethical puzzles to very specific problems of, for instance, how to design catchment schemes for water in landscapes under some legal circumstances. For this reason, it seems useful to distinguish various theoretical layers (Schultz et al. 2008). At one end of the spectrum is a layer of principles of justice and development; at the other end are indicators and monitoring devices for very specific domains (e.g., local water management). These distinctions are *inter alia* useful for distinguishing different domains of refutation. For example, empirical falsification based on prediction is irrelevant on the level of principles of justice and development. On this level, various metaethical considerations and methods allow for a highly sophisticated discussion of normative ideas (including refutations, such as the refutation of utilitarianism in the reflective equilibrium).

Transparency as intrinsic ethos in science, metaethical explication of basic assumptions in any concept of sustainability, sustainability embedded in the system of ethical beliefs, and last but not least, specific conflict analysis within single projects are some parameters that define sustainability science's overall ethical quality. This implies that more ambitious sustainability science projects should incorporate ethical expertise. Such expertise cannot be substituted by good will and political correctness.

Normativity as a key feature of sustainability science also has implications for the weak versus strong sustainability debate. As noted, the burden of proof in this debate should be even handed and thus the premises of weak *and* strong sustainability should both be critically examined.[17] For example, the premise that we are largely uncertain or ignorant about the detrimental consequences of depleting natural capital is not just a faith-based assumption, but a premise that has been justified. A key argument concerns the multifunctionality of many ecosystems. As soon as we move away from the economic focus on resources such as oil and the (seemingly) simple

[17] See footnote 15.

Table 1 Comparison of approaches.

Perspective	Popper	Kuhn	Neumayer's Framing	Sustainability Science
Structure of science	Conjecture & refutation in open society	Paradigms of scientific communities	Paradigms	Conjecture and refutation (in a wide sense) in hybrid communities.
Selection criteria for the quality of scientific claims	Falsification	Sociological (scientific community as ultimate source of authority)	Falsification	Explicit normativity. Justified inclusion of non-scientists. Explicit temporal reference of research to what is at stake. Cooperation of relevant natural and social scientists based on joint problems.

substitution questions they pose, and as soon as we move to ecosystems and their services, then the premise that we are largely uncertain about the detrimental consequences of depleting natural capital is empirically the state of the art (MEA, 2005). As far as we know, WS proponents have no decisive objection to this premise and attempts to substitute ecosystems in artificial biosphere experiments have failed.

This argument is closely linked to the fact that ecosystems deliver a variety of benefits to humans and other living beings and thus provide a nexus of human values. Not just economic, but also aesthetic, recreational, and spiritual benefits are associated with cultural ecosystem services. Even if diverse groups do not value these services for the same normative reasons—not just preferences—there is still an overwhelming, if ill-defined, general support to sustain natural capital. These and other normative considerations suggest in our view a *prima facie* plausibility of strong sustainability for normative reasons.[18] They are all open to critical refutation. Note, however, that they do not yield any *a priori* decisions of what to sustain or how to sustain. Here thinking in levels of theory is useful. Ecosystem approaches and the ethical considerations they involve support a convincing case for strong sustainability *in general*. Thus, we reach exactly the opposite conclusion as Neumayer, who makes a persuasive case for *specific types* of natural capital. In our view, there is a convincing case that natural capital in general ought to be preserved, whereas turning to specific practical domains of application ensures much controversy with respect to specific issues of conservation or preservation, not least due to the many value considerations quite independent from sustainability.

Conclusion

This article first explores the way in which philosophy of science constructs a key debate in sustainability science, showing how philosophy of science can thereby become a problematic heritage. We have also argued that a critical examination of this heritage points the way to an enabling, critical re-examination of the way sustainability science understands itself. Table 1 summarizes the central considerations of the respective views. The quality of sustainability science is in our view a matter of constantly stating and re-examining the reasons for the inclusion of nonscientists, the normative issues at stake (and in conflict), the temporal relation of the research to the stakes at hand, and finally, the cooperation of the relevant natural and social sciences based on joint problem formulation. Keeping in view the debate of weak versus strong sustainability throughout our discussion of these key features, we conclude that comprehensive questioning supports strong sustainability.

The key features of sustainability science do not yield indicators or evaluation tools that every sustainability science project has to meet. Rather, they concern background considerations that in different contexts are important and that scientists will have to judge as particularly relevant.[19] Arguably, only large research programs that have the resources can be expected to consider all features in depth.

The last point suggests that it could be useful to conclude in terms of a culture of sustainability science—in terms of a more general understanding shared by members who in any specific situation will have to make choices and focus on specific issues. If culture is understood as shared norms and values, the culture of sustainability science is a "thin culture;" the normative commitment is vague and more precise conceptions of sustainability and sustainable development are contested. Still, there is a general norma-

[18] We introduce here only one argument, but see Ott & Döring (2008) for an extended discussion.

[19] See Peterson (2006) on the importance of judgment for interdisciplinary environmental science.

tive commitment as well as a commitment to the inclusion of nonscientists, to the consideration of urgency, and to the cooperation of natural and social scientists.

In view of these criteria, the culture in question is not homogeneous but hybrid, bringing together natural and social scientists and nonscientists. If the Kuhnian view tends toward a homogeneous community of the "initiated," and if the Popperian view tends toward a society of "atomistic" individuals, then the present perspective tends toward a third view of a methodologically heterogeneous culture with shared, thin values and in dialogue with nonscientists. The image of a seaport comes to mind where the adventures of "science at sea" (Neurath, 1932) meet with the people from the land and their needs.[20] A specific feature of this idea of culture is a commitment to bring together different perspectives. This diversity is the key "division of labor" for this culture and the key to the wealth it seeks to sustain and foster.

Culture also stands for cultivation and improvement. Taking seriously, not dogmatically, the key features of sustainability science can foster its cultivation, or so we would suggest. Questioning can be deep and comprehensive. For a specific project, the deep questioning of one or two features might be irrelevant (for example, because the relevant temporal and ethical questions are obvious). For sustainability science as a whole, however, questioning must be deep and comprehensive. The fulfillment of this requirement no doubt makes sustainability science as much an idea as a reality.

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[20] A point that is important for science as research just as much as for science as education (Ziegler, 2008).

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