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Philosophy of Science for Sustainability Science

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Abstract

Sustainability science seeks to extend *scientific* investigation into domains characterized by a distinct problem-solving agenda, physical and social complexity, and complex moral and ethical landscapes. In this endeavor it arguably pushes scientific investigation beyond its usual comfort zones, raising fundamental issues about how best to structure such investigation. Philosophers of science have long scrutinized the structure of science and scientific practices, and the conditions under which they operate effectively. We propose a critical engagement between sustainability scientists and philosophers of science with respect to how to engage in scientific activity in these complex domains. We identify specific issues philosophers of science raise concerning current sustainability science and the contributions philosophers can make to resolving them. In conclusion we reflect on the steps philosophers of science could take to advance sustainability science.

1 Introduction

Sustainability science is a novel field of research in many respects. Its practical orientation, transformational ambitions, and inter- and transdisciplinary core require the reconfiguring of both the way science is organized and the relationship between science and practice (Clark and Dickson 2003; Kates 2011; Jerneck et al. 2011; Bettencourt and Kaur 2011). When combined with the ethical dimensions of sustainability, this raises many serious philosophical concerns. Sustainability scientists have been hard at work in recent years developing conceptual resources and novel methodologies to address these concerns (Adler et al. 2018; Caniglia et al. 2017; Clapp 2018; Livoreil et al. 2017; Nelson and Vucetich 2012; Lang et al. 2012), and philosophers of science have long been posing similar questions about scientific methodology (Winsberg 2018; Cartwright and Hardie 2012), the appropriate role of science in society (Longino 1990; Mitchell 2009), and the various ethical and epistemic issues that arise in scientific practice (Douglas 2009; Steel 2015; Koskinen and Rolin 2019). Moreover, much contemporary philosophy of science is a continuation of science proper, as philosophers have begun to engage directly with the same theoretical questions that scientists ask (e.g., Davis et al. 2018). Accordingly, our claim here is that philosophers of science are uniquely positioned to contribute to the development and soundness of sustainability science, both from an outsider perspective and in partnership with sustainability scientists. A critical viewpoint from the philosophy of science could promote the further development of many theoretical discussions in sustainability science on the one hand, while on the other, collaborative efforts could help to focus philosophical work on specific issues in the field. Collaborative efforts such as these have been endorsed by several academic units, including the School of Sustainability at Arizona State University, the Helsinki Institute of Sustainability Science at the University of Helsinki, and Purdue University's Center for the Environment, all of which have hired philosophers of science (including some of us) to collaborate with sustainability scientists.

In the following we identify three salient areas in which philosophers of science can readily facilitate theoretical, methodological, and ethical progress in sustainability science: (1) epistemological issues, (2) conceptual questions, and (3) the role of values. What we offer under these headings, however, is by no means an exhaustive or comprehensive account of all the ways in which philosophers could contribute to tackling the problems of sustainability science.[2] We merely provide a sample selected to illustrate the general potential for such contributions. Our objective is to initiate a mutually enriching conversation between philosophers of science and sustainability scientists, thus responding to recent calls from the latter for more inclusive

[2] For example, ontology is a salient area of sustainability science to which philosophers can contribute but we do not discuss it in this paper (but see Section 4 below). In fact, recent debates on *process ontologies* in sustainability science (e.g. Hertz et al. 2020) draw heavily on the philosophy of biology (Nicholson and Dupré 2018). Social ontology is also relevant to sustainability science, in particular the *performative* and *constructive* functions of scientific models at the science-policy interface, as well as in the co-production of knowledge and governance, which philosophers and sociologists of science have discussed in some detail (MacKenzie et al. 2007; Zeiss and Van Egmond 2010 and references therein).

engagement with the humanities and social sciences (e.g. Hulme 2011; Jetzkowitz et al. 2018; Laplane et al. 2019; Díaz-Reviriego 2019).

2 What is Sustainability Science?

Given that neither the outer boundary nor the inner core of sustainability science has completely settled or solidified, we do not wish to impose any definitions on developing practices. However, it would be useful to give a broad characterization of the field to focus our discussion. Sustainability has a long and varied intellectual history (Caradonna 2014). Sustainability *science*, on the other hand, grew out of the concerns—most famously expressed in the 1987 World Commission on Environment and Development report *Our Common Future* (Brundtland, 1987)—with tensions between balancing the needs of present generations with those of future generations without disrupting the life-support system of the planet (Shahadu, 2016). As a proper field, it emerged only in the early 2000s (Bettencourt & Kaur, 2011; see also Kates et al. 2001; Clark and Dickson 2003; Komiyama and Takeuchi 2006). Kates et al. (2001) is a starting point of sorts, and was perhaps the first attempt at giving the field both a name and a more tangible direction.

From early on, sustainability science has been characterized as a field devoted to studying—and ultimately transforming—the way human societies interact with and depend upon the natural environment (Kates et al. 2001; Kates 2011; Komiyama and Takeuchi 2006; Balvanera et al. 2017). Arguably, its roots lie in ecological economics, which focuses on integrative theorizing of human-nature or economy-ecology relationships (Costanza 2019) and has been defined broadly as "the science and management of sustainability" (Costanza 1991).[3] Although ecological economics has much in common with sustainability science, it is the latter that has made an unequivocal turn toward participatory democratic processes in knowledge production, notably inter- and trans-disciplinarity, participatory experimentation, and practice-based research (Norström et al. 2020).

Two themes of sustainability science have persisted in the course of its development, although the emphasis has changed over time. The first theme concerns the dynamics of complex systems, the epistemological limitations and constraints such systems impose, and the wider implications for both science and practical decision-making (Kates et al. 2001; Clark et al. 2016; Ostrom 2007). Early attempts at characterizing the field, such as Kates et al. (2001) (see also Kates 2011; Kates 2012), emphasize the need for better models and modelling approaches to handle the complexity of targeted human-natural systems. This has changed, to some extent, to focus on 'genuine'—or at least more pluralistic—interdisciplinarity, and finding the means for making sustainability science a more inclusive project that incorporates the social sciences and the humanities to a greater extent (Ness 2013; Isgren et al. 2017; Jerneck and Olsson 2020).

The second theme concerns the role of transformation and (social) change, and the role sustainability scientists should play in their promotion. Sustainability science needs to be tightly coupled to decision- and policy-making processes, rather than being merely "curiosity-driven" (Spangenberg 2011; Clark and Dickson 2003). Although, broadly speaking, the centrality of this aim has been recognized from the beginning (Kates et al. 2001), many alternative ways of framing the concept have been proposed. Sustainability science has thus been thought of as a *problem*- or *solution*-oriented science (Clark 2007; Miller et al. 2014; Jerneck and Olsson 2020)

[3] The International Society for Ecological Economics published the inaugural issue of the journal *Ecological Economics* in 1989.

focused on the *usefulness* of the knowledge it produces (Clark et al. 2016), an *applied science* (Ostrom et al. 2007), an *action-oriented* science (Spangenberg 2011; Cash et al. 2003; Fazey et al. 2018), and a *transdisciplinary* venture (Huutoniemi and Tapio 2014; Lang et al. 2012; Wiek et al. 2012) that achieves transformation through the deep involvement of stakeholders and relevant constituencies in the research process.

These two themes are subject to considerable discussion and engagement within sustainability science, and they touch a range of concerns—methodological, epistemological, practical, and conceptual—that are fundamentally philosophical in nature. This motivates and provides an opportunity for deeper engagement and exchange between the two fields. In what follows we outline three main areas in which we see particular opportunities for such exchange. They are: (1) epistemological issues, including methodology, inter- and transdisciplinarity, and the science-policy interface, (2) conceptual work and analysis, and (3) normativity and values in sustainability science.

3 Epistemological Issues: Methodology, Inter- and Transdisciplinarity, and Science Policy

Epistemology in general concerns the justification and truth of beliefs. The philosophy of science focuses principally on *scientific* knowledge, but including the *processes and conditions* of knowledge production and application. The latter range from specific research methods, relations between scientific disciplines, and broader contexts in which science as an activity takes place. In this section we discuss these matters in turn.

Rethinking the Scope and Character of Methodologies in Sustainability Science: Sustainability scientists have recently started discussing a range of methodological issues, including the transferability of case-based transdisciplinary knowledge (Adler et al. 2018), the taxonomy of experimentation (Caniglia et al. 2017), evidence synthesis (Livoreil et al. 2017), and the synthesis of scientific and non-scientific knowledge such as indigeneous knowledge (Tengö et al. 2017). These all revolve around the question of how to produce knowledge that is both epistemically reliable and practically usable. Philosophers of science have been working on these methodological questions for decades, scrutinizing scientific methods of theorizing, modelling, and evidential reasoning. Contemporary philosophers of science typically approach these problems by analyzing well-documented cases or episodes from mature disciplines such as biology, economics, and cognitive science, attempting thereby to extract some general methodological lessons. On the other hand, sustainability scientists face an urgent need to develop some frameworks or heuristics to organize and guide heterogeneous practices in their own field. As a result, typological and taxonomical frameworks proliferate, often with no critical examination or justification of how they generate reliable and usable knowledge. With this unique situation in mind, we suggest that the philosophy of science could complement efforts to develop the methodology of sustainability science. Sustainability scientists are already drawing on the philosophical literature: Adler et al. (2018) cite Cartwright (2012) and Cartwright and Hardie (2012) to argue against taking randomized controlled trials as the gold standard for producing evidence for public policy, for example, whereas Caniglia et al. (2017) cite Mitchell (2009) to argue against context- and value-free ideals of science. However, such contributions could be more substantial and constructive.

To give an example, Adler et al.’s (2018) case for analogical reasoning could be further developed by building on existing methodological debates on external validity and extrapolation. Adler et al. propose using argument by analogy as a means of transferring substantive knowledge from one transdisciplinary study to another. It is therefore crucial to understand whether or not two contexts are similar enough to warrant analogical reasoning, but how can one be confident that the original context and the new contexts are similar enough in relevant ways? If one already knew this, would it not make the knowledge transfer redundant? This problem, *the extrapolator's circle* (Steel 2008), has been extensively discussed in the philosophical literature. Of the several methodological solutions that have been put forward, the most notable are *comparative process-tracing* (Steel 2008) and *analogical reasoning* (Guala 2005; 2010; Steel 2010). Both accounts explicitly formulate inferential strategies for operationalizing 'relevant similarities' to make extrapolation more reliable, and therefore could be usefully applied in the context of extrapolation in sustainability science (see e.g. Parker 2010 for climate science). Similarly, one could enrich Caniglia et al.'s (2017) case for value-laden and context-dependent sustainability science by engaging with the philosophical literature on values in science (see Section 5 below). Such examples also provide an opportunity for philosophers to test and develop their analytical tools against some of the unique methodological challenges that sustainability science poses.

Interdisciplinarity and Transdisciplinarity: Interdisciplinary and transdisciplinary (ID/TD) modes of scientific research are widely embraced as the *modus operandi* of sustainability science. Although there is some disagreement and inconsistency with regard to how the concepts of transdisciplinary and interdisciplinary research are and should be formulated, many scholars, funding agencies and others have settled on defining the latter as *integrative* problem-solving across university disciplines (Lattuca, 2001). Integration is not operationally defined in the literature, but it is understood as a process of combining methodologies or practices through which novel synthesized approaches would emerge (see Huutoniemi et al. 2010). Current disciplines, it is claimed, do not in themselves have effective methodologies for resolving sustainability problems. There is thus a need for methodological innovations that transgress current epistemic standards and norms within disciplines, and thereby force disciplines to aim toward specific, problem-driven targets. This point serves to rationalize the need for problem-solving contexts in order to have effective ID. Simply combining methodologies, or applying them independently in the context of a joint research project, is usually considered a form of "mere" *multidisciplinarity*, which is deemed less effective and efficient than ID in terms of achieving satisfactory solutions (but see Mennes, 2019).

Transdisciplinarity is usually treated as a variation of interdisciplinarity, requiring that integrative interactions further include extra-academic stakeholders (Jahn et al. 2012; Pohl et al, 2011). As such, the relevant problem-context is better able to represent the interests and knowledge of stakeholders in the problem, helping the scientific process to devise more robust solutions. The literature on sustainability science has contributed substantially to the development and advocacy of transdisciplinary research, including as a means of handling so-called "wicked problems" (Bernstein 2015).

In our view, although plenty of research has been carried out to create strategies and plans for doing ID/TD (see Lang et al., 2012) or parsing these concepts in terms of taxonomies (Klein, 2010), some of the basic underlying motivations have yet to be properly articulated or tested. Why, for instance, is cross-border collaboration such a preferred means for implementing ID, particularly given that much effective interdisciplinary innovation has come about without strict collaboration (see e.g. Harman and Dietrich, 2013)? Arguably, ecological economics is a case in point of innovative benefits not being bound collaboratively to economists or traditional economics. Indeed many positions behind the contemporary enthusiasm for both ID and TD, in the science studies and elsewhere, seem to reflect views that are not strictly based on epistemological argument—having a principally political or ideological dimension (Godin 1998; Jacobs 2012)—and/or are not sufficiently justified in epistemological terms. More specifically, they are not justified with respect to the constraints under which effective science happens. Such views promote speculative optimism about the potential of these integrative forms of ID and TD, which has not been borne out in practice to the desired extent (see Yegros-Yegros et al., 2015). Some of us have studied the epistemological and cognitive issues that arise in interactions between disciplines, and the ways in which the disciplinary structure of science drives the development of interdisciplinarity and transdisciplinarity in practice (MacLeod and Nagatsu, 2016, 2018; MacLeod 2018; Thorén and Persson 2013; Thorén and Breian 2016; Persson et al. 2018; Koskinen & Mäki, 2016). These critical analyses ultimately bolster enthusiasm for ID/TD work by providing a methodological reality check, as it were, moving beyond speculative optimism and improving efficiency. Specifically, they should complement ID/TD typologies in sustainability science (Lang et al. 2012; Brandt et al. 2013), giving them a better grounding in practice.

Two issues stand out in this regard. First, the discipline-free ideal championed by some proponents of transdisciplinarity in sustainability science (Frodeman, 2013; Spangenberg, 2011), which is often founded on a general commitment to the methodology of systems dynamics, underestimates the role that disciplinary knowledge and methods should play. It is not clear why a discipline-free conceptualization is ideal, or how it can produce outcomes superior to a multidisciplinary or interdisciplinary model (Mäki, 2016). Moreover, given that much current empirical work evolves from formal modelling frameworks developed in established disciplines (rather than, say, systems dynamics models), the discipline-free conceptualization of transdisciplinarity seems out of step with how it is commonly practiced.

This leads to the second issue, namely the relationship between natural and social science (Philipson et al. 2009). Many sustainability scientists consider it critical to overcome the obstacles generated by the different aims, concepts, norms, and methods that characterize these two broad fields. Indeed, some have argued that bringing the natural and social sciences together is a necessary precondition for their success (Jerneck et al. 2011; Kates et al. 2001). This applies to very general differences such as that between the goals of interpretation guiding some social sciences and the goals of explanation and prediction guiding natural science, as well as to more specific differences such as those between economics and ecology. Various philosophers have investigated the background assumptions and conceptual and methodological inconsistencies that inhibit efficient interaction across these disciplinary boundaries, such as different conceptions of “natural” and “artificial” (DesRoches et al. 2019; Inkpen and DesRoches 2019; Inkpen and DesRoches forthcoming), and diagnosing such impediments is at least a first step toward overcoming them. Others have identified methodological options for integrating data and concepts across boundaries into formal models such as Bayesian Belief Network methods, and these methods can be collected and evaluated in terms of their capacities to do so (MacLeod and Nagatsu, 2018).

If observations such as these are taken into account, the hope is that philosophers, in combination with others concerned with sustainability, might help to fashion more pragmatic approaches to ID and TD that are grounded in the affordances and constraints of existing methodologies and practices. This, in turn, could foster the formulation of norms and policies that incentivize such approaches. For example, model-coupling across disciplinary boundaries may not achieve fully optimal solutions to sustainability problems given the extent to which the coupled models rely on disciplinary legacy models. However, it does offer the potential for complex accounts of coupled human and natural systems to be brought to bear on difficult sustainability problems. Making such couplings function well is a substantial computational and mathematical problem, which demands its own theoretical work (Voinov and Shugart, 2013). In contrast to most expectations of ID or TD, however, this work is primarily theoretical and does not directly concern a specific sustainability problem. Nevertheless, it is inherently interdisciplinary, and arguably should be a target of funding policy.

Social epistemology and science policy: As noted above, sustainability and other societal problems have been strong drivers of recent policy trends toward funding problem-driven, interdisciplinary research. In turn, sustainability science has greatly benefited from these recent policy trends. However, one needs to ask whether this makes sustainability science not only more profitable for those who obtain the grants, but also better as a scientific enterprise from the epistemic and practical perspectives. Evidence to this effect is surprisingly scarce. Meanwhile, some authors point out the negative unintended consequences of policy shifts toward inter- and transdisciplinarity (e.g. Ash 2019), and there is suspicion amongst some scientists that interdisciplinarity produces lower-quality outcomes (Leahey et al., 2017). It is not yet known how these policy trends affect the reliability and relevance of the knowledge produced in the long run. Philosophers of science have long recognized that the quality of scientific knowledge depends not only on individual geniuses but also on the social conditions under which science is practiced. *Social epistemology* is an approach in philosophy that focuses on the normative study of the social dimensions of scientific knowledge and practice,[4] and on the ways interactions between individuals and groups in scientific communities affect the reliability of knowledge thus produced (Longino 1990; Kitcher 1993). These epistemic agents collaborate to find truths, but they also compete for scarce resources such as fame, funding, and tenure. Their choices and actions are restricted by rules and practices. Accordingly, by tinkering with institutional variables, science policy could have a substantial impact on the focus and outcomes of science. In recent years, too, philosophers of science have increasingly started to pay attention not only to the social but also to the *institutional* dimension of scientific knowledge production. This has resulted in normative work on how various institutional changes and incentives affect scientific results, for example, and on the epistemic risks that arise from different funding incentives (cf. Reiss and Kitcher 2009; Turner 2019).

The perspective of social epistemology raises several questions in sustainability science, some of which relate to the epistemic quality of the research. For example, how does an emphasis on the practical impact (e.g. solution-orientation, work with extra-academic partners) affect the reliability of the produced knowledge? Is there a trade-off between the immediate gain of applicable knowledge and the long-term development of general theoretical knowledge, which might turn out to be valuable later in unexpected domains (e.g. evolutionary game theory)? How does the demand for interdisciplinary collaboration affect the reliability of traditional disciplinary norms and standards? How do we strike a practical balance when there are trade-offs between ethical demands such as inclusiveness, and epistemic demands such as predictive accuracy? Other questions concern the future of the field. Currently, for instance, sustainability

[4] Normativity in this context concerns both how best to arrange social conditions for robust knowledge (normative epistemology), and how to ethically evaluate certain knowledge practice in terms of justice, equity, and so on (normative ethics). We focus mainly on the former in this section.

science seems to benefit from the trends in science policy , but it is known that policy trends change. What happens to sustainability science and the momentum toward methodological standardization when sustainability loses its political appeal as an organizational principle for science policy? What are the risks in allowing science policy to determine a discipline's course instead of letting it evolve according to more endogenous factors? These are some of the most pressing questions of social epistemology that sustainability science needs to address if it is to outlive current policy trends and develop into a mature, epistemically successful field.

4 Conceptual work for Sustainability Science

Scrutinizing the meanings and uses of scientific concepts is a standard, traditional activity in the philosophy of science. This includes analyzing general concepts discussed above, such as *theory*, *model*, or *evidence*, in an epistemological context , as well as those associated with specific disciplines such as *species* or *gene* in biology, *symmetry* in physics, and *preference* in economics. Within cognitive science, even the concept of *concept* has been analyzed extensively. Meanwhile, sustainability scientists draw on abstract concepts from a wide range of disciplines, and develop and deploy them in new and different contexts in which they may well carry different meanings and implications. As a result, notions such as *adaptive capacity*, *social ecological system*, *complex adaptive system*, *self-organization*, *Anthropocene*, *ecosystem services*, *vulnerability*, *adaptation*, *complexity* and *resilience*—to name a few—all qualify as potentially benefiting from philosophical analysis. There are several reasons to assume that such a venture could be of use within sustainability science.

To begin with, sometimes there is a need to develop better, more consistent or precise definitions. This is especially true in specific situations and technical contexts, and is particularly relevant to sustainability science in which concepts and terms from different disciplines frequently intersect. Among the major issues requiring conceptual clarity are the ontological, in other words basic questions about what exists. The concept of *resilience* is a case in point. As a notion it has been used in a range of disciplines, and draws from current usage in ecology, psychology, and economics (Thorén 2014; Thorén 2020). Ontological subtleties have practical implications in the present context. What does it mean for a complex adaptive system to persist through time? How can one distinguish between the adaptation of a system and the transformation of one system into another? Conceptual clarity in such matters is crucial for operationalizing phenomena effectively, generalizing results, and extracting the correct empirical implications from abstract theories and models.

Nevertheless, precise definitions providing necessary and sufficient conditions are not always desirable (Strunz 2012; see also Thorén 2014; Brandt and Jax 2007). In the context of moral psychology, for example, Stich (2018) recently argued that the concept of *morality* did not pick out a natural kind and that, as a result, decades of work attempting to define "morality" in a principled way had been a waste of time. Others point out that concepts such as resilience and ecosystem services are *boundary objects* (Brandt and Jax 2007; Abson et al. 2014)—that is to say, concepts that are rigid enough to maintain identity across sites whilst at the same time being sufficiently flexible to accommodate local needs (Star and Griesemer, 1989), thus better serving interdisciplinary ends. Sustainability in itself is frequently described as something like a "discursive field" (Caradonna 2014) in which the lack of a precise and commonly agreed upon definition is neither avoidable nor reason to be dismissive of the notion itself. Thus, determining when concepts do require principled definitions and when they do not may well be a difficult conceptual problem in its own right, and one that philosophers are directly trained to address.

Moreover, it seems that there is a wealth of *thick evaluative concepts* in the domain of sustainability, in which normative and descriptive elements are inextricably intertwined (Putnam 2002, Williams 1985, cf. Gallie 1956). Questions regarding *values*—as we discuss in the next section—thus become unavoidable, despite the fact that they might fall beyond the scope of science. Alternatively, concepts may play other extra-scientific roles such as *motivating* sustainable behavior rather than explaining it. All these issues nevertheless fall under the heading of conceptual analysis, as we understand it, further illustrating the fruitfulness of thinking about concepts in a thorough and rigorous way.

Third, and perhaps most importantly, conceptual analysis can increase the efficiency and effectiveness of interdisciplinary work. Many of the most basic concepts addressed in the literature are basic precisely because of their affordance for integration across disciplinary boundaries. The concept *ecosystem services* was proposed to facilitate the integration of economics with ecology, for example, and many have had high hopes that the concept *resilience* will make modelling frameworks of population ecology available to the social sciences (see Abson et al. 2014). Although these concepts do serve to identify certain similarities shared by phenomena across contexts, there is much more to theoretical and methodological integration than the mere identification of similarities. When these concepts are operationalized in different empirical domains it is often hard to determine the explanatory value of the similarities they pick out. For instance, the concept of resilience has been applied to many different types of systems, yielding notions of ecological resilience, social-ecological resilience, community resilience, and psychological resilience—to mention just a few (see e.g. Berkes et al 2013; Thorén 2014; Fraccascia et al. 2018). However, the causal mechanisms that *explain* resilience in these domains are radically different, hence it is far from clear how describing them all as resilient enhances explanatory or predictive power. Genuine integration requires detailed analysis of the concepts being integrated, which is sufficient to connect abstract similarities with the concrete observations that need to be explained and predicted.

Finally, given the practical focus of sustainability science, it is necessary for conceptual work to facilitate the *application* of scientific knowledge, in addition to its production. The importance of such applications is evidenced in the growing attention given to “green nudges” in recent years (Schubert 2017). However, much of this attention is focused on ethical value rather than the ways in which scientific knowledge can be applied in executing green nudges effectively. Ethical work is not necessarily conceptual in the sense emphasized here. Davis et al. (2018), in contrast, drawing on the literature concerning the evolution of social norms and cooperation, develop the concept of *normative motivation*, which they use to argue that interventions designed to promote sustainable behavior have overlooked a crucial source of motivation. Existing interventions focus almost entirely on individuals' *instrumental* motivation to adopt sustainable behavior—desires based on instrumental means for achieving other goals such as reducing taxes or avoiding fines. Yet humans also possess an innate and universal capacity to internalize norms, or to acquire the *intrinsic* motivation to do what is right and to avoid what is wrong, regardless of the instrumental costs and benefits. Because such motives evolved precisely to perform the function of producing costly, prosocial cooperation, they are at the same time independent of motives of self-interest and therefore potentially very powerful. Moreover, in that particular normative motivations are transmitted culturally through social learning, they have the potential to spread rapidly and to be maintained at equilibrium in populations by the natural dynamics of cultural evolution, without requiring governments to pay the costs of monitoring and regulation. This illustrates how conceptual work within the social sciences could promote the application of scientific knowledge to the practical goals of sustainability.

We thus envisage conceptual work not only as the disambiguation and refinement of definitions—although this is sometimes important—but also as the development of new concepts, and the transfer of "old" concepts into "new" domains across disciplinary boundaries (experimental philosophers have begun this inquiry, see Robinson et al. 2019). This may well require sensitivity to and knowledge of the historical development of the science, in addition to familiarity with current meanings, uses and applications across a variety of contexts. We take such work to be its own form of interdisciplinary endeavor, in which methods and skills from the humanities are deployed in the service of sustainability science.

5 Normativity and Values in Sustainability Science

No sustainability scientist would assert that the field operates independently of values.[5] On the contrary, it is, and ought to be, replete with value judgements. Wiek et al. (2011) argue that sustainability scientists should be trained to be "normatively competent," in order to develop interventions that make the world a better—more sustainable—place. Normative competence is commonly defined as "the ability to collectively map, specify, apply, reconcile, and negotiate sustainability values, principles, goals, and targets. This capacity enables, first, to collectively assess the (un-)sustainability of current and/or future states of social-ecological systems and, second, to collectively create and craft sustainability visions for these systems. This capacity is

[5] We follow the standard categorization of values as *epistemic* and *non-epistemic* in the philosophy of science. The former concerns what you value in knowledge (empirical accuracy, generality, etc.); the latter concerns everything else. This conventional categorization is not meant to implicitly value knowledge more than other things we care about, but it is a useful way to organize thoughts when talking about values in the context of an enterprise (viz., science) that is fundamentally oriented toward epistemic goals.

based on acquired normative knowledge including concepts of justice, equity, social-ecological integrity, and ethics" (Wiek et al. 2011, 209). If sustainability scientists are encouraged to become normatively competent, certain value judgments are *explicitly* and *systematically* integrated into the field even if they disagree on the exact nature and role of such judgements in specific contexts.

Arguably, value commitments and a strong sense of urgency to resolve pressing environmental problems serve as the ultimate motivation of most sustainability scientists. They insist that values not only guide their decisions about which research projects to pursue, but also may legitimately influence some scientific inferences. For example, when the stakes are high and the consequences of being incorrect are severe or catastrophic, it seems that (non-epistemic) ethical values *should* influence (epistemic) decisions about what counts as sufficient evidence for accepting scientific claims. However, the putative roles of such values in science raise serious questions about scientific objectivity (Nelson and Vucetich, 2012; Henrichs *et al.* 2016). The standard, value-free ideal of science insists that ethical values and justice should have *no* influence over the reasoning of scientists, whose concerns should be restricted solely to epistemic values such as explanatory power and empirical accuracy, particularly when it comes to hypothesis testing (Douglas 2009). In the face of these well-documented worries, sustainability science will need a compelling story that explains why such non-epistemic values are scientifically legitimate.

Consider, for example, the hypothesis that Equilibrium Climate Sensitivity (ECS) is between 1.5 °C and 4.5°C. Accepting or rejecting this hypothesis would have significant consequences for practical action and, therefore, one might suppose that the decisions to accept or reject it should depend in part on ethical value judgements that concern the wider social implications and risks of making an error. This is known among philosophers of science as the argument from inductive risk, which consists of three propositions: (1) One central aim of scientific inference is to decide whether to accept or reject hypotheses; (2) Decisions about whether to accept or reject a scientific hypothesis can have implications for practical action, and when this happens, acceptance decisions should depend in part on non-epistemic value judgements about the costs of error; (3) Therefore, non-epistemic values can legitimately influence scientific inference (Douglas 2009; Steel 2015).

In fact, the extent to which science is and ought to be free of non-epistemic values is hotly disputed (see Longino 1990; Brown 2013; Douglas 2013; Elliott and McKaughan 2014; Steel 2015; Winsberg 2018). Without defending a particular form of the argument from inductive risk, our point is simply to insist that it is crucial for the success of sustainability science (i) to justify how some values, including the ethical values of sustainability scientists, may legitimately enter into science, and (ii) to design methods and institutions capable of countering the problematic biases that values might produce (see Longino, 1990; Brown, 2013; Douglas, 2013; Elliott and McKaughan, 2014; Steel 2015).

Another way in which non-epistemic values enter sustainability science is through the choice of management or decision-making models. The growing use of formal decision-support modelling frameworks (e.g. Bayesian network analysis methods; multi-criteria decision analysis methods; integrated assessment modelling) (see Benson and Stephenson, 2018) raises important questions regarding the trade-off between epistemic and ethical values (Vezér et al. 2018). Although the propagation and standardization of a relatively small number of modelling frameworks or templates have the methodological advantage of facilitating theoretical work and model development (Humphreys, 2004; MacLeod and Nagatsu, 2018), relying on the same set of models could also embed assumptions that bias outcomes and undermine reliability (Wimsatt, 2007). Analogously, focusing on the same set of management models could produce ethical biases, implicitly prioritizing some values over others, often for epistemic reasons, without sufficient ethical justification. As such, decision-making models may face a trade-off between epistemic values (such as operationalizability, computability, and rigor) and the inclusion of relevant ethical values. Philosophers' model-focused analysis, as well as case studies conducted by science and technology scholars (e.g. Zeiss and Van Egmond 2014) could enhance understanding of how such trade-offs figure in practice.

Although distinguishing between epistemic and non-epistemic (including ethical) values may be very difficult in concrete cases (Schneider et al. 2019), it has significant merit in terms of illuminating different aspects of normative orientation. An additional challenge related to analytic engagement with norms and values concerns the practice of sustainability science: given the complex collaborations involving diverse experts and multiple stakeholders, values are applied in pluralistic ways that may well be implicit and mutually conflicting. Although exposing implicit values and negotiating among them remains an essential task in sustainability research (Fazey et al 2018), the last few decades have witnessed a proliferation of tailored ethical approaches (such as bioethics and indigenous studies), which although not always compatible, have often guided the scientific outcomes of inter- and transdisciplinary collaboration in the field. Unlike traditional philosophers of science, who are overwhelmingly concerned with keeping illegitimate non-epistemic values out of science, sustainability scientists openly accept them but have not, in general, addressed the issue of illegitimate non-epistemic values. In practice, sustainability scientists acknowledge the distinction between the variety of non-epistemic values held by the (i) actors or stakeholders involved, (ii) sustainability scholars and scientists, and (iii) on-the-ground decision-makers, although the roles of these non-epistemic values in sustainability research tend to be discussed only in vague terms (Horcea-Milcu et al. 2019). The resulting “messy” ethical frameworks have sometimes contributed to unclear scientific outcomes, making it difficult to align research approaches and to transfer or extrapolate results from case studies to wider research areas (Luederitz 2016; Adler et al. 2018). As mentioned above with regard to conceptual analysis, dissecting which specific values are in play and how values enter into sustainability science requires detailed attention to how epistemic and ethical values are embedded in concrete scientific practices.

Consider, for example, research on sustainable food systems: there is a highly polarized debate between agricultural intensification, focusing on increased efficiency in food production, and agro-ecology, focusing on paradigm change in the design and governance of food systems. Although both sides are committed to sustainability, their scientific approaches diverge because of mutually incompatible systems of values: increasing efficiency of the current system vs. a fundamental re-designing (Clapp, 2018). Implicit and complex value commitments of this kind are present in the day-to-day research of sustainability scientists, and traditional frameworks of ethical assessment are insufficient in terms of exposing them. Making such value commitments explicit may require alternative ethical frameworks that are specific to sustainability science, with its value-laden contexts dominated by complexity and urgency (Whitbeck, 2011; Stojanovic, 2019). These frameworks must be able to explicate the practical, ethical, and epistemic value judgements embedded in research practices, and suggest ways to integrate them in a transparent and accessible way.

6 Conclusion

Sustainability science is stepping into novel territory in its effort to achieve practical scientific outcomes in highly complex and context-rich problem-solving environments. This territory is not a complete *terra incognita*, however, in that one can consult various maps developed in the philosophy of science and its neighboring fields that have examined a wide range of diverse scientific practices, both historical and contemporary. In this overview article we have briefly sketched three key areas in which these prior insights may contribute to the development of sustainability science. The first concerns epistemology and methodology: we illustrate how the production of reliable and usable knowledge is supported by the analysis of (a) inferential strategies such as analogical reasoning, (b) new practices such as inter- and transdisciplinary research, and (c) social and institutional conditions such as science policy that incentivize new research practices. The second concerns conceptual issues: we illustrate how philosophical analysis can (a) make key concepts in sustainability science clear and precise, (b) identify the functions of necessarily ambiguous and thick evaluative concepts, and (c) develop new concepts that are useful for applying sustainability science to the practical goals of sustainability. The third area concerns normative and ethical issues, and we highlight the importance of (a) making the role of values in scientific inferences explicit and legitimate, (b) identifying and untangling tensions between epistemic and ethical values, and (c) developing context-specific ethical frameworks for complex and urgent decision-making.

This sampling of issues reflects the authors' areas of expertise, and it is not meant to be an exhaustive list of ways in which the philosophy of science, let alone philosophy in general, can contribute to sustainability science. We conclude by reflecting on a few options for further developing a philosophy of sustainability science that sustainability scientists might recognize as relevant and useful. First, and most obviously, more philosophers of science should take an interest in sustainability science. Specifically, we need to engage more with its novel and evolving practices such as ID/TD research, experimentation, and action-oriented research with explicit ethical commitments, and to develop relevant tools. Second, and more subtly, these features should be examined critically on epistemic, conceptual and normative grounds, but not as anomalies to some idealized scientific method. Philosophers of social science tell us that it is more productive to directly engage with the unique challenges in studying human behavior, the mind, society and so on than to decide pre-scientifically whether social science can become a 'genuine' science like physics (e.g, Guala 2007). Philosophers interested in sustainability science should adopt a similar, complementary approach (cf. Chang 2004), remaining empirically informed about, and participating in, developments in the field. Third, this requires more constructive interactions between philosophers and sustainability scientists, including joint research as well as critical correspondence.[6] We hope that these thoughts will stimulate productive interactions between the two communities in the future.

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[6] For example, this article was written by philosophers, but it has benefited greatly from critical comments given by anonymous reviewers who are experts in sustainability science.

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