

What kind of a science is sustainability science?

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Sustainability science, as described by the PNAS website, is "...an emerging field of research dealing with the interactions between natural and social systems, and with how those interactions affect the challenge of sustainability: meeting the needs of present and future generations while substantially reducing poverty and conserving the planet's life support systems." Over the past 7 y, PNAS has published over 300 papers in its unique section on sustainability science and has received and reviewed submissions for many hundreds more. What kind of a science is sustainability science?

The article by Bettencourt and Kaur (1) on the evolution and structure of sustainability science provides one answer. It confirms this characterization of an emerging field of research, plots its extraordinary growth over time, identifies its geographical locations and contributing disciplines, and measures its cohesion as a unified science. As such, it places the PNAS effort in long-term perspective, discovers for sustainability science a very different field structure than for most sciences, and argues for its unification in an exceptional collaborative network.

The authors begin with assembling a huge database of scientific publications in English written between 1974 and 2010 that contain the words "sustainability" and/or "sustainable development" in their title, abstract, or key words. The base contains about 20,000 papers, authored by about 37,000 authors found in 174 countries and in 2,200 cities. The ability to create and analyze very large datasets has opened new possibilities in many fields, as explored in a recent special feature of *Science* (2).

The publications themselves are quite varied, as shown in the word cloud of bigrams (figure S3 in ref. 1 reproduced below as Fig. 1). The database, although surely a major achievement, is probably not equivalent to sustainability science, given the nature of the word search. Researchers in the field might argue that all sustainability science publications should contain integrated research and not include papers that only offer perspectives, frame issues, or advocate policies, and some research articles do not contain the word "sustainability" or "sustainable development."

Plotted against time (figure 1 in ref. 1), sustainability articles grow rapidly beginning in the 1990s and are doubling about every 8 y. However, perhaps the most im-

pressive thing about the very large number of papers and authors is where they were written and the disciplines from which they were drawn. Sustainability science, as represented by the authors' addresses and institutions, is widely distributed and includes many authors beyond the normal concentration in such centers of traditional science as Japan, the United States, and Western Europe. These include almost all the emerging BRICS (Brazil, Russia, India, China, South Africa) economies but also such developing countries as Kenya and Nigeria. Home cities and institutions for papers also differ from traditional centers, with many originating in political centers (e.g., Beijing, Canberra, London, Tokyo, Washington) and in much more varied institutions, including corporate laboratories, government, and non-governmental organizations, as well as universities large and small.

Sustainability science, as reflected in the disciplinary classification of the journals in which the papers were published, is also extraordinarily multidisciplinary, spanning the natural, social, and technological sciences, with a third of the papers appearing in social science journals, a quarter in biological journals, and a fifth in engineering journals. Finally, in the judgment of Bettencourt and Kaur (1), using network analysis of coauthorship, sustainability science unifies around the year 2000, with most scholars and places connected with links of authorship.

Bettencourt (with affiliations in applied mathematics) and Kaur (with affiliations in informatics) are outsiders to sustainability science. Their study of the evolution and structure of sustainability science began as a complement to their other studies of the evolution of new research fields in physics and biology (e.g., cosmic strings, H5N1 influenza, prions, quantum computing) (3). I am a sustainability science insider, having cochaired with William Clark the National Research Council study (4) that was among the early promoters of sustainability science; taken part in a series of international meetings that elicited views on the nature of and needs for sustainability science around the world (5); and, most recently, completed an electronic *Readings in Sustainability Science and Technology* (6). As an insider, I found myself highly stimulated by the study by Bettencourt and Kaur (1), but I can also add some significant dimensions of sustainability science not captured by their bibliometric analysis.

One such dimension is the balance in sustainable development papers between those that emphasize research on environment and those that emphasize research on development. Most insiders I know have backgrounds originally in the environmental sciences, and their research topics often reflect this despite their commitment to a science of both environment and development. In an analysis of titles of 232 research papers in the sustainability section of PNAS, 62% had a major focus on sustaining environmental life support systems, as contrasted with 38% that primarily addressed human well-being and a few that addressed poverty alleviation (7).

Another major dimension in sustainability science is the emergence of academic fields of study in a number of countries with concentrations, majors, and graduate degrees in sustainability science. It is possible to get a doctorate or master's degree in sustainability science, sustainable development, interdisciplinary environmental science/studies with a focus on sustainability, or specific disciplines with programs in sustainability. The Association for the Advancement of Sustainability in Higher Education Web site lists eight doctorate programs and 41 master's degree programs.

The evolution and structure paper also leads me to question one of our insider assumptions as to the relative importance of the international initiatives and publications in launching the field. In our insider story, sustainable development emerged in the early 1980s from scientific perspectives on the interdependence of society and environment (8). It entered the high political agenda through the publication by the Brundtland-led World Commission on Environment and Development (1983–1987) report, *Our Common Future* (9) and the subsequent United Nations Conference on Environment and Development held in Rio de Janeiro in 1992. Although a great political success, many scientists find it difficult both to conceptualize and to measure sustainable development and make it a subject of scientific inquiry. To assist, the US National Academy of

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See companion article on page 19540.

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