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CHARACTERIZING AND MEASURING SUSTAINABLE DEVELOPMENT

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■ **Abstract** Sustainable development has broad appeal and little specificity, but some combination of development and environment as well as equity is found in many attempts to describe it. However, proponents of sustainable development differ in their emphases on what is to be sustained, what is to be developed, how to link environment and development, and for how long a time. Despite the persistent definitional ambiguities associated with sustainable development, much work (over 500 efforts) has been devoted to developing quantitative indicators of sustainable development. The emphasis on sustainability indicators has multiple motivations that include decision making and management, advocacy, participation and consensus building, and research and analysis. We select a dozen prominent examples and use this review to highlight their similarities and differences in definition of sustainable development, motivation, process, and technical methods. We conclude that there are no indicator sets that are universally accepted, backed by compelling theory, rigorous data collection and analysis, and influential in policy. This is due to the ambiguity of sustainable development, the plurality of purpose in characterizing and measuring sustainable development, and the confusion of terminology, data, and methods of measurement. A major step in reducing such confusion would be the acceptance of distinctions in terminology, data, and methods. Toward this end, we propose an analytical framework that clearly distinguishes among goals, indicators, targets, trends, driving forces, and policy responses. We also highlight the need for continued research on scale, aggregation, critical limits, and thresholds.

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1. INTRODUCTION

The recent World Summit on Sustainable Development, although disappointing to many, did find that sustainable development is part of the mission of countless international organizations, national institutions, sustainable cities and locales, transnational corporations, and nongovernmental organizations (1–3). That the oxymoron-like character of sustainable development can be so inclusive must surely lie in its inherent ambiguity that seeks to finesse the real conflicts between economy and environment and between the present and the future. Some combination of development, environment and equity or economy, society, and environment are found in most attempts to describe it. However, proponents of sustainable development differ in their emphases on what is to be sustained, what is to be developed, how to link environment and development, and for how long a time.

To clarify the definitional ambiguities associated with sustainable development, we have found it useful to use the 2×3 taxonomy of the goals described in the extensive literature that defines or debates sustainable development shown in Table 1 (4). In the first column, under the heading "what is to be sustained," are three major categories: nature, life support systems, and community. A plurality of the literature seeks to emphasize sustaining life support systems in which nature or environment is a source of resources and services for the utilitarian life support of humankind (5, 6). In contrast, a significant portion of literature values nature for its intrinsic qualities and biodiversity rather than for its utilitarian qualities (7, 8). Finally, there are claims to sustain cultural diversity, livelihoods, groups, and places that constitute distinctive and threatened communities (9–11). Similarly, there are three quite distinct categories of what should be developed: people, economy, and society. The plurality of early literature focused on the economy, with its productive sectors providing both employment and desired consumption and wealth. In this literature, the economy provides the incentives and the means for investment as well as funds for environmental maintenance and restoration (12). Most recently the focus has shifted to people with an emphasis on human development, increased

TABLE 1 Taxonomy of sustainable development goals (4)

What is to be sustained	What is to be developed
Nature	People
Earth	Child survival
Biodiversity	Life expectancy
Ecosystems	Education
	Equity
	Equal opportunity
Life support	Economy
Ecosystem services	Wealth
Resources	Productive sectors
Environment	Consumption
Community	Society
Cultures	Institutions
Groups	Social capital
Places	States
	Regions

life expectancy, education, equity, and opportunity (13–15). Finally, there are also calls to develop society emphasizing the well-being and security of national states, regions, and institutions and the social capital of relationships and community ties (16–19).

In practice, groups and institutions tend to acknowledge the many multiple and conflicting objectives to be both sustained and developed but then adopt implicit objective functions that take the forms of such statements as sustain only, develop mostly, develop only but sustain somewhat, sustain, or develop—for favored objectives. Similarly, hard choices between sustainable development objectives can be avoided by adopting implicit time horizons. The Brundtland report itself chose a usefully ambiguous and now widely accepted time horizon as "now and in the future" (20). But in a future of a single generation, 25 years, almost any development appears sustainable. Over an infinite forever, none does because even the smallest growth extended indefinitely creates situations that seem surely unsustainable.

Despite the persistent definitional ambiguities associated with sustainable development, much work has been devoted to developing quantitative indicators of sustainable development. The *Compendium of Sustainable Development Indicator Initiatives* lists over 500 sustainability indicator efforts. Of this number, 67 are global in scope, 103 national in scope, 72 are state or provincial in scope, and 289 are local or metropolitan in scope (21). Several efforts have addressed criteria and methodology for constructing indicators; these efforts include work by the Scientific Committee on Problems of the Environment (22), the Balaton Group (23, 24), and others (25, 26). This literature is somewhat distinct from the theoretical

and primarily economic treatment of the theory and norms of defining sustainable development (27–31).

The goal of this review is to assess the state of practice for characterizing and measuring sustainable development. Rather than attempt to exhaustively review the vast body of work in this field, we select a dozen prominent examples (introduced in Section 2) and use this review to highlight their similarities and differences by asking the following questions of each effort:

- Section 3—How is sustainable development defined?
- Section 4—Why characterize and measure sustainable development?
- Section 5—How are goals, indicators, and targets selected?
- Section 6—How are indicators constructed?

These comparisons suggest that there major sources of confusion in the field that inhibit future progress, and we conclude by offering our judgment of needed directions for the field.

2. TWELVE SELECTED EFFORTS TO CHARACTERIZE AND MEASURE SUSTAINABLE DEVELOPMENT

We selected our sample of a dozen efforts to characterize and measure sustainable development to be both representative of the field as a whole and to illustrate the diversity of approaches to definition, motivation, process, and technical methodology. We explicitly wished to include efforts ranging from global to national to local scales; governmental to nongovernmental sponsorship; and frameworks that focus on administrative units (e.g., countries) to frameworks that focus on specific actors (e.g., corporations). We did not consider efforts that primarily characterized themselves as state of the environment reports (32, 33). Pragmatic considerations also limited our pool of candidates to those efforts for which we could readily acquire sufficient documentation and background information to support our review. As a result, our sample over represents global scale and U.S.-based efforts.

2.1. United Nations Commission on Sustainable Development

The United Nations Commission on Sustainable Development (CSD) was created in 1992 under the auspices of the Economic and Social Council as a direct result of the United Nations Conference on Environment and Development. A major element of its work to date has focused on the development and testing of a suite of 58 indicators, whittled down from an initial list of 134 indicators, that cover social, environmental, economic, and institutional aspects of sustainable development (34). Although the original intent was to establish a common set of country-level indicators that could eventually be published as a comprehensive comparative time series dataset, recent CSD deliberations stressed that they are "intended only for use by countries at the national level on a voluntary basis, suited

to country-specific conditions, and shall not lead to any type of conditionalities, including financial, technical and commercial" (35).

2.2. Consultative Group on Sustainable Development Indicators

The official work of the CSD has been complemented by several independent efforts. The Consultative Group on Sustainable Development Indicators (CGSDI), an international panel of a dozen experts in the field, was established in 1996 with funding from the Wallace Global Fund "to harmonize international work on indicators and to focus on the challenge of creating a single sustainability index." This work produced a "Dashboard of Sustainability," a set of 46 indicators organized into 4 clusters (environment, economy, society, and institutions) for over 100 countries. In parallel, the CGSDI developed a software package that allows users to select alternate methods for computing overall scores from the individual indicators and to graphically analyze the aggregated results (36).

2.3. Wellbeing Index

The World Conservation Union (IUCN) sponsored the development of the "Wellbeing Assessment" that was published in *The Wellbeing of Nations*: *A Country-by-Country Index of Quality of Life and the Environment* (37). The Wellbeing Index is a composite of 88 indicators for 180 countries. The indicators are aggregated into two subindexes (human wellbeing and ecosystem wellbeing). The human wellbeing index is in turn a composite of indices for health and population, wealth, knowledge and culture, community, and equity. The ecosystem wellbeing index is a composite of indices for land, water, air, species and genes, and resource use. In this scheme, the most sustainable countries include the northern European countries (Sweden, Finland, Norway, and Iceland), and the least sustainable countries are Uganda, Afghanistan, Syria, and Iraq. The United States ranks twenty-seventh, Hungary forty-fourth, and Brazil ninety-second out of 180 countries.

2.4. Environmental Sustainability Index

The World Economic Forum's Environmental Sustainability Index is also composite index derived from 68 indicators for 148 countries (38, 39). These indicators are aggregated into 5 components and 20 core indicators: environmental systems (air quality, water quantity, water quality, biodiversity, and land); reducing environmental stresses (air pollution, water stresses, ecosystem stresses, waste and consumption pressures, and population growth); reducing human vulnerability (basic human sustenance and environmental health); social and institutional capacity (science and technology, freedom to debate, environmental governance, private sector responsiveness, and ecoefficiency); and global stewardship (participation in international collaborative efforts to reduce greenhouse gas emissions and transboundary environmental pressures). At the extremes the Environmental

Sustainability Index agrees well with the Wellbeing Index. However, Hungary is ranked eleventh, Brazil is ranked twentieth, and the United States is ranked forty-fifth out of 148 countries, significantly different results than for the Wellbeing Index.

2.5. Global Scenario Group

The Global Scenario Group uses a set of 65 indicators describing aspects of international equity, national equity, hunger, energy use, water use, deforestation, carbon emissions, sulfur emissions, and toxic waste (40, 41). In contrast to the retrospective efforts above, these indicators are used characterize four alternative scenarios of future global responses to the sustainability challenge through 2050: *market forces*, *policy reform*, *fortress world*, and *the great transition*. In *market forces*, competitive, open, and integrated global markets drive world development. Social and environmental concerns are secondary. *Policy reform* assumes that comprehensive and coordinated government action is initiated for poverty reduction and environmental sustainability. *Fortress world* features an authoritarian response to the threat of breakdown, as the world divides into a kind of global apartheid with the elite in interconnected, protected enclaves, and an impoverished majority outside. The *great transition* validates global solidarity, cultural cross-fertilization, and economic connectedness while seeking a liberative, humanistic, and ecological transition.

2.6. Ecological Footprint

Redefining Progress produces two sustainability indices: ecological footprint and the genuine progress indicator. The Ecological Footprint is a global and country-by-country calculation of consumption and waste relative to the Earth's capacity to create new resources and absorb waste. It is constructed from impact measures for managing the use of croplands, grazing lands, forests, fisheries, infrastructure, and fossil fuels. These measures are then compared with the global stock of each resource. The result is a trend that steadily increases from 0.68 Earth consumed in 1961 to 1.22 in 1999, which indicates that consumption now exceeds the renewable supply of resources (42, 43).

2.7. Genuine Progress Indicator

The Genuine Progress Indicator (GPI) is a measure of the economic performance of the United States that includes the economic contributions of household and volunteer work while subtracting factors such as crime, pollution, and family breakdown. In contrast to gross domestic product per capita (GDP/capita), which steadily increased from 1959–1999, the GPI/capita peaked in the mid 1970s, then steadily declined through the early 1990s, and then increased though 1999 (44). The GPI is but one prominent example of effort to introduce economic externalities into systems of national accounts (12, 45–50).

2.8. U.S. Interagency Working Group on Sustainable Development Indicators

As another example of a national effort, we analyze the work of the U.S. Interagency Working Group on Sustainable Development Indicators (IWGSDI). It is a collection of 13 economic indicators, 16 environmental indicators, and 11 social indicators. No effort is made to construct composite indices of indicators. However, of the 40 indicators, 30 showed trends with clear impact relevant to sustainable development, and 17 of these 30 showed positive national trends (51).

2.9. Costa Rica System of Indicators for Sustainable Development

A third example of a national scale effort is Costa Rica's Sistema de Indicadores sobre Desarrollo Sostenable (System of Indicators for Sustainable Development) first published in 1998 (52). In contrast to the U.S. effort, Costa Rica uses the concept of sustainable development to organize the country's primary statistical abstract. The result is a compendium that currently contains 255 statistical tables organized into 3 broad categories: social (83 tables), economic (97 tables), and environmental (75 tables). The structure of the indicators varies from national time series (e.g., infant mortality, external debt, and energy intensity), to canton-by-canton and district-by-district comparisons of an aggregated social development index computed for 1999. There are also some efforts to situate Costa Rica in the international context using the Human Development Index (15), GDP/capita, inflation rates, prices of key commodities (petroleum, bananas, and coffee) and short term interest rates for U.S. dollars. As with other national statistical abstracts, the presentation is factual with virtually no commentary or overall assessment and spare use of graphics.

2.10. Boston Indicators Project

As an example of a community-based effort, we analyzed the work of the Boston Indicators Project (53). This effort assessed 159 indicators organized into 10 themes: civic health, culture, economy, education, environment, housing, health, safety, technology, and transportation. Figures are given by neighborhood, for Boston as a whole, and for the broader metropolitan area. Each theme includes narrative describing the historical context, regional context, citywide focus, neighborhood focus, and remaining challenges. As with the IWGSDI described above, no effort is made to construct composite indices. Other community-based indicator efforts include the Central Texas Sustainability Indicators Project (54), the Durban Metro State of the Environment and Development report (55), the Ghent Barometer of Sustainable Development (56), Hamilton Ontario's Vision 2020 (57), the Lancashire Green Audit (58), and Sustainable Seattle (59).

2.11. State Failure Task Force

The approaches described above define sustainability in terms of goals to be achieved. In contrast, several efforts take the converse approach by attempting to define indicators of the syndromes or nightmares we wish to avoid such as overuse of marginal lands (the "Sahel Syndrome"), damage of landscapes as the result of large scale projects (the "Aral Sea Syndrome"), or social-ecological degradation through uncontrolled urban growth (the "Favela Syndrome") (60, 61). An example of such efforts is the U.S. Central Intelligence Agency State Failure Task Force (16, 62–64). This group compiled a country-by-country historical record of 127 so-called state failures—revolutionary wars, ethnic wars, genocides or politicides, and adverse or disruptive regime crises—from 1956–1996. It then used data mining techniques such as stepwise multivariate regression and neural networks to inductively find indicators capable of predicting the onset of such events two years in advance. A pool of 75 indicators spanning social, economic, political, and environmental topics was considered. The best model on a global basis used indicators for infant mortality, trade openness [(imports + exports)/GDP], and the level of democracy. Countries with infant mortality above the median for a given year, trade openness below the median for a given year, and with partial democracies exhibited greater risk of failure. This simple model is able to predict approximately two thirds of the failure and nonfailure cases correctly.

2.12. Global Reporting Initiative

All of the above examples use pieces of territory (e.g., countries, counties, or cities) as their object of analysis. However, sustainability can be measured for other objects as well. For example, there is growing interest in rating the sustainability of companies. The most prominent of these efforts is the Global Reporting Initiative, an effort to establish globally applicable guidelines for reporting on the economic, environmental, and social performance initially for corporations and eventually for any business, governmental, or nongovernmental organization. These guidelines specify indicators for each of the three sectors that should be routinely reported by these organizations. The guidelines are now in use, in various degrees, by 156 companies, which include notables such as 3M, ABB, AT&T, Bristol-Myers Squibb, Danone, Dow, Ford, General Motors, and International Paper (65).

3. HOW IS SUSTAINABLE DEVELOPMENT DEFINED?

We use the taxonomy of the sustainable development goals described above to summarize the definitions of sustainability either explicitly or implicitly adopted by each of our selected efforts in Table 2 below and draw three conclusions. First, there is an extraordinarily broad list of items to be sustained and to be developed. This seems to be due both to the inherent ambiguity of sustainable development and to specifics of individual characterization and measurement efforts. Efforts that

TABLE 2 Definitions of sustainable development implicitly or explicitly adopted by selected indicator initiative

Indicator initiative	Implicit or explicit?	What is to be sustained?	What is to be developed?	For how long?
CSD	Implicit, but informed by Agenda 21	Climate, clean air, land productivity, ocean productivity, fresh water, biodiversity	Equity, health, education, housing, security, stabilized population	Sporadic references to 2015
CGSDI	Implicit, but informed by Agenda 21	Same as above	Equity, health, education, housing, security, stabilized population	Not stated, uses data for 1990 and 2000
Wellbeing Index	Explicit	"A condition in which the ecosystem maintains its diversity and quality—and thus its capacity to support people and the rest of life—and its potential to adapt to change and provide a wide change of choices and opportunities for the future"	"A condition in which all members of society are able to determine and meet their needs and have a large range of choices to meet their potential"	Not stated, uses most recent data as of 2001 and includes some indicators of recent change (e.g., inflation and deforestation)
Environmental Sustainability Index	Explicit	"Vital environmental systems are maintained at healthy levels, and to the extent to which levels are improving rather than deteriorating" [and] "levels of anthropogenic stress are low enough to engender no demonstrable harm to its environmental systems"	"People and social systems are not vulnerable (in the way of basic needs such as health and nutrition) to environmental disturbances; becoming less vulnerable is a sign that a society is on a track to greater sustainability" To have "in place institutions and underlying social patterns of skills, attitudes, and networks that foster effective responses to environmental challenges" Cooperation "with other countries to manage common environmental problems" and reduce "negative transboundary environmental impacts on other countries to levels that cause no serious harm"	Not stated, uses most recent data as of 2002 and includes some indicators of recent change (e.g., deforestation) or predicted change (e.g., population in 2025)

(*Continued*)

TABLE 2 (*Continued*)

Indicator initiative	Implicit or explicit?	What is to be sustained?	What is to be developed?	For how long?
Global Scenario Group	Explicit	"Preserving the essential health, services and beauties of the earth requires stabilizing the climate at safe levels, sustaining energy, materials and water resources, reducing toxic emissions and maintaining the world's ecosystems and habitats"	The ability to "meet human needs for food, water and health, and provide opportunities for education, employment and participation"	Through 2050
Ecological Footprint	Explicit	"The area of biologically productive land and water required to produce the resources consumed and to assimilate the wastes produced by humanity"	—	Not explicitly stated, computed annually from 1961–1999
Genuine Progress Indicator	Explicit	Clean air, land, and water	Economic performance, families, and security	Not stated, computed annually from 1950–2000
U.S. IWGSDI	Explicit	Environment, natural resources, and ecosystem services	Dignity, peace, equity, economy, employment, safety, health, and quality of life	Current and future generations
Costa Rica	Implicit	Ecosystem services, natural sources, and biodiversity	Economic and social development	Not stated, includes some time series dating back to 1950
Boston Indicators Project	Implicit	Open/green space, clean air, clean water, clean land, valued ecosystems, biodiversity, and aesthetics	Civil society, culture, economy, education, housing, health, safety, technology, and transportation	Not stated, uses most recent data as of 2000 and some indicators of recent change (e.g., change in poverty rates)
State Failure Task Force	Explicit	—	Intrastate peace/security	Two years
Global Reporting Initiative	Implicit	Reduced consumption of raw materials and reduced emissions of environmental contaminants from production or product use	Profitability, employment, diversity of workforce, dignity of workforce, health/safety of workforce, and health/safety/privacy of customers	Current reporting year

are defined by the need to establish a broad consensus among varied stakeholders have more difficulty being explicit about definitions than do the independent efforts. In the case of the CSD, the stakeholders are nations engaged in negotiations about how to compare their relative progress toward sustainable development. In the Boston case, the stakeholders are members of the community with varied opinions about policy and investment priorities for the future. In the case of the Global Reporting Initiative, the stakeholders are corporations, investors, and regulatory agencies that must agree on common principles and practices for evaluating the relative contributions of corporations toward or away from sustainability. In the context of such negotiation, it is not surprising that underlying definitional differences are downplayed in favor of reaching a common set of indicators, and in order to be inclusive, the range of indicators becomes very broad. In contrast, small self-appointed groups that share a common definition of sustainable development control their own efforts and can, therefore, be more explicit about their terms.

Second, few of the efforts are explicit about the time frame of sustainable development. When time frame is addressed at all, there is a clear bias toward the present or the near term. However, there are three exceptions worth noting. The Global Scenario Group attempts to quantify its scenarios through 2050, approximately two generations. The CSD also makes occasional reference to some of the human development targets established via international negotiations such as the World Summit on Social Development. These targets tend to be defined in terms of a single generation (15–25 years). Although the Ecological Footprint does not explicitly establish a time horizon, it does suggest that a global environmental footprint that is larger than the carrying capacity of the Earth cannot be indefinitely sustained. All of the remaining efforts focus on the present and, in some cases, the recent history leading up to the present. None of our examples approach sustainable development in terms of civilizations or millennia, though such sweeping approaches are occasionally found in the literature (66).

Third, the vast majority of the efforts are deductive, or top-down, in nature. They establish definitions of sustainability on the basis of first principles or negotiated consensus and then let these definitions drive their choice of indicators. Of our examples, only the State Failure Task Force uses an inductive, or bottom-up, approach in which significant indicators emerge from the analysis as powerful statistical predictors.

4. WHY CHARACTERIZE AND MEASURE SUSTAINABLE DEVELOPMENT?

Given the definitional ambiguity outlined above, why even bother to characterize and measure sustainable development? There are at least four major purposes: decision making and management, advocacy, participation and consensus building, and research and analysis. Table 3 summarizes the stated objectives of our dozen examples.

TABLE 3 Implicit and explicit motivations for characterizing and measuring sustainable development

Indicator initiative	Motivation
CSD	"Indicators can provide crucial guidance for decision-making in a variety of ways" Chapter 40 of Agenda 21 "calls on countries at the national level, as well as international, governmental and non-governmental organizations to develop and identify indicators of sustainable development that can provide a solid basis for decision-making at all levels" "Make indicators of sustainable development accessible to decision-makers at the national level, by defining them, elucidating their methodologies and providing training and other capacity building activities"
CGSDI	Not stated
Wellbeing Index	Provide "a clearly stated goal" Provide "a way of measuring progress toward the goal" Provide "an analytical tool for deciding priority actions" Provide "a process to keep the goal constantly in mind and to help people learn how to reach it"
Environmental Sustainability Index	"Assist the move toward a more analytically rigorous and data driven approach to environmental decision making" "Identification of issues where national performance is above or below expectations" "Priority-setting among policy areas within countries and regions" "Tracking of environmental trends" "Quantitative assessment of the success of policies and programs" "Investigation into interactions between environmental and economic performance and into the factors that influence environmental sustainability"
Global Scenario Group	"Offer guidance on how to act now to direct the flow of events towards desirable futures and away from undesirable ones" "Examine the prospects for world development in the twenty-first century" "Illuminate the vast range of possibilities in a structured way"
Ecological Footprint	"Help inform production choices." "Keep the market [as a whole] on an efficient path over time" Adjust market prices to include the costs borne by third parties "Provide indications of the consequences of the current distribution of resource access within and between generations from which, along with moral criteria, new distributions of rights might be made"
Genuine Progress Indicator	To replace Gross Domestic Product (GDP) as the primary scorecard of the nation's well-being for the general public, policymakers, and the media
U.S. IWGSDI	"Encourage a national dialogue that will ultimately result in a set of national indicators of sustainable development"
Costa Rica	To disseminate information that promotes the analysis of the sustainable development To serve as connection between producers and users of information To advance the development of sustainable development indicators
Boston Indicators Project	"Provide information to assist with community planning and problem-solving" "Help business, government, community, and civic leaders find effective points of intervention and collaboration" "Build relationships across traditional boundaries: sectors, races, neighborhoods, generations, levels of government, and between Boston and its metropolitan neighbors"

(*Continued*)

TABLE 3 (*Continued*)

Indicator initiative	Motivation
	"Tell the story of Boston's successes and challenges in ways obscured by conventional measures, so that problems can be assessed within the context of our social, economic and environmental assets"
	"Market Boston not only to newcomers but to Bostonians, who, with the help of the media, tend to see our glass as only half full when we compare ourselves with other cities and regions"
State Failure Task Force	"Develop a methodology [to] identify key factors and critical thresholds signaling a high risk of crisis in countries some two years in advance"
Global Reporting Initiative	To provide communities, investors, governments, and businesses timely, credible, and consistent information on an organization's economic, environmental, and social performance
	"Elevate sustainability reporting practices worldwide to a level equivalent to financial reporting"

Much of the literature in the field adopts the old axiom, "what gets measured, gets managed." For example, the Balaton Group states, "Intuitively we all use indicators to monitor complex systems we care about or need to control" (23). Thus the major role of indicators is to indicate progress toward or away from some common goals of sustainable development in order to advise the public, decision makers, and managers. This management control also implies the use of various policy responses, and indicators are to be used to identify opportunities for such responses, select priority actions, and evaluate their effectiveness. Examples of these motivations include the CSD statement that, "Indicators can provide crucial guidance for decision-making in a variety of ways" (34), the Global Scenario Group's goal of offering "guidance on how to act now to direct the flow of events towards desirable futures and away from undesirable ones" (67), and the Boston Indicators Project goal to "provide information to assist with community planning and problem-solving" (53).

Although it is true that characterization and measurement initiatives are almost always justified in terms of informed decision making,[1] it is important to recognize that there are other stated and unstated motives at work as well. Indeed, any effort to influence decision making involves value choices and hence is a form of advocacy. The fact that the concept of sustainable development has both broad political appeal and little specificity has created an environment that is particularly ripe for advocacy groups to leverage the political appeal by producing indices that define sustainable development in ways that advance their political agendas. This leads to considerable debate between advocacy groups regarding the relative merits of their respective indicator efforts. Indeed, the debate between the Friends of the Earth and the World Economic Forum is a good example of this

[1]Of our eleven examples, the only exception is Costa Rica where the stated purposes are presented purely in terms of information exchange and dissemination.

phenomenon (68). There is explicit acknowledgment of advocacy as partial motivation in the Wellbeing Index, the Environmental Sustainability Index, the Ecological Footprint, the Genuine Progress Indicator, the Boston Indicators Project, and the Global Reporting Initiative. While not explicitly stated, one can also assume that some degree of advocacy is also present in the motivation of the other efforts as well.

Sustainability indicators are also used as the focusing mechanism for participatory processes designed to broaden consensus on goals and for building working relationships across traditional political and institutional divides. This is most evident in the stated objectives of the IWGSDI and Boston Indicators Project. The IWGSDI is perhaps best understood as a negotiated consensus among the various agencies of the U.S. federal government. Similarly, the Boston Indicators Project can be viewed as a facilitated negotiation between the city government and the many interest groups within the city to build a vision for the future. Although the CSD does not explicitly state that consensus was a goal in and of itself, the extensive consultative processes employed by this effort suggest that this was indeed the case.

Sustainability indicators are also used to characterize the results of scenarios and modeling efforts and for research. The Global Scenario Group is a good example of how indicators are used to characterize scenarios and modeling efforts. Of our examples, only the State Failure Task Force has an explicit research agenda—to understand the correlations between sustainability indicators and a specific set of undesirable outcomes.

5. HOW ARE GOALS, INDICATORS, AND TARGETS SELECTED?

Characterizing and measuring sustainability involves making choices about how to define and quantify what is being developed, what is being sustained, and for how long. The goals, indicators and targets of sustainability that we review here are derivative of these choices. In our taxonomy, *goals* are broad, but specific qualitative statements about objectives chosen from the major categories of what to sustain and what to develop. Thus, a statement such as "we will spare no effort to free our fellow men, women and children from the abject and dehumanizing conditions of extreme poverty" as found in the United Nations Millennium Declaration is a human needs goal (13), and "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" as found in the United Nations Framework Convention on Climate Change is a life support system goal (69). *Indicators* are quantitative measures selected to assess progress toward or away from a stated goal. For example, the Millennium Declaration uses the proportion of the world's people whose income is less than one dollar a day as basic indicator of extreme poverty (13). Similarly, indicators of greenhouse gas concentrations include measures of carbon dioxide and global warming potential in the atmosphere (70). *Targets* use

indicators to make goals specific with endpoints and timetables, such as cutting the proportion of people living on less than one dollar a day in 2000 in half by 2015 (13) or reducing overall emissions of greenhouse gases by at least 5% below 1990 levels by 2008–2012 (70). Finally, *trends* are changes in the values of indicators over time, and *driving forces* and *policy responses* are processes that influence trends and our ability to meet agreed upon targets.

Many targets arise from consensus processes of selection and negotiation (71), but targets can also be chosen based on scientific theory and research. Thus the Global Scenario Group sought to establish targets based on consensus processes for social goals, such as reducing hunger, unsafe water, and illiteracy, by half in each generation until 2050. But in the absence of such consensus for many of the environmental goals, they selected targets based on existing scientific analysis of both what seems to be needed and what seems to be possible to do by 2050 (40, 41).

The distinction between indicators, driving forces, and policy responses is important. As defined above, indicators are limited to quantitative measures of progress toward or away from a stated goal. This definition of indicators explicitly excludes factors that influence progress and instead labels such factors as driving forces or policy responses. It also excludes measures of good intent, such as the existence of a national sustainability plan or membership in international organizations. We make these separations explicit because the widespread adoption of the "pressure-state-response" (72) and derivative frameworks (73) has resulted in a number of measurement efforts that lump indicators of desired outcomes with a smorgasbord of indicators of contestable cause and effect relationships (33). Thus, inputs in the form of driving forces, or more often as policy responses, substitute for the measurement of actual outcomes in achieving a goal. For example, the CSD includes an indicator for the presence of a national sustainable development strategy (34), the Wellbeing Index includes a measure for the number of Internet users per 10,000 population (37), and the Environmental Sustainability Index includes an indicator for the number of IUCN member organizations per million population (38).

As with any assessment effort, the process and methods with which various measurement efforts make choices about goals, indicators, and targets are closely related to their effectiveness in accomplishing their primary objectives (decision making and management, advocacy, participation and consensus building, and analysis and research). These processes and methods can be characterized by three attributes—salience, credibility, and legitimacy. *Salience* refers to relevance of the measurement system to decision makers, *credibility* refers to the scientific and technical adequacy of the measurement system, and *legitimacy* refers to the perception that the production of the measurement system is respectful of stakeholders' divergent values and beliefs, unbiased, and fair in its treatment of opposing views and interests (74–76). Table 4 briefly describes each of our examples using these three characteristics. Efforts to ensure any one of these attributes often result in the diminution of another. For example, the perceived lack of legitimacy and fears of policy misuse led the CSD to sharply curtail the scope of its work plan on sustainability indicators. It is also possible, however, that attempts to increase one

TABLE 4 Salience, credibility, and legitimacy in efforts to characterize and measure sustainable development

Indicator initiative	Salience	Credibility	Legitimacy
CSD	Mandate from Agenda 21 and Review at Rio+5 and World Summit on Sustainable Development	Effort primarily staffed by United Nations technocrats and in-depth consultations with selected countries via pilot process	Decision making by consensus of national delegates and in-depth consultations with selected countries via pilot process
CGSDI	Science-policy dialogue	Selective participation of experts on indicators	Self-appointed group of experts and informal consultations with others through workshops and meetings
Wellbeing Index	Author/publisher assessment and marketing by publisher	Credentials of author, publication in book form by respected publisher in field with backing by IUCN, and independent peer review conducted by publisher	Self-appointed expert
Environmental Sustainability Index	Association with World Economic Forum led to heightened press coverage	Credentials of lead authors, internal review process, publication by respected publisher in field, and independent review conducted by publisher	Self-appointed group of experts
Global Scenario Group	Producer/client relationships with the Commission on Sustainable Development, the United Nations Environment Programme, the U.S. National Academy of Sciences, the Organization for Economic Co-operation and Development, the Intergovernmental Panel on Climate Change, and the Millennium Ecosystem Assessment	Credentials of group members and authors and internal review process	Self-appointed group of experts with membership chosen to represent multiple disciplines and both developed and developing country perspectives

Ecological Footprint	Author assessment	Credentials of authors and publication of methods in Proceedings of the National Academy of Sciences	Self-appointed group of experts/ advocates
Genuine Progress Indicator	Author assessment	Credentials of lead authors	Self-appointed group of experts/ advocates
U.S. IWGSDI	Mandate from President's Commission on Sustainable Development	Credentials of working group members	Chartered working group with representation from many U.S. federal agencies
Costa Rica	Mandate from Agenda 21 (national commitment) and backing by minister of national planning and political economy	Credentials of production team	Core publication of government statistical agency
Boston Indicators Project	Backing by the mayor and the Boston Foundation provided leverage for press exposure	Credentials of lead authors and researchers and extensive review and comment process with participation by academic and practitioner experts	Blessing from popular mayor, and extensive consultation and review by stakeholders
State Failure Task Force	Series of analysis mandates from high-ranking policy makers	Credentials/expertise of task force members and limited publication of results, methods, and data	Group of experts appointed by U.S. federal government
Global Reporting Initiative	Growing list of major companies that publish reports that conform to the guidelines	Credentials of working group members	Steering committee representative of stakeholders and open process with multiple opportunities for stakeholder involvement

attribute can act in a complementary fashion. For example, the outreach efforts by the Boston Indicators Project incorporated a formal review process that also improved the technical credibility of the effort.

On the whole, efforts to ensure salience are rather weak. With the notable exceptions of the State Failure Task Force and the Global Reporting Initiative, none of our select efforts is closely linked to specific decision makers and decisions. In the case of the State Failure Task Force, the mechanism to ensure salience was a series of direct requests from high-ranking officials. In the case of the Global Reporting Initiative, salience is ensured by the economic clout of a diverse community of socially responsible investors that manages over $2 trillion (77). Although it is true that Boston and Costa Rican cases have general statements of support from key decision makers, they are not crafted in a manner that would directly influence any specific decisions. In cases such as the Wellbeing Index, Environmental Sustainability Index, and Ecological Footprint, salience relies upon the ability of their respective authors to assess the policy market for their publication and then use media exposure as their primary means to influence decision making. This observation is consistent with Mitra, who writes, "urban sustainability indicator programs are neither tied to, nor recognized by, local planning and government processes. As a volunteer effort operated parallel to city programs and not incorporated either as a process or used as a source of information, [these efforts] remain at the sidelines of the public policy debate. This often leads to a growing disinterest in continuing regular indicator analyses and updates" (78).

As with salience, many indicator efforts do little to ensure credibility. On the whole, there appears to be a belief that by drawing upon data from reliable sources with their own independent reservoirs of credibility, the effort as a whole will itself become technically credible. However, this does not lend credibility to the selection of indicators, any subsequent computations, or assessments of whether the condition is getting better or worse. Of our dozen efforts, only the Wellbeing Index, the Environmental Sustainability Index, the Ecological Footprint, and the Boston Indicators Project were subjected to formal independent reviews. Most of the efforts rely upon the credentials and expertise of selected participants to establish credibility. In some cases credibility has been enhanced by third-party publication. For example, the work of the Global Scenario Group was extensively used by the United Nations Environment Programme in its third Global Environment Outlook (32), the Wellbeing Index was published by Island Press, the Environmental Sustainability Index was published by Oxford University Press, and an article describing the methods of the Ecological Footprint was published in the *Proceedings of the National Academy of Sciences*.

As noted above, efforts that have primarily sought to establish a broader consensus placed greatest emphasis on mechanisms for establishing legitimacy. These mechanisms range from open and transparent processes with multiple opportunities for stakeholder involvement, as found in the Boston Indicators Project and Global Reporting Initiative, to formal systems of representation and decision making as found in the CSD. In contrast, efforts focused primarily on advocacy, such as

the Ecological Footprint and the GPI, place less emphasis on ensuring legitimacy and rely on their own opinions to resolve any conflict. The middle ground is occupied by groups of experts, generally chosen to ensure either implicit or explicit representational goals. For example, the U.S. IWGSDI representation was chosen to establish a consensus among federal agencies; the Global Scenario Group representation was chosen to ensure a mix of disciplinary expertise and developed and developing country perspectives; and the State Failure Task Force was chosen to ensure a mix of disciplinary and theoretical approaches to the problem of violent intranational political conflict.

The contrast between the dominant stated goal, to inform decision making, and the relatively weak efforts to ensure salience, credibility, and legitimacy is striking and indicates a surprising degree of political naïveté among the sustainable development indicators community. Future work on indicators of sustainable development clearly needs to emphasize these concepts throughout the design and production of indicator systems. The approaches employed by the recently published *State of the Nation's Ecosystems* report may serve as an appropriate point of departure from past practice (33, 79).

6. HOW ARE INDICATORS CONSTRUCTED?

Numerous technical approaches have been employed in the development of characterizations and measurement systems for sustainability. Although most efforts are explicit about their own methods, the terminology is often inconsistent, and there is little discussion of the relative merits and drawbacks of alternate methods. The key methodological choices involve issues of data availability and use, spatial and temporal scale, selection of indicators, and the aggregation of indicators. We briefly summarize the methods employed by each of our examples in Table 5.

Almost all of the indicators used are derived from existing data sources. The nature of the data sets differs widely. They include indicators that have been routinely measured, reported, and assessed on a global basis sufficient to establish a long-term trend, indicators that are currently being measured and are likely to be so in the future, indicators that are not directly measured but only estimated through extensive modeling and extrapolation, and indicators that are not directly measured but are given rough contemporary estimates using proxies as available. Within each category, the quality also differs widely by virtue of what is being measured, where it is done, and the effort expended.

A second methodological choice of any measurement system involves issues of spatial and temporal scale. The first choice is the overall scope of the measurement system. All of our example efforts define scope in terms of contiguous geography (e.g., global, national, and metropolitan region). However, alternate scopes, such as land used for irrigated agriculture, are possible and may be more appropriate for certain types of analysis. Scale also has a temporal component that defines the period over which indicators will be reported. The Ecological Footprint, the Genuine

TABLE 5 Technical characteristics of indicators

Indicator initiative	Scale	Units of analysis	Selection criteria	Aggregation method
CSD	Global, present year	Country and year	Data availability and must meet specified scope and units of analysis	None
CGSDI	Global, present year	Country (most recent year available)	Data availability and must meet specified scope and units of analysis	Weighted index
Wellbeing Index	Global, present year	Country (most recent year available)	Data availability and must meet specified scope and units of analysis	Weighted index
Environmental Sustainability Index	Global, present year	Country (most recent year available)	Data availability and must meet specified scope and units of analysis	Weighted index
Global Scenario Group	Global, 1995 to 2050	Region and year	Data availability/model output and must meet specified scope and units of analysis	None
Ecological footprint	Global, 1961 to most recent year available	Country and year	Data availability, must support aggregation to a common scale, and must meet specified scope and units of analysis	Common scale

Genuine Progress Indicator	United States, 1950 to most recent year	Sectors	Data availability, must support aggregation to a common scale, and must meet specified scope and units of analysis	Common scale
U.S. IWGSDI	United States, 1790 to present (though most is focused on more recent periods)	Multiple	Data availability	None
Costa Rica	Costa Rica, 1950 to present (though most is focused on more recent periods)	Multiple	Data availability	None
Boston Indicators Project	Boston, 1980 to present (though most is focused on more recent periods)	Metropolitan region, Boston, neighborhoods	Data availability	None
State Failure Task Force	Global, 1955–present	Country and year	Data availability and must meet specified scope and units of analysis	Statistical model
Global Reporting Initiative	Global, current year	Corporate/ nongovernmental organization entities	Theoretical	None

Progress Indicator, the Global Scenario Group, and the State Failure Task Force explicitly define their temporal scope. Others, such as the CSD, CGSDI, Wellbeing Index, and Environmental Sustainability Index, are focused on producing values that reflect current conditions, but they do not describe trends over a period of time. The Boston, Costa Rica, and U.S. IWGSDI efforts let the availability of data define temporal scale. This latter approach results in scales that vary widely from indicator to indicator.

Scale also refers to the way in which the measurement system breaks down the overall scope of the effort into comparable units of analysis. Most of our selected efforts define these units geographically and nest the units within the larger scale of analysis. Thus, most of the global efforts use countries for their units of analysis. The one exception being the Global Scenario Group that uses 10 regions, each consisting of multiple countries, for its units of analysis. Of these global efforts, those that explicitly deal with time report trends for each country or region by year. However, the Global Scenario Group does not report its trends annually, rather it reports them for just 1995, 2025, and 2050. The Boston Indicators Project is unique in its explicit effort to report indicators for three distinct units of analysis—the greater metropolitan region, the city as a whole, and for each neighborhood within the city. It is important to note that units of analysis do not necessarily need to be defined in geographic terms. For example, the unit of analysis for the Global Reporting Initiative is the firm. Similarly, indicator efforts could be constructed in which the units of analysis are individuals (80), family units, political parties, climatic region, land cover type, or ecosystem type.

The selection of scale and comparative units of analysis are important for two reasons. The first relates to the intended audience of the effort. If the units of analysis do not correspond to the way in which the audience can effect change, there is little likelihood that the effort will have much salience. For example, if the intended audience is a national legislature, then an appropriate scope would be national with units of analysis that correspond to the constituencies of individual legislators. Alternatively, if the audience consists of park managers, then the scope would be the park as a whole, and an appropriate unit of analysis might be ecosystem type. The second reason is that alternate units of analysis result in different types of aggregation anomalies. This is best understood using the example electoral districting. Even though the voting age population in a given state has the same set of characteristics, the way in which the electoral districts are drawn within the state strongly influences the party, racial, and ethnic structure of the state legislature. It is striking that not one of our examples performs any kind of sensitivity analysis to see if their conclusions would be substantially different if they had used an alternate unit of analysis.

Once questions of scale are addressed, a next major technical distinction among measurement systems is the method by which indicators are selected and aggregated. Although all of the efforts are guided by some implicit or explicit definition of sustainable development, some are much more beholden to the ready availability of supporting data than others. Of our examples, the Boston, Costa Rica,

and U.S. IWGSDI efforts are at the furthest end of this extreme because they report any data they could acquire that fit their broad definitions of sustainable development. The CGSDI, Wellbeing Index, Environmental Sustainability Index, Global Scenario Group, and State Failure Task Force are also largely driven by data availability, but they are more strongly focused in their search by guiding principals of sustainable development and the need to use indicators that conform to explicit definitions of scope and units of analysis. However, these efforts retain a significant amount of flexibility about indicators because they use subjective methods to compute an overall grade with no associated units. In contrast, efforts such as the Ecological Footprint and the GPI attempt to compute aggregate indices using scientific methods to establish equivalencies to a common unit of measure. These efforts are still limited by data availability, but their searches are more directly constrained by the underlying theoretical construct required to produce common scale indices. Other than bemoaning data gaps, none of our selected efforts makes explicit recommendations about additional data that should be acquired in the future to paint a more complete picture of sustainable development. This is in sharp contrast to a recent study of ecosystem health in the United States that specifically identified indicators that were needed but not currently available (33, 80).

7. CONCLUSION

In an emergent sustainability science, much work has been done on indicators of sustainable development. Perhaps more work has been done on this topic than on any of the other core questions of sustainability science (81). Yet to date, there are no indicator sets that are universally accepted, backed by compelling theory, rigorous data collection and analysis, and influential in policy (4). Why is this so? We offer three major reasons:

1. the ambiguity of sustainable development;
2. the plurality of purpose in characterizing and measuring sustainable development; and,
3. the confusion of terminology, data, and methods of measurement.

Although the definitional ambiguity of sustainable development persists, it is gradually being resolved. Increasingly, goals and targets for sustainable development are being adopted by global and local consensus. Thus, it is not semantic or philosophical clarification that is better at defining sustainable development, but normative judgments as to goals and targets reified in formal agreements, treaties, and declarations. These consensus goals and targets are converging on a minimal definition of sustainable development that includes meeting human needs, which reduces hunger and poverty, while preserving the life support systems of the planet (4, 72). However, these normative judgments are only a beginning. Additional

research is required to scientifically identify needed goals and targets by identifying essential limits, boundaries, and thresholds in meeting human needs and preserving life support systems (82).

There is also a growing recognition that the plurality of purpose in characterizing and measuring sustainable development—decision making and management, advocacy, participation and consensus building, and research and analysis—each has its uses and serves different communities. However, these motives need to be clearly identified and stated. This would enable strategic design of procedural and technical methods in ways that would make explicit and optimize the trade-offs between salience, credibility, and legitimacy.

A major step in reducing the confusion of terminology would be the acceptance of the suggested distinctions between goals, indicators, targets, trends, driving forces, and policy responses. There is also a need to conduct research to evaluate the sensitivity of indicator systems to choices in scale, develop and refine methods for aggregating multiple indicators to a common scale, and identify critical limits and thresholds. In our judgment, a most pressing immediate need is for regular measurement of reporting of indicators that track progress toward or away from the growing sets of commonly accepted goals and targets. Elsewhere, we have attempted to design such a set using 14 such goals and targets of development and environment. We were generally successful in identifying a key single indicator for each goal by eliminating much of the repetitive use of similar indicators simply because data are available. However, several key indicators such as ocean biological community condition and land use/cover change are not available and require both further scientific work on creating common scale composite measures and then actually measuring them (72).

Much of the work on measuring sustainable development is driven by a desire to find a new universal indicator of progress akin to GDP or the Human Development Index. Indeed, many of the efforts include explicit references to the inadequacy of GDP as a measure of progress. In our opinion, it is unlikely that the community will soon be able to offer up an alternative to GDP that is as universally accepted, backed by compelling theory, rigorous data collection and analysis, and influential in policy. It must first resolve the persistent definitional ambiguity associated with the notion of sustainable development, the plurality of purpose in measurement, and the confusion of terminology, data, and methods. However, given the progress to date, it is clear that global and local measurement systems can and should serve as navigational aids for a sustainability transition. As we move forward, we must improve the integration of sustainable development theory with the practice of characterization and measurement and recognize that the process is as important as product. It is the process that establishes salience, credibility, and legitimacy and will ultimately lead us toward widespread consensus regarding measurable definitions of sustainable development. At the same time, pluralism is an important element of this process because it allows us to compare and contrast a plethora of approaches and then select the best attributes of each to pursue the next generation of research and

application. This article provides a framework for making such comparisons and selections.

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