Framing the Elusive Concept of Sustainability: A Sustainability Hierarchy

JULIAN D. MARSHALL*
Energy and Resources Group, University of California, Berkeley, California 94720

MICHAEL W. TOFFEL
Haas School of Business, University of California, Berkeley, California 94720

Usage of the word "sustainability" is widespread and incorporates a plethora of meanings. After reviewing four extant sustainability frameworks, we propose a Sustainability Hierarchy to structure a broad array of issues that have been associated with sustainability. These issues vary widely in their urgency, severity and uncertainty of consequences, and temporal and spatial dimensions. It categorizes actions some view as unsustainable based on their direct or indirect potential to (i) endanger the survival of humans; (ii) impair human health, (iii) cause species extinction or violate human rights; or (iv) reduce quality of life or have consequences that are inconsistent with other values, beliefs, or aesthetic preferences. Effects considered include impediments to the ecosystem functions that support human life, human health, and species viability. This paper argues that for sustainability to become a more meaningful concept, the many worthy issues in the fourth category (values, beliefs, and aesthetic preferences) should not be considered sustainability concerns. Implications for companies, policy makers, and scientists are discussed.

Introduction

The 1972 book *The Limits to Growth* (*1*) rekindled a centuries-old debate (*2*) about whether continued industrial growth would result in serious, potentially irreparable harm to humans. Originally framed in terms of famine and overpopulation, much of the debate has turned to the function of ecosystems and the consumption of natural resources. Such concerns, along with the terms "sustainability" and "sustainable development", gained global notoriety in 1992 at the United Nations-sponsored Earth Summit in Rio de Janeiro.

Robust answers to questions such as *what is sustainability?*, *what is a sustainable society?*, and *what is a sustainable organization?* have proved elusive. At the Earth Summit, sustainable development was discussed in the context of a 1987 report by the World Commission on Environment and Development, chaired by Gro Harlem Brundtland. This report defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (*3*). This definition, widely used since, offers the intuitive appeal of the dictionary definition of sustainability, which refers to the capability of maintaining something in existence (*4*).

Some, however, have criticized this definition as being difficult or impossible to operationalize and implement. How should this definition be used to evaluate policy choices or business decisions? To avoid impeding the "ability of future generations to meet their own needs" requires predicting both their needs and their abilities, which in turn requires forecasting their available technologies. The inaccuracy of historical predictions of today's technologies does not paint an encouraging picture of our ability to predict technologies several generations hence. Predicting the needs of future generations also seems a tall task. If we want the world to be a better place for future generations, should they not be able to do more than only meet their needs? Developing a global consensus about future needs and abilities seems particularly unlikely, considering how difficult it is to develop a consensus about the current population's needs and abilities. Absent any practical way of developing a common vision about future generations' needs and abilities, the Brundtland Commission's definition appears unhelpful in evaluating the sustainability implications of current decisions.

The failure of any organization or institution to acquire a legitimate leadership role over the issues discussed at the Earth Summit has resulted in a plethora of organizations offering their own sustainability definitions and metrics (*5*). By the mid-1990s, there were well over 100 definitions of sustainability (*6*). This definitional chaos has nearly rendered the term *sustainability* meaningless and is distracting from the need to address ongoing environmental degradation.

At one extreme, many companies apparently consider sustainability simply a new term for responsible environmental and labor management practices, evidenced by the fact that many of today's "Corporate Sustainability Reports" merely include the same indicators (e.g., energy consumption, waste volumes, worker injuries) that were used in Corporate Environment, Health and Safety reports throughout the 1990s (*7*). The Dow Jones Sustainability Index defines corporate sustainability as "a business approach that creates long-term shareholder value by embracing opportunities and managing risks deriving from economic, environmental and social developments" (*8*). Using this definition, what company does *not* practice corporate sustainability? At the other end of the spectrum, many have suggested that sustainability ought to include a vast, diverse set of goals, such as poverty elimination and fair and transparent governance. Sustainable Measures, a consultancy "dedicated to promoting sustainable communities", suggests "sustainability is related to the quality of life in a community—whether the economic, social and environmental systems that make up the community are providing a healthy, productive, meaningful life for all community residents, present and future" (*9*). They provide hundreds of sustainability indictors, such as the percentage of front-line employees who have attended employer-sponsored training, the average age of commercial fish harvesters, and the percentage of major streets that have sidewalks (*10*). These indicators have little to do with intergenerational equity or future generations' needs and abilities but instead refer to achieving a more desirable community with long-term economic viability.

* Corresponding author phone: (510)642-7394; fax: (206)600-6347; e-mail: julian@socrates.berkeley.edu.

10.1021/es040394k CCC: $30.25
Published on Web 12/22/2004

This practice of applying the label *sustainable* to objects and approaches that are desirable or of value is common. For example, extant strategies for sustainable building design include items such as "provide operable windows", "accommodate persons with differing physical abilities" (*11*), and maximizing the use of daylight (*12*). Products and services that are more environmentally friendly than average, and institutions and organizations that are particularly aware of environmental issues are often labeled as sustainable. For example, Nike refers to their eco-friendly products as "a sustainable shoe" and "a sustainable running singlet" (*13*).

Streets should have sidewalks, and buildings should have wheelchair ramps, but are such design features aspects of sustainability? More environmentally friendly goods and services are desirable, but does that make them or their use sustainable? Will responding to environmental and social developments make companies sustainable? If not, what differentiates sustainable organizations, goods, and services from those that are merely more environmentally friendly than average? What differentiates a sustainability indicator from a quality of life indicator? This article explores these questions.

We aim to contribute to the evolving debate on this elusive topic by providing a framework for categorizing sustainability issues. This paper has five parts. First, we briefly review four extant sustainability frameworks. Second, we present a four-level Sustainability Hierarchy. This hierarchy organizes many sustainability issues we identified in our literature review on this topic. Third, we highlight ecosystem function as a fundamental metric for sustainability. Fourth, we debate whether all four levels of the hierarchy should be considered under the umbrella of sustainability. Finally, we discuss implications of our framework for companies, policy, and scientific research.

Four Extant Sustainability Frameworks

In this section, we describe four leading sustainability frameworks: the Triple Bottom Line, The Natural Step, the Ecological Footprint, and Graedel and Klee's method to calculate sustainable emissions and resource usage. The first framework emphasizes the need to balance economic, social, and ecological goals. The remaining three focus on measuring and reducing damage to the natural assets that provide ecosystem services necessary for human well-being. Rather than defining sustainability explicitly, these four frameworks describe conditions, characteristics, and indicators of sustainability.

The Triple Bottom Line. Advocates of "the triple bottom line" believe that organizations pursuing sustainability ought to make decisions based not only on economic returns but also on environmental protection and social justice. The three elements of the triple bottom line—economic, environmental, and social—can be combined: eco-efficiency refers to optimizing economic and environmental goals; fair trade refers to economic activities conducted with particular attention to social consequences; and environmental justice refers to social equity with respect to environmental protection (*14*). Because these objectives are important to society, advocates argue that companies should consider them in daily decisions. The triple bottom line concept is being adopted by a growing number of multinational companies (*15*–*17*).

Implementing the triple bottom line requires organizations to consider the societal impacts of their actions. Eco-efficiency, fair trade, and environmental justice may each be desirable, but there is no guarantee that these practices, even if implemented by all companies, would lead to sustainability. Critics have argued that "The triple bottom line concept lacks a meaningful foundation. Companies should have other bottom lines beyond profit but they don't stop at three—they should have an ethical bottom line, for example" (*18*). Others have noted that because "it is difficult to find anything that looks like a careful definition of the concept, let alone a methodology or formula (analogous to the calculations on a corporate income statement) for calculating one of the new bottom lines" (*19*). The triple bottom line may in fact be a "good old-fashioned single bottom line plus vague commitments to social and environmental concerns" (*19*).

The Natural Step. The Natural Step defines a sustainable society as one where four conditions are met: "nature is not subject to systematically increasing (1) concentrations of substances extracted from the earth's crust, (2) concentrations of substances produced by society, or (3) degradation by physical means; and, in that society, (4) human needs are met worldwide" (*20*). By this definition, several current trends are unsustainable, including the combustion of fossil fuels, which increases concentrations of atmospheric carbon dioxide; emissions of persistent bioaccumulative chemicals; systematic loss of rainforests and wetlands; and a substantial under-nourished population. Nonprofit organizations have emerged in 10 countries to promote The Natural Step framework and to engage "with companies to transform the way they do business by integrating sustainability principles into their core strategies, decisions, operations—and bottom line" (*21*). Several large companies are exploring how to apply The Natural Step framework to their business strategy and operations (*22*).

The Ecological Footprint. The Ecological Footprint compares the environmental impact of specific actions to the limitations of the earth's natural resources and ecosystem functionality. The Ecological Footprint calculates a ratio of "how many earths" would be required to provide enough biologically productive land area to maintain the flows of resources and wastes, if everyone lived like a specific person or group of people (*23*, *24*). The Ecological Footprint has been implemented across a wide range of units of analysis, including a consumer product (e.g., a personal computer, washing detergent); an individual company; an economic sector; specific regions and nations; and the earth (*25*–*28*). Urban economists have used the Ecological Footprint to evaluate the environmental impacts of commuting in Barcelona, Spain, as a function of transportation technology and residents' locations (*29*). The Ecological Footprint highlights global inequity in resource consumption.

Graedel and Klee's Sustainable Emissions and Resource Usage. Graedel and Klee (*30*) propose a four-step process for determining a sustainable rate of resource use: (i) calculate the available supply of virgin materials (mass); (ii) allocate consumption of this supply over a specific time scale and among the global population (mass per person per year); (iii) account for recycling and for existing stockpiles including landfills and then update the allocated consumption rate; and (iv) consider this rate to be the maximum sustainable consumption rate and compare it to the current usage rate. A time scale of 50 years is employed, based on the argument that a sustainable resource consumption rate must last at least two human reproductive generations, which they assume is 50 years (*30*). Sustainable emission rates are determined in a comparable manner: (i) determine the total annual global anthropogenic emissions of a particular substance that meets a political target or that is below a threshold that would cause permanent environmental change (mass); (ii) divide this total by the current global population and by 50 years to calculate an allocated emission rate (mass per person per year); (iii) account for recycle schemes such as sequestration and then update the allocated emission rate (mass per person per year); and (iv) consider this rate to be the maximum sustainable emission rate and compare it to the current emission rate. These four-step processes include several novel aspects. First, they highlight that assessing

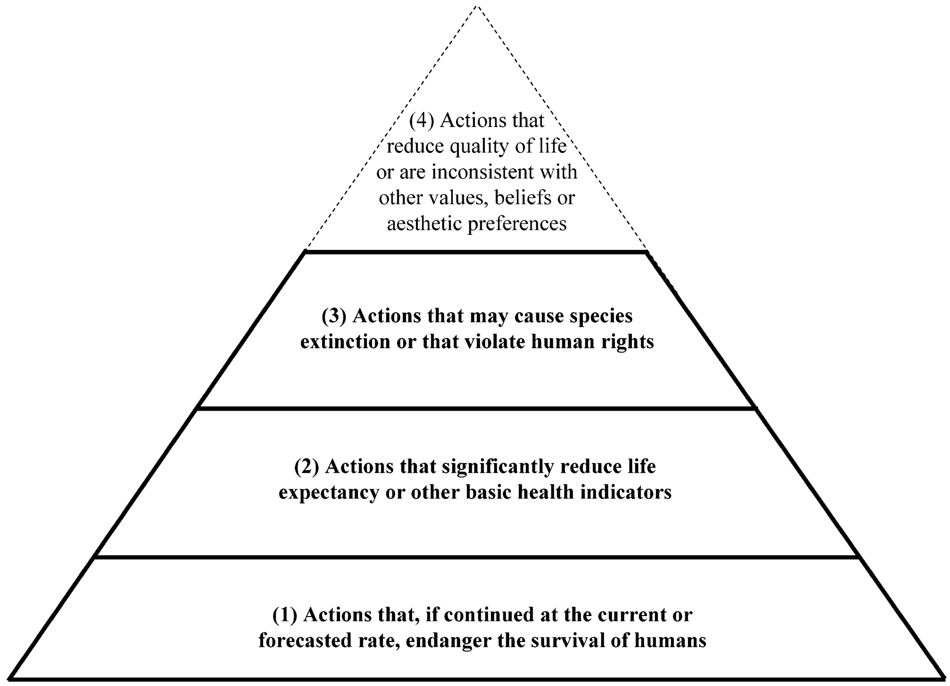

FIGURE 1. Sustainability Hierarchy, with the most basic sustainability needs at the bottom. This hierarchy incorporates ways in which the term "sustainability" is currently used. This paper argues that while level 4 issues are important, they should not be considered within the rubric of sustainability.

whether a consumption or emission rate is sustainable requires specifying an explicit time scale. Second, they suggest that certain rates of non-renewable resource consumption are sustainable. While considering the depletion of a finite resource to be a sustainable action contradicts the dictionary definition of sustainability, it may be consistent with the Brundtland concept if substitutes are identified to satisfy the needs of future generations.

Sustainability Hierarchy

While the Bruntland definition identifies meeting future human needs as the goal of sustainability, the four sustainability frameworks highlighted above are ambiguous with regard to *what* is being sustained. The widespread use of the label "unsustainable" has referred to several distinct but related concepts, which we have categorized as four levels in a Sustainability Hierarchy (Figure 1).

Level 1: Actions that, if continued at the current or forecasted rate, endanger the survival of humans.

Level 2: Actions that significantly reduce life expectancy or other basic health indicators.

Level 3: Actions that may cause species extinction or that violate human rights.

Level 4: Actions that reduce quality of life or are inconsistent with other values, beliefs, or aesthetic preferences.

Each level refers to a broad array of issues with spatial scales ranging from local to global, as discussed below. Levels 1 and 2 cover the survival and basic health of people; level 3 addresses species extinction and human rights; level 4 refers to values not covered elsewhere in the hierarchy, such as the desires for robust ecosystems for recreational use, the preservation of open space for aesthetic reasons, and social justice and equity.

The urgency and severity of a sustainability threat depends on which level is being considered. It also depends on factors such as the likelihood of a certain action leading to adverse consequences, the scope and prevalence of these consequences, and the delay between action and consequences.

Our sustainability hierarchy is analogous to the Hierarchy of Needs described by the psychologist Abraham Maslow. Maslow asserted that humans are motivated by unsatisfied needs and that certain lower needs must be satisfied before higher needs can be (*31*). He ordered five types of needs from basic to sophisticated: (i) physiological (access to air, water, food, sleep, and sex), (ii) safety (security, stability), (iii) belongingness (feeling part of a group), (iv) ego (favorable self-opinion), and (v) self-actualization ("the desire to ... become everything that one is capable of becoming") (*31*). Similarly, basic *environmental* sustainability forms the foundation (level 1) of our sustainability hierarchy, and successive levels refer to increasingly higher-order sustainability needs that incorporate health, quality of life, and value-laden concerns. This structure illustrates that an action can be considered sustainable on one level, while unsustainable at another. Individuals should specify which sustainability level they are considering when labeling an action as sustainable or unsustainable.

With no consensus as to which of these meanings (i.e., the four Hierarchy levels) are appropriate, all are in use. The importance of sustainability is eroded when unsustainable can have such a wide range of meaning, scope, and severity. Among the range of impacts that human activities can have on ecosystems, what level is unsustainable? Which meaning is the most useful or appropriate? Defining sustainability too narrowly would exclude important issues. If sustainability is defined too broadly, it becomes difficult to prioritize among topics or, worse, the term becomes diluted to the point of being meaningless. If sustainability incorporates value-driven issues, as in level 4, then the decision of what actions are unsustainable incorporates personal preferences. In this case, achieving consensus about what constitutes sustainable or unsustainable actions would be challenging within a community and unlikely or impossible across larger settings.

The sustainability hierarchy categorizes various ways sustainability has been used by scholars, policy makers, companies, and NGOs. As we point out in the discussion, there is disagreement about whether all levels of the hierarchy should be considered sustainability issues. Each level of the sustainability hierarchy is described below.

Level 1. The first sustainability level—actions that, if continued at current or forecasted rates, endanger the survival of humans—provides a baseline for sustainability definitions. It incorporates environmental impacts only insofar as they influence products and services provided by the natural environment that benefit humans, such as nature's ability to filter wastes and to provide food, water, and air. This baseline definition of sustainability provides a floor and a useful starting point for understanding sustainability. However, in many situations "merely" ensuring the survival of humans is too narrow and is thus insufficient.

Level 2. Level 2 is a natural extension of level 1. This level considers as unsustainable those actions that significantly reduce life expectancy or other basic health indicators. For example, an action that degrades the stratospheric ozone layer and thus impedes human health (*36, 37*) is unsustainable according to level 2. That global warming may significantly increase the global incidence of infectious diseases (*38*, *39*), such as mosquito-borne tropical diseases (*40*), is a level 2 concern.

Level 3. Level 3 includes activities with two types of significant consequences: species extinction or violations of human rights. Many cultures and religions embrace the preservation of species as a core value. Species preservation is also critical from an anthropocentric, utilitarian perspective. Biodiversity—the preservation of diverse species—offers significant opportunities for new crops and medicine, and may be vital to regenerating oxygen (*41*). "Sheer self-interest impels us to be cautious" (*42*). The U.S. Endangered Species Act of 1973 provides stringent protection for endangered and threatened species and the ecosystems required to support them, even when such protection limits economic development (*43*). Species extinction is a concern shared by over 150 nations that have ratified the 1973 Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), which regulates the global trade in threatened and endangered species and extends protection to over 34 000 plant and animal species (*44*).

Level 3 also includes activities that threaten commonly accepted human rights. Only a few core human values are so basic to the human condition as to be considered level 3 issues; we defer to past global efforts to define such values, such as the United Nations Universal Declaration of Human Rights (*45*). (We consider all other values to be level 4 issues.) Accordingly, the displacement of island cultures and other people living in low-lying areas due to sea level rises accompanying global climate change may be viewed as unsustainable according to level 3. (This example also illustrates that whether an issue is sustainable is context-specific: islander dwellers who are unable to relocate would consider sea level rise unsustainable on level 1.)

Level 4. This level categorizes actions as unsustainable when their consequences are not consistent with values, beliefs, or aesthetic preferences. For example, some label as unsustainable urban sprawl leading to congestion and a lack of preserved open space or long-range air pollution deteriorating visibility in pristine wilderness areas. The fourth system condition of The Natural Step, which calls for equitably meeting human needs worldwide, is an example of avoiding consequences that are not consistent with other values, beliefs, or aesthetic preferences. In seeking to align organizations' actions more closely with societal objectives of environmental protection and social justice, the triple bottom line incorporates values and beliefs. Similarly, when Graedel and Klee (*30*) compare current carbon emissions from inhabitants of various countries with a global average per-capita allocation of the sustainable annual total, they illustrate the extent to which individuals are living beyond or within the average. Equity concerns about shared natural resources (e.g., the initial allotment of credits in a pollution trading scheme) also relates to level 4. Not surprisingly, sustainability definitions that fall within level 4 of the sustainability hierarchy are particularly likely to incur disagreement, in part because they are based on values and beliefs.

Overlap. Real-world issues often span multiple levels of the hierarchy. Many institutions working on sustainability issues seek to simultaneously improve health (level 2) and quality of life (level 3) issues. For example, the United Nations Millennium Development Goals seek to significantly reduce the number of people that lack access to safe drinking water and to "achieve significant improvement in [the] lives of at least 100 million slum dwellers" (*46*). There are important feedback loops between levels 2 and 3. For example, there is growing evidence that climate change threatens the extinction of many species (*47*), and that these extinctions would significantly and detrimentally impact people in developing nations who rely on these species for goods and services such as food, shelter, and medicine (*48*).

Ecosystem Function

Ecosystem function is a general term that describes the activity level of an ecosystem. In our formulation, ecosystem function refers to the goods and services provided by the natural environment that are required to support human life, human health, and species viability. Changes in ecosystem function can indicate changes in the health of the ecosystem. Graedel and Klee (*30*) highlight global ecosystem functions that sustainability should entail: "Holocene-style climate (thermal balance, ocean currents, etc.), functioning planetary ecological systems (wetlands, forests, etc.) ... [and] Earth's organisms". The Ecological Footprint's concern about the amount of bioproductive land necessary to sustain various consumption and waste patterns aligns it with level 1 of the hierarchy. Ecosystem function can be measured locally or globally in several ways, such as biomass per land area, the rate at which an ecosystem uses sunlight to convert atmospheric CO_2 into biomass per land area, diversity of species per land area, or food web complexity. Perturbations to ecosystem function may threaten sustainability. Such perturbations can occur because of consumption beyond regenerative rates or waste emission beyond nature's assimilative capacity, as explained below. Preventing these two scenarios ensures what others have labeled "strong sustainability" (*32*).

Consumption. Consuming resources beyond regenerative rates can impede ecosystem function and eventually lead to ecosystem collapse. The literature on agricultural and resource economics has addressed this concept in terms of sustained yields from fisheries and other natural resources (*33*). The impacts of consumption beyond sustained yields can be direct (e.g., fishing a species to extinction) or indirect (e.g., fishing one species to a declined population level can deplete a food source or predator from an aquatic ecosystem and impact the populations of other species). Because ecosystems and food webs are complex, indirect impacts are often difficult to predict.

Emissions. There is a natural rate at which a substance degrades in an ecosystem. If emissions exceed degradation and removal rates, the concentration increases. Even nutrients that are necessary to the functioning of an ecosystem can cause harm at high concentrations. For example, excess nitrogen or phosphorus can cause algal blooms in lakes and rivers that can deplete dissolved oxygen and release toxicants, thereby impairing the aquatic ecosystem. In an ecosystem whose function is unimpaired, the emission rates of all wastes, including both toxicants and nutrients, are within the

TABLE 1. Comparison of Common Toxicology Principles with Sustainability Principles

issue	toxicology	sustainability
definition is needed, but often a basic definition is too narrow to be useful	legal definition for "toxic" in the United States, which involves the median lethal 24-h dose to albino rabbits, provides a floor that is appropriate only in some situations; often, this floor is too narrow to be useful (e.g., when considering whether an infant chew-toy is "nontoxic")	level 1 of the hierarchy provides a floor; level 1 is appropriate to some situations, but in other situations, it is too narrow to be useful
dose–response relationship	if a small amount of a substance harms an organism, more of the substance is likely to cause more harm to the organism; a large enough amount of any substance can be toxic; "the dose makes the poison"	if a small perturbation reduces ecosystem function, magnifying the same perturbation is likely to reduce ecosystem function further; a large enough perturbation of any type can impede ecosystem function
how much impact is "too much?"	establishing what is an "acceptable" intake of a toxin necessarily requires establishing an acceptable level of harm or risk	establishing what is an "acceptable" ecosystem perturbation requires establishing an acceptable level, time scale, and spatial scale of change to ecosystem function
impacts are meaningful only in a relative sense	influence of a substance on organism function should be assessed on a marginal basis (i.e., comparing the organism's functioning with vs without a substance) and should consider the baseline variability of the organism's function; for example, increased cancer risk must be understood in terms of baseline cancer risk, and a reduction in speed and agility must be understood in terms of an organism's baseline speed and agility	influence of a perturbation on an ecosystem should be assessed on a marginal basis (i.e., consider ecosystem function with vs without a perturbation), and should consider the baseline variability of the ecosystem's function; for example, understanding the influence of a reduction in rainfall rate requires understanding the rate and variability absent the perturbation
robust systems are resilient to a variety of impacts	impact of a toxic substance on an organism's function depends on the resilience and reserves of the organism; organisms may have backup mechanisms to reduce harm caused by some types of damage; for example, if one of two eyes is impeded an organism can still see, and if one set of a duplicated gene is damaged, the backup copy still functions	loss in ecosystem function caused by a perturbation depends on the robustness of the ecosystem; ecosystems have backup mechanisms to reduce the harm caused by some perturbations; for example, plants can store water to get through drought months, and interconnected food webs may offer resilience to perturbations against a few members
predicting impacts can be difficult, owing to system complexity	multiple metabolic pathways exist; organism's response systems interact with each other and depend on multiple environmental factors; mixtures of toxins can cause synergistic reactions	feedback loops are abundant and interconnected; multiple perturbations can cause synergistic reactions

assimilation capacity. The first three system conditions of The Natural Step framework—those that address ecosystem degradation and increasing concentrations of substances—address the need to preserve ecosystem functionality and to limit waste streams to the pace at which natural systems can assimilate them.

Ecosystem Function's Response to Perturbations. What is sustainability sustaining? The first and third levels of the Sustainability Hierarchy highlight the need to sustain ecosystem function. Actions that impair ecosystem function too much are unsustainable, while those that maintain ecosystem function are sustainable. But how much is "too much" depends on the particular circumstance and the level considered. A parallel between perturbations to ecosystem function and toxic effects on human health is instructive (Table 1). Toxicological principles such as dose–response curves, the nonlinearity of threshold effects, and synergistic interactions can inform the sustainability debate. The toxic impact of a dose refers to the extent to which it impairs health. Similarly, the degree to which a perturbation is unsustainable refers to the extent to which it impairs ecosystem function. While the question "how much is too much?" refers to health impairments in the case of toxicity, with sustainability it refers to ecosystem function impairment. In both contexts, the answer is both quantitative and value-laden as discussed next.

Figure 2 shows four archetypal ecosystem responses to a perturbation:

I. Restoration of original ecosystem functionality.

II. Minor loss of original ecosystem functionality.

III. Major loss of original ecosystem functionality.

IV. Total collapse of ecosystem function; ecosystem function declines to zero.

Four values are labeled on the vertical axis in Figure 2: F_0, F_1, F_2, and zero. F_0 is the initial level of ecosystem function. From among the many possible perturbation–response functions that an ecosystem could exhibit, the ecosystem shown in Figure 2 responds according to the following rules. If the perturbation reduces ecosystem function to a point above F_1, as in line I, ecosystem function will fully recover to F_0. An example of line I is harvesting trees from a forest in a manner that enables the ecosystem to return to its previous state. If the perturbation reduces ecosystem function past F_1 but not beyond F_2, as in lines II and III, only partial ecosystem functionality will be restored. An example of these lines is tree harvesting done via clear-cutting techniques that cause soil erosion, coupled with incomplete reforestation. If the perturbation reduces ecosystem function below F_2, as in line IV, ecosystem function will collapse to zero. Examples of this line are acid rain or mining pollution eliminating a stream's fish population, or hunting or destroying habitat that eradicates the local population of a species.

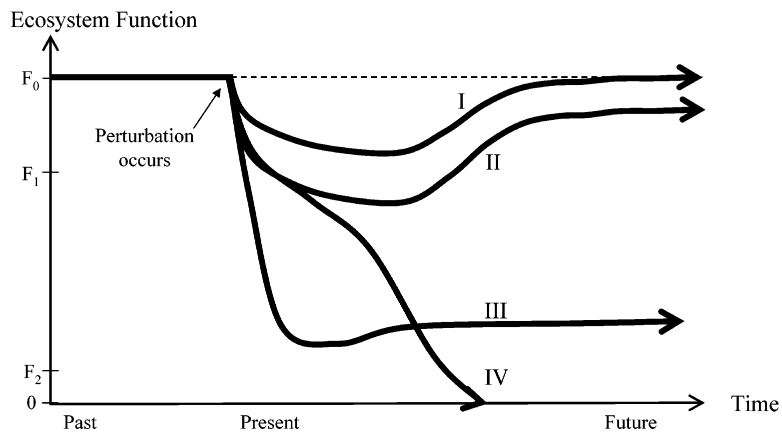

FIGURE 2. Changes over time in ecosystem function from initial level F_0, in response to a perturbation. For line I, ecosystem has fully recovered from the perturbation. Lines II and III dip below F_1, and ecosystem function has partially recovered. Line IV falls below F_2, and ecosystem function does not recover. The system would typically be considered sustainable if the response follows line I and not sustainable if the response follows line IV. If the response is projected to follow lines II or III, the system may or may not be considered sustainable.

Which of the four responses in Figure 2 should be considered sustainable? Those who believe that sustainability is about preserving the current level of ecosystem function would only find line I to be sustainable. Those willing to accept significant loss of ecosystem function might find lines II and III to be acceptable and thus view the perturbation leading to these ecosystem responses to be sustainable. Finally, those with intermediate values might consider a perturbation associated with line II to be sustainable, but a perturbation associated with line III to be unsustainable.

Time Scales. Beyond judgments about how much loss in ecosystem function is acceptable, determining which ecosystem perturbations are sustainable may also depend on the time required for the ecosystem to stabilize and the benchmark employed. Time scales could be important for several reasons. Those who believe sustainability requires rapid restoration of ecosystem function to its original level might not consider line I to be sustainable if ecosystem recovery requires centuries or millennia.

The longer an ecosystem takes to recover, the more likely it is that other perturbations will become important during this recovery period. The ecosystem that follows lines II or III in Figure 2 might not collapse due to the perturbation shown, but it may be more vulnerable to collapse from subsequent perturbations. Conversely, if the ecosystem response to a perturbation is collapse, but this collapse will take several millennia, the perturbation may seem insignificant relative to perturbations that act on shorter time scales. The evaluation of which lines are sustainable may also be influenced by whether technologies currently exist that could restore or improve ecosystem function, and if they do not, how likely one thinks that such technologies will be developed in the future.

Assessing whether an action is sustainable also depends on the benchmark used as the basis of comparison. Consider England's deforestation during the Industrial Revolution. Deforestation happened in degrees, and there was no a priori demarcation indicating when England should have stopped cutting down trees to either preserve the original ecosystem or avoid ecosystem collapse. Now, several generations later, there is little cultural memory of what England's forests were like prior to the Industrial Revolution. To current generations, today's level of forestation in England appears to be an appropriate benchmark against which to assess the sustainability of future actions. Similarly, it is unclear how future generations will view large-scale environmental changes occurring today. Recent evidence that historical land use changes may influence current climate change concerns (*34*, *35*) suggest that extant ecosystem attributes are not necessarily the best benchmark for sustainability metrics. In short, determining whether an action is sustainable depends on the sustainability hierarchy level, temporal duration, and benchmark considered.

Discussion

Actors operating over various spatial scales are responsible for causing and preventing environmental decline. For example, after a few companies developed chemicals that destroy stratospheric ozone, some national governments called for international bans on their production. This required support from political constituencies including companies and individuals who used these products and whose support politicians seek. Similarly, the issue of global climate change involves decisions by individuals (e.g., how much electricity to use, what transportation mode to use for commuting, how large a house to occupy) and companies (e.g., how energy efficient to make their operations, how much to invest to develop alternative energy technologies, whether to purchase electricity generated by renewable energy sources). These decisions are shaped by policies formed by local governments (e.g., zoning affects commuting and shopping distances), regional governments (e.g., how much mass transit to provide, whether to tax fuels and road use), and national governments (e.g., whether to commit to binding emission limits). Transforming unsustainable practices to sustainable ones often requires simultaneous actions by actors at many levels, from individuals to local and national governments to international organizations (*49*).

The sustainability hierarchy in Figure 1 frames and categorizes ways that sustainability has been used in the literature and in public discourse. There is disagreement among scholars about several aspects of the hierarchy. For example, there is not consensus regarding the appropriate unit of analysis, whether it should be products, factories, organizations, urban areas, nations, or the earth. More fundamentally, it remains an open question whether all the diverse concepts that have been associated with sustainability (and thus comprise the four levels of the Hierarchy) ought to be considered sustainability issues. We turn now to the normative question suggested in our introduction, of whether sustainability *should* incorporate all levels of the hierarchy.

Those who believe current problems are not severe enough to threaten the survival of humans would likely not include level 1 in the hierarchy. For example, they might argue that while global climate change may require social and environmental changes that we should seek to avoid, humans will survive such changes through innovation and the development of new technology (*50*−*52*). Given current trends and uncertainty in future events, we do not believe humans' future presence on this planet is guaranteed over the next millennia, for several reasons. Historically, countless civilizations have collapsed from human activities such as overfarming and overpopulation (*53*, *54*). We live in a time of significant global environmental change, the consequences of which remain poorly understood. Species are disappearing at 1000−10 000 times the normal rate, and "a quarter or more of all species could vanish within a couple of decades" (*55*), weakening the robustness of ecosystems. (Such concerns illustrate an important link between hierarchy levels 3 and 1.) Without effective control of greenhouse gases, climate change may alter global atmospheric and oceanic circulation systems during this century (*56*). The impacts of such changes may include, for example, disrupting the seasonal monsoons upon which Asia's billions of people depend for agriculture (*57*).

Hierarchy level 1 represents the necessary foundation and starting point for sustainability. Perhaps more controversial is the inclusion of level 4 issues (values and beliefs) within the definition of sustainability. Some have argued against including level 4 within the hierarchy. Global diversity in cultures and beliefs suggests that one can neither satisfy, nor try to satisfy, all people's values simultaneously. Meeting individuals' values is a moving target because these values change over time. Maslow posited that as an individual's existing needs are addressed, a new set rises to prominence. The same is true for societies. If sustainability means addressing or satisfying all of our values and wants, it is inherently an unobtainable goal because these are moving targets. Others believe that level 4 issues are essential to the hierarchy. They argue that sustainability should be a broad concept, containing a myriad of desirable social and environmental improvements. In this case, sustainable becomes a synonym for "quality," and sustainable development is "good" development, however the speaker defines "good".

While both views have merit, we believe that sustainability should not encompass level 4 issues. The concept of sustainability has become too broad, largely due to attempts to incorporate too many diverse views and opinions about desirable policy objectives. As a result, the concept is losing meaning and utility. Using the word sustainable as a synonym for quality, such as when operable windows are considered a feature of sustainable building design, distracts much-needed attention from the many crucial challenges in ensuring the survival of humans, fundamental human rights, and basic levels of health. Level 4 includes many worthy goals, such as seeking a fairer and more just world, but it is our opinion that these aims cannot be considered sustainability issues without making the notion of sustainability unworkably broad and beholden to the diversity of individual opinion.

Implications

We agree that "sustainability means transforming our ways of living to maximize the chances that environmental and social conditions will indefinitely support human security, wellbeing, and health" (*58*). Indeed, this offers a useful working definition for "sustainability". While improving the health, security, and quality of life for humans is an ethical imperative, the morally *desirable* level of improvement extends beyond that which is required for human survival, health, or human rights. As such, to preserve meaning in the term *sustainability*, people must be explicit about the hierarchy level to which they are referring and be cognizant of the term's spatial and temporal dimensions. As discussed above, we discourage those addressing level 4 issues from labeling their work—worthy as it is—as sustainability. We also discourage the use of sustainability as a synonym for "good" or for "having a reduced environmental impact". Below, we describe implications of the sustainability hierarchy to companies, governments, and scientists.

Implications for Companies. Common usage of the term sustainability implies a wide variety of units of analysis: societies, technologies, corporations, buildings, and industrial processes. Despite efforts to define a "sustainable organization" (*59*−*63*) and the recent emergence of "sustainability management systems" (*64*, *65*), some argue that "individual organizations cannot become sustainable: individual organizations simply contribute to the large system in which sustainability may or may not be achieved" (*60*). We posit an intermediate view by claiming that organizations are an inappropriate unit of analysis for some sustainability hierarchy levels but appropriate for others.

At level 1 of the hierarchy, it is impossible to evaluate the sustainability of organizations in and of themselves. Particular technologies and organizations are too small a unit of analysis to be considered in isolation. The footprint of an organization or technology extends well beyond its boundaries, and its net impact can be reduced via emissions trading or offsets. Furthermore, the sustainability of an organization's products and services depends on how they are used, how much they are used, their ultimate disposition (e.g., recycled, incinerated), and the impact of their use within a broader context.

Still, it is possible to evaluate the sustainability of a technology or organization in context. "This involves [a company's] looking not only at the total lifecycle of its own products, but also at all the components and materials that they use, and at the environmental and social impacts involved" (*66*). For example, many people would consider the fossil fuel internal combustion engine to be unsustainable at several levels of the hierarchy. It is unsustainable at level 1 because, at current and forecasted usage, consumption of fossil fuels exceeds regeneration rates and pollutant emissions exceed assimilative capacities and are leading to the decline of ecosystem function (e.g., by contributing to global climate change). However, internal combustion engines are not inherently sustainable or unsustainable: if the use of such engines consumed resources at or below regenerative rates and produced wastes within assimilation rates, then they would not impair ecosystem function and their use would be sustainable at level 1. Because motor vehicles are a significant contributor to the hazardous air pollutants that are ubiquitous to urban areas, they are not sustainable at level 2. If their emissions were adequately controlled, however, they could be sustainable at this level. Finally, level 4 proponents might find vehicles' noise pollution and haze/visibility impacts to be unsustainable on an aesthetic basis.

A single organization, in isolation, is unlikely to violate levels 1, 2, or 3. Instead, organizations can explore their sustainability implications at each level of the hierarchy by asking "What if others acted as I do?". This approach is similar to the one employed by The Natural Step, the triple bottom line, and the Ecological Footprint: all three frameworks implicitly link organizations' actions to their broader impact on society by asking "what if others acted in the same manner?". The environmental edict to "think globally, act locally" employs the same logic. In considering this question, organizations could use whole-systems frameworks such as life-cycle assessment and mass-flow analysis. For example, when organizations announce their intention to meet Kyoto-style targets (e.g., a 10% reduction in greenhouse gas emissions relative to year-1990 levels, by the year 2010) (*67*, *68*), they typically refer only to their internal operations and ignore the environmental impacts of their products and services (e.g., for automotive manufacturers and petroleum refineries, their consumers' use of fossil fuels).

Why should companies voluntarily act upon unregulated sustainability issues such as carbon emissions in the United States? Adopting to anticipated regulations can sometimes reduce costs directly (*69*), but such fortuitous instances are more likely the exception than the rule (*70, 71*). Why else, then, should profit-seeking companies agree to do so? Even when such actions increase a company's costs, first-movers can gain competitive advantage by acquiring a progressive image, by starting down a learning curve sooner than their competitors, and by lobbying governments to lock-in the solutions they developed to generate licensing fees or market share gains from disrupted competitors.

Companies may face choices that involve different levels of the sustainability hierarchy and can use the hierarchy to prioritize their efforts. For example, a growing number of companies are requiring their suppliers to adopt codes of conduct that specify how they should manage environmental, human rights, and labor issues. If a company prioritized their requirements based on the hierarchy, they would consider that suppliers' providing a safe and healthful working environment, potable water, and not using forced labor (level 2 and 3 issues) to be more important than corruption and freedom of association (level 4 concerns). Implementing codes of conduct in this type of phased approach can help both companies and their suppliers address the most important issues first.

Finally, companies can avoid contributing to the definitional chaos surrounding sustainability by *not* claiming that all efforts toward the worthy goals of eco-efficiency, environmental justice, fair trade, or corporate social responsibility are sustainability. Companies can help restore meaning to sustainability by restricting their use of the term to those actions that actually promote the survival of humans (level 1), promote basic health (level 2) and fundamental rights (level 3), and prevent species extinction (level 3).

Policy Implications. Achieving sustainability on any of the hierarchy levels will require new public policies. The fact that so many ecosystems are in decline (*72*) is evidence that current public policies are insufficient to ensure ecosystem health necessary for long-term human survival and species preservation.

Determining whether a policy is sustainable depends on a host of factors such as local environmental conditions, the cultural context, the hierarchy level considered, and the spatial and temporal scale of the issue. A straightforward example of the importance of local environmental contexts is that a sustainable water use policy for a wet region may not work for a dry region (*73*). China's one-child policy, whereby most citizens are strongly discouraged from having more than one child, illustrates the importance of cultural context and hierarchy level. Some might argue that this policy is sustainable on level 1 because it seeks to avoid overwhelming China's natural resources and on level 2 as an attempt to stabilize food supply and improve health. Those who consider family planning choices to be a human right would argue the policy is *un*sustainable on level 3. Determining whether the policy is sustainable using level 4 (beliefs and values) depends on whether one believes that it enhances quality of life and appropriately values the needs of society over individuals or that it infringes upon individual liberties. (Here, "liberties" denotes actions that one might *expect* a government or society would allow individuals to perform, but one that is not so core to the human condition as to be a human right (*45*).) The sustainability hierarchy provides a structure for discussing sustainability and for clarifying issues on which people may or may not agree, but it does not eliminate disagreements or controversy.

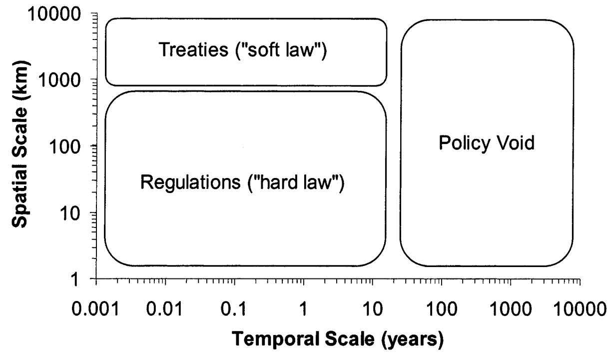

FIGURE 3. Temporal and spatial scales of environmental policies. There is often a policy void for sustainability issues in part because of the large temporal and spatial scales.

Long-term environmental sustainability issues, even those at level 1 of the hierarchy, often fall into a policy void. "Most existing regulations are not intended to achieve sustainability, but only to avoid extremes of environmental damage and social inequity" (*66*). There are many reasons for the dearth of policy on sustainability issues. First, there remains scientific uncertainty associated with sustainability issues, particularly with long-term sustainability issues. This uncertainty is often used to legitimize inaction. Second, to the extent that sustainability is used in the sense of level 4 of the hierarchy, policy makers are likely to consider such value-laden issues to be merely one of many advocacy positions vying for attention. Third, many policies that address sustainability issues are perceived to require significant short-term sacrifice. Such policies, such as fuel taxes to address global climate change, are likely to be unpopular. The typical short-term focus of the electorate and politicians in multiparty democracies can undermine political solutions to long-term issues. Politicians in Singapore's dominant political party lack serious electoral competition, which allows them to vote for proactive policies that are unpopular in the short-term. In more contested polities, voting for policies such as severe restrictions on vehicle ownership might cost politicians their reelection.

Fourth, sustainability issues often require policy makers to restrict activities based on preliminary evidence that they might harm the environment or human health. Sustainability policies may require prioritizing the collective over individual liberties. This aspect of sustainability issues may explain to some extent why climate change policies have been more readily adopted in the more socialistic European Union than in the more individualistic United States.

A fifth contributor to the policy void is the fact that sustainability issues typically occur over larger spatial and temporal scales than most current regulations (Figure 3). Nearly all extant legislation addresses short- and medium-term issues within the well-defined political borders of country, state, and locality. Because sustainability issues seldom occur neatly within political domains or election cycles, jurisdictional issues and domestic politics can impede coordination across political domains and stymie effective governance. A few treaties, most notably The Montreal Protocol on Substances that Deplete the Ozone Layer (1987), provide some hope that long-term global environmental problems can be solved diplomatically. Unfortunately, many treaties that address long-term environmental concerns contain few enforceable provisions, such as the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1974) (*74*). The struggle to convince enough countries to ratify the Kyoto Protocol to the United Nations Framework Convention on Climate Change (1997) for its entry into force, despite the scientific consensus about climate change, illustrates the difficulty many nations face garnering domestic political support to address long-term global concerns.

Implications for Future Scientific Research. "Addressing sustainability ... is a vital response to a rapidly evolving crisis and should be at the top of our research agendas .... [T]o change understanding and policy ... [science] needs to be fully engaged in this challenge" (*58*). There is an acute need for scientists and engineers to incorporate sustainability concerns in their work, such as by exploring the full social and environmental impacts of technologies and technical systems (*75*). While tools such as pollution prevention and industrial ecology are useful, "alone [they] are not sufficient to achieve sustainability, because even systems with efficient material and energy use can overwhelm the carrying capacity of a region or lead to other socially unacceptable outcomes" (*75*).

More research is needed to predict how potential ecosystem perturbations may affect short- and long-term ecosystem functionality. Natural scientists and social scientists need to come together to understand better human/environment interactions (*56*). The "syndrome" approach, whereby investigators evaluate symptoms of sustainability similar to a doctor evaluating a patient's symptoms in order to identify a specific disease or syndrome, appears promising (*76*). The syndrome approach highlights the interrelation between levels of the hierarchy. For example, increasing poverty levels (a level 3 issue) can lead to widespread use of agriculturally marginal land, causing environmental decay that reduces agricultural yield and potentially causing widespread famine (a level 1 issue) (*76*). A level 1 environmental change that endangers people's survival (e.g., inability to grow food because of desertification or flooding) can cause people to relocate, possibly becoming refugees, which can cause severe political and economic instability (potentially a level 3 issue) (*77*, *78*).

While we describe several problems that can impair ecosystem function, we have not proposed comprehensive methods for quantifying ecosystem function. Ecosystems are not static; natural perturbations occur at various spatial and temporal scales. Given ecosystems' nonequilibrium dynamics, one technical challenge is quantifying whether and how much the ability of ecosystems to meet human needs is changing over time. Secondary indicators of ecosystem function have arisen, such as predicted change in global average temperature, predicted sea-level rise, and predicted carbon dioxide concentration, but the relationship between these secondary indicators and ecosystem function is often poorly understood. There is a great need for further progress in this area, for example, by improving metrics for biodiversity, genetic diversity, and climate stability; by aggregating specific ecosystem metrics into broader measures of ecosystem function; and by providing tools to connect such metrics to societal choices such as development pathways and infrastructure investments. Such tools and insights will lay the foundation for the new subfields within sustainability science and engineering.

Acknowledgments

We gratefully acknowledge comments from Greg Deemer, John Harte, Arpad Horvath, Jessica Marshall, Adam Smith, Kristen Steck, and Sissel Waage on an earlier version of this manuscript. We also thank the Editor (Mitch Small) and four anonymous reviewers for their helpful comments.

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Received for review March 25, 2004. Revised manuscript received October 12, 2004. Accepted October 19, 2004.

ES040394K