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From basic research to applied solutions: are two approaches to sustainability science emerging?

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Despite its widespread emergence and adoption, sustainability science continues to suffer from definitional ambiguity within the academe. A review of efforts to provide direction and structure to the science reveal a continuum of approaches anchored at either end by differing visions of how the science interfaces with practice (solutions). At one end, basic science of societally defined problems informs decisions about possible solutions and their application. At the other end, applied research directly affects the options available to decision makers. While clear from the literature, we also point to survey data that suggests the dichotomy does not appear to be as apparent in the minds of practitioners.

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Introduction

Despite the widespread emergence of sustainability science, complete with associated journals [1–4] and programs of study [5–8], sustainability *per se* remains surrounded by conceptual ambiguity, even within the research academy at large [9]. In recent years, several efforts to characterize sustainability research using bibliographic analysis have been undertaken [10••,11•,12–16,17•]. These studies reveal that the core concerns of sustainability science are rooted in consideration of the function of the Earth system and ecosystems that enable resource provisioning and other environmental services [12,17•,18], and, in the socioeconomic development and well-being of humankind [17•,19••], including questions of equity [20] and justice [21].

Within this context, various formal and informal assessments and frameworks have emerged worldwide that seek to provide structure and direction to the theory and application of sustainability science. These efforts, we propose, have formed a continuum of characteristics anchored at either end by differing visions of how this science interfaces with practice (solutions), consistent with typology of science (Figure 1). At one end, proposed implicitly and explicitly in various publications [1,3,4,22••], basic science of societally defined problems informs decisions about possible solutions and applications, akin to the Pasteur quadrant of science in Stokes' 1997 formulation[5] [23]. The other end of the spectrum coincides with Edison's quadrant engaged in applied research seeking solutions, often technological in kind, that directly affect the options available for decision makers [24]. This approach has no formal literature proclamation but, we suggest, has emerged in the practice of certain research communities (e.g. [2,24–28,29•,30]).

Is this view of the range of engagement in sustainability/sustainability science, foremost the Pasteur–Edison

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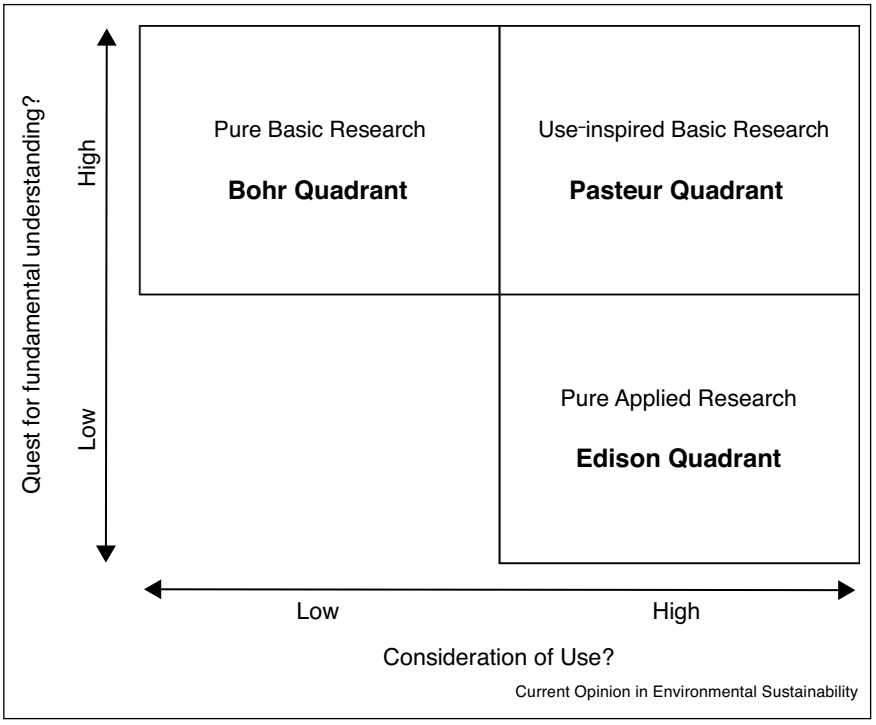
[5] At the end of World War II, Vannevar Bush, the Director of the U.S. Office of Scientific Research and Development during the war, proposed a peace time role for science that was anchored by 'basic research' on the one hand and 'applied research' on the other. Basic research was defined as research performed 'without thought of practical ends.' Applied research, in contrast, was then intended to convert discoveries from basic science into technological innovations to meet 'the full range of society's economic, defense, health, and other needs' [23]. In his 1997 critique, Donald Stokes extended the dichotomy into a two-dimensional spatial grid oriented along two axis, the first: consideration of use, the second: quest for fundamental understanding. Stokes placed Bush's basic research in the low use/high understanding quadrant and labeled it Bohr's quadrant in honor of Niels Bohr, the Nobel Prize winning physicist. He further placed Bush's applied research in the high use/low understanding quadrant and labeled it Edison's quadrant honoring Thomas Edison, the prolific American inventor. Finally, Stokes proposed a third role for science, naming the high use/high understanding quadrant Pasteur's quadrant, in honor of Louis Pasteur, a French biologist, microbiologist and chemist whose work was revolutionary for vaccines, microbial fermentation and pasteurization.

Figure 1



Stokes quadrant for classification of research inspiration.
Modified from Stokes [23].

anchors, accurate? Does it help to capture the state-of-the-art of this emerging field or fields of study and research? We explore these questions through two initial, if incomplete, data sources — a subjective assessment of publications and use of a small-sample practitioner survey.

Assessment of publications

We drew 200 publications from more than 60 journals (Table 1) and books from across a wide range of disciplines contributing to 'the science of sustainability' identified by Bettencourt and Kaur [10••: Fig. 3]. This sample is by no means exhaustive, but captures several broad themes and some of the more highly cited works within the primary sustainability outlets and related journals [14].

This literature reveals to us a set of shared research questions consistent with the sustainability challenge of meeting the needs of humanity while preserving the life support systems of Earth [31]. This framing, in turn, leads to a shared phenomenon of study, social–environmental systems (SES; a.k.a. coupled human–environment systems, coupled human–natural systems, social–ecological systems), although individual research efforts tend to examine only a subset of the components or processes in these systems by way of analyses that vary in their scale dynamics. Conceptually, this literature tends to address such common themes as tradeoffs between subsystems or among components within one subsystem (e.g. [32]); complexity, non-linearity and uncertainty (e.g. [33]); resilience and vulnerability (e.g. [34,35••]); equity and intergenerational wealth in which natural capital is included [36,37]; and, adaptive management (e.g. [38]).

A substantial cohort of the reviewed research focused on basic research of societally defined sustainability problems (Pasteur's quadrant), somewhat akin to the agricultural sciences [20]. These problems are treated as the outcome of interacting processes operating between and within the two subsystems at multiple scalar dimensions (spatio-temporal and hierarchical). Employing mixed methods [39,40] within scientific modes of understanding, the goal is to understand these interactions, or parts of them, sufficiently to project the states of SESs and their consequences into the future [41], thus providing science-based insights for decision-making (e.g. [40,42,43]). It is recognized, however, that complexity of SESs are such that few, if any, sustainability panaceas exist [44,45], reflecting the inherent interdependencies in human–environmental relationships in the Anthropocene [46]. We recognize at least two subgroups among this cohort. The first is an outgrowth of interest in global environmental change but refocused on sustainable development [20,47,48,49•]; the second includes the longstanding efforts addressing environment-development, resource