Wu, J. and T. Wu. 2012. Sustainability indicators and indices. Pages 65-86 In: Christian N. Madu and C. Kuei (eds), Handbook of Sustainable Management. Imperial College Press, London

# Chapter 4

## SUSTAINABILITY INDICATORS AND INDICES: AN OVERVIEW

Jianguo Wu[a,b] and Tong Wu[c]
[a]*School of Life Sciences and Global Institute of Sustainability, Arizona State University, P.O. Box 874501, Tempe, AZ 85287, USA*
[b]*Sino-US Center for Conservation, Energy, and Sustainability Science (SUCCESS), Inner Mongolia University, Hohhot 010021, China*
*Jingle.Wu@asu.edu*
[c]*School of Forestry, Northern Arizona University, Flagstaff, AZ 86011, USA*
*Tong.Wu@nau.edu*

Human activities have profoundly transformed the biosphere, and various signs — including global climate change, biodiversity loss, and urban pollution — indicate that our world is on an unsustainable trajectory. To insure the well-being of the current and future generations, operationalizing the concept of sustainability has become the most salient challenge of our time. To meet this challenge, a cogent set of metrics — sustainability indicators and indices — is indispensable, which allow us to locate our present condition relative to conditions that have prevailed in the past, and to develop relevant perspectives to frame actions for the future. This, however, can be a difficult task given the diversity of perspectives and disciplines concerned with sustainability, and the complexity of issues that need to be addressed. In this chapter, we present an overview of this broad but still emerging body of research. We discuss the basic principles and scientific perspectives underlying the concept of sustainability or sustainable development. Then, based on these lines of inquiry, a survey of inclusive and influential indicator frameworks is presented. These organizing schemes constitute a foundation that is crucial to the construction, interpretation, and application of sustainability indicators. Then, we examine a selection of commonly used sustainability indices. Finally, we conclude the chapter with some reflections on the nature and future of sustainability measures.

### 1. Introduction

Mounting evidence indicates that our world has been on an unsustainable trajectory, particularly in the past few centuries. As the most dominant ecosystem engineers, human influences on earth are no longer restricted to taming desired species and extracting valued minerals. We have also begun to domesticate whole ecosystems and landscapes of increasing spatial extent, transforming the entire biosphere in fundamental ways (Kareiva *et al.*, 2007; Wu 2008, 2010). The global human population has increased from fewer than 1 billion before the onset of the Industrial

Revolution in the late 18th century to more than 6.8 billion today. The rate of population growth is astonishing: it took about 10,000 years for human population to increase from 5 million to 1 billion, but only an additional 130 years to reach the third billion and only 40 more years to surpass the sixth billion! The accelerated human dominance of the earth system has led to a number of environmental, as well as social and economic, problems, including biodiversity loss, global climate change, overexploitation of natural resources, degradation of environmental quality, and socioeconomic inequity and instabilities.

Achieving sustainable development is, therefore, is arguably the most pressing issue of our time. One of the main reasons is the simple fact that we have no other viable choice. As Bossel (1999) put it, "There is only one alternative to sustainability: unsustainability." Thus, it is not surprising that sustainability has become a buzzword in both academia and public discourse. There is no doubt that we have entered a sustainability movement of global reach. As with any other human endeavor, ensuring ultimate success through continuing progress means being able to effectively gauge our performance. In the context of sustainable development, these performance metrics are primarily sustainability indicators and indices (SIIs), which have played an increasingly important role in the science and practice of sustainability.

While indicators for assessing and tracking environmental and ecological conditions have been used for more than half a century (Niemi and McDonald, 2004), the development of indicators for gauging sustainable development has a relatively short history. Its major development started after the United Nations Conference on Environment and Development (Earth Summit), held in Rio de Janeiro of Brazil in 1992, which proposed the fundamental principles and the program of action for achieving sustainable development. In particular, the Rio Summit called for the development of sustainability indicators with its Agenda 21, an action plan endorsed by more than 170 national governments. The World Summit on Sustainable Development (Earth Summit, 2002) convened by the United Nations in Johannesburg, South Africa, in 2002 strongly reaffirmed the UN's commitment to the Rio principles and the full implementation of Agenda 21. Consequently, a number of international organizations, governmental agencies, NGOs, local communities and corporations, and academic scholars have devoted significant effort to the design and implementation of indicators that gauge the state and trajectory of environmental conditions and socioeconomic development (see Table 1 for a list of international organizations that have contributed significantly to the development of sustainability indicators). Today, hundreds of indicators and indices of sustainable development have been developed and used at the global, national, and local scales. For example, the Compendium of Sustainable Development Indicator Initiatives, created by the International Institute for Sustainable Development (a Canada-based policy research institute), lists 894 indicator initiatives as of August 2010 (http://www.iisd.org/measure/compendium/).

This chapter's main objectives are to review key conceptual and methodological issues of sustainability measures, examine a selected set of commonly used SIIs, and

Table 1. List of international organizations significantly contributing to the development of sustainability indicators.

| Name of organization | Web site |
|---|---|
| Balaton Group | http://www.balatongroup.org/ |
| International Institute for Sustainable Development (IISD) | http://www.iisd.org/ |
| Organization for Economic Co-operation and Development (OECD) | http://www.oecd.org/ |
| Scientific Committee on Problems of the Environment (SCOPE) | http://www.icsu-scope.org/ |
| United Nations Commission on Sustainable Development (CSD) | http://www.un.org/esa/dsd/csd/csd_index.shtml |
| United Nations Development Program (UNDP) | http://www.undp.org/ |
| United Nations Environment Program (UNEP) | http://www.unep.org/ |
| United Nations Statistical Division (UNSD) | http://unstats.un.org/unsd/default.htm |
| World Bank | http://www.worldbank.org/ |

discuss some of the major challenges and future directions. Owing to the complex nature of sustainability, the diversity of SIIs, and the proliferated literature on both topics, it is impossible to cover the entire range of sustainability measures in great detail. Our strategy here is to focus on the major themes and issues, and illustrate the uses and usefulness of SIIs through specific examples.

## 2. What is Sustainability?

As SIIs are designed to measure sustainability, any meaningful discussion on SIIs requires a basic understanding of what the concept of sustainability encompasses. In the search for solutions to the apparent conflict between conservation (the protection of natural resources) and development (the exploitation natural resources), the terms "sustainability" and "sustainable development" were coined in the early 1970s, and have acquired a great number of definitions since then (Kidd, 1992; Du Pisani, 2006). The most commonly cited definition of sustainable development or sustainability is the one given in the report by the United Nations World Commission on Environment and Development (WCED) chaired by Gro H. Brundtland (the former Prime Minister of Norway), published in 1987 and subsequently known as the Brundtland Report (WCED, 1987). The general and intentionally vague definition states that sustainable development is development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Thus, sustainability concerns our ability to maintain a coupled human–nature system at a desirable state for multiple generations in the face of anthropogenic and environmental perturbations and uncertainties. Considering the complexity arising from the multiplicity of components and their intricate interactions, it is difficult to define sustainability in specific terms without controversy.

However, if sustainability is to be more than a purely academic exercise or a political catchphrase, it must be operational. As Bell and Morse (2008) argue, "Sustainable development . . . embodies an ultimate practicality since it is literally meaningless unless we can 'do' it." At the very least, we need to adequately define what is to be sustained, what is to be developed, and how these components should be balanced or integrated (Kates *et al.*, 2005). Although it is by no means an actionable recipe, the concept of the triple bottom line, or the three pillars, of sustainability defines the major constituent domains of sustainable development (Fig. 1A). This perspective views sustainability as composing of three fundamental dimensions: environment, economy, and society (frequently, the three bottom lines have also been called "planet, people, and profit"). In each of the three domains, certain elements need to be sustained and others developed if sustainability is to be achieved.

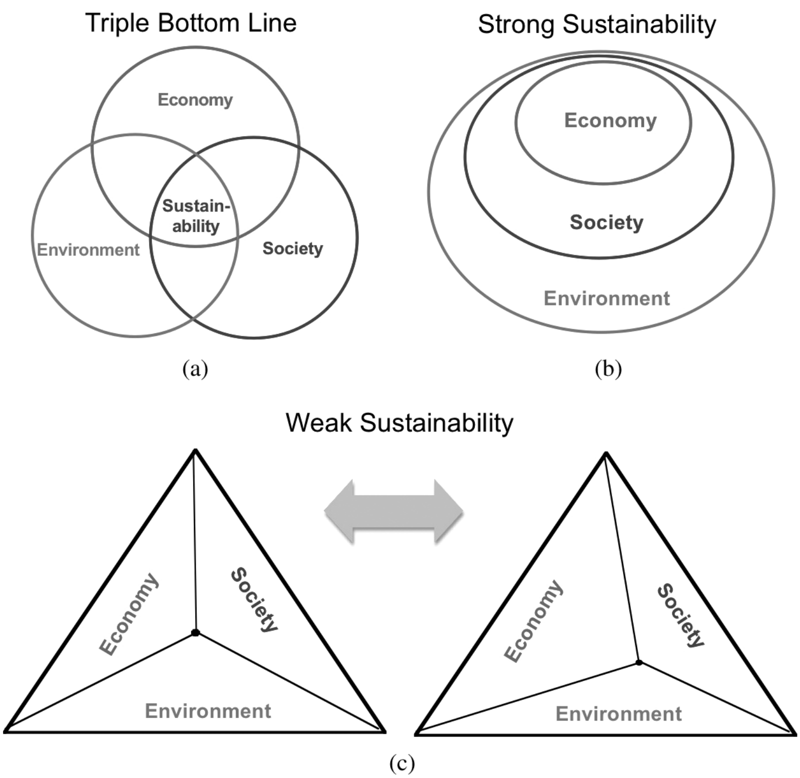



Fig. 1. Illustration of key components of sustainability and their relationships. (A) The triple bottom line concept, most commonly represented as a Venn diagram, implies that the three pillars are all necessary and equally important to sustainability. (B) Strong sustainability is depicted as three nested circles, implying that the environment provides natural resources and ecosystem services necessary for economic and social development — thus mutual substitutability between natural and human-made capital is not sensible. Economic development depends on both social and environmental capital, whereas both economic and social processes influence environmental conditions. (C) Weak sustainability focuses on the attainment of a non-declining level of the overall capital while allowing for mutual substitution between the three pillars of sustainability.

While the three dimensions are widely recognized in the literature, their relationships with each other remain controversial. For instance, can a high level of economic development be substituted for a low level of environmental quality? Whether or not sustainability allows for substitution between natural and human-made (manufactured) capital has been the focus of debate on "weak" *versus* "strong" sustainability (Ayres *et al.*, 1998). Weak sustainability permits mutual substitutability among the three dimensions, whereas strong sustainability does not (Fig. 1B,C). Because of the increased scarcity of natural resources and pressures on the environment imposed by the growing human population, the environmental dimension is increasingly recognized as a fundamental basis for sustainability. A simple yet compelling argument for this is that, without an adequate level of biodiversity and ecosystem functioning and services, no economic or social development is sustainable.

These conceptual issues have important implications for the construction and application of sustainability measures. For example, based on the triple bottom line concept, sustainability-related measures can be classified into environmental, economic, and social indicators, and only those that cover all three dimensions simultaneously can measure sustainability in its entirety. Whether strong or weak sustainability is used as an operational principle will in turn determine how overall sustainability is measured. The development of quantitative measures can help clarify and refine sustainability-related concepts, improve our understanding of the intricate relationships among components of sustainability in practical terms, and thus promote the science and practice of sustainable development. When constructing quantitative measures of sustainability, we have to explicitly specify what aspects of sustainability we want to measure, which ones we want to conserve or develop, and how these different aspects should be related to each other or integrated together. By so doing, the development of indicators can add rigor and accuracy to the notion of sustainability (although being quantitative and precise does not always translate into being rigorous and accurate).

## 3. What are Sustainability Indicators?

There are numerous definitions of indicator. Broadly speaking, an indicator can be a sign, symptom, signal, tip, clue, grade, rank, object, organism, or warning of some sort — many things in everyday life (Meadows, 1998). In a more restricted sense, as is often used in the scientific literature, an indicator refers to a variable or an aggregate of multiple related variables whose values can provide information about the conditions or trajectories of a system or phenomenon of interest. In other words, an indicator is simply "an operational representation of an attribute (quality, characteristic, property) of a system" (Gallopin, 1997).

For an indicator to be useful, there ought to be an established reference, benchmark, or threshold that represents a normal state, desired behavior, or goal to be achieved. For example, as we know what its normal range is, body temperature or blood pressure has become an indicator of our health conditions; when we know the speed limit of a given street, the speedometer of our car is an indicator that helps us avoid speeding tickets; when we know the atmospheric chemical composition in rural surroundings, the levels of greenhouse gases in a city can be indicators of air pollution due to urbanization. The reference levels or target values of indicators need to be determined based on relevant knowledge of the system of concern or shared understanding of the community that the system involves. Even for indicators whose reference levels or targets are difficult to define, the preferred direction of change should still be specified (e.g., household income or people's happiness).

Sustainability indicators are indicators that provide information on the state, dynamics, and underlying drivers of human–environmental systems. In general, indicators become sustainability (or unsustainability) indicators when time dimension, limits, or targets are associated with them (Meadows, 1998). The values of sustainability indicators are obtained from environmental and socioeconomic data from actual measurements or observations. A group of indicators used together for a particular purpose or project is often referred to as an indicator set. Sustainability includes environmental, economic, and social dimensions (sometimes institutions are listed as the fourth dimension), each of which has a number of components. Accordingly, indicators of sustainability can be as diverse as system components, and vary with regard to worldviews, purposes, and scales of time and space. Many indicators only reflect certain aspects of human–environmental systems, some are more integrative than others, and none is adequate to gauge the multiple dimensions of sustainability by itself.

On the other hand, presenting too many indicators can also be a problem by creating more confusion than understanding, especially when indicators differ in both the magnitude and direction of change. To reduce the number of indicators or to reflect the integrative characteristics of a system, indicators are often combined through mathematical manipulations to produce indices (Fig. 2). In other words, an index is an aggregate of two or more indicators. In reality, the distinction between an indicator and an index can be difficult and unnecessary because both are frequently aggregates of variables themselves, which means that their difference is merely a matter of the degree of aggregation. Thus, in the literature, the phrase "sustainability indicators" often includes both indicators and indices of sustainable development.

Sustainability researchers and specialists, increasingly working with stakeholders of different kinds, produce SIIs from environmental and socioeconomic data to inform policy makers and the public on implementing sustainability actions (Fig. 2). As the leaders in producing SIIs, researchers and specialists are usually responsible for data acquisition and processing as well as the subsequent construction of SIIs. The primary users of SIIs are intended to be policy makers and the public who often do not need, or care about, the details of the data used to generate SIIs. For the public, the most effective sustainability measures are often highly aggregated indices that are easy to understand and directly related to the environment and human well-being (Braat,

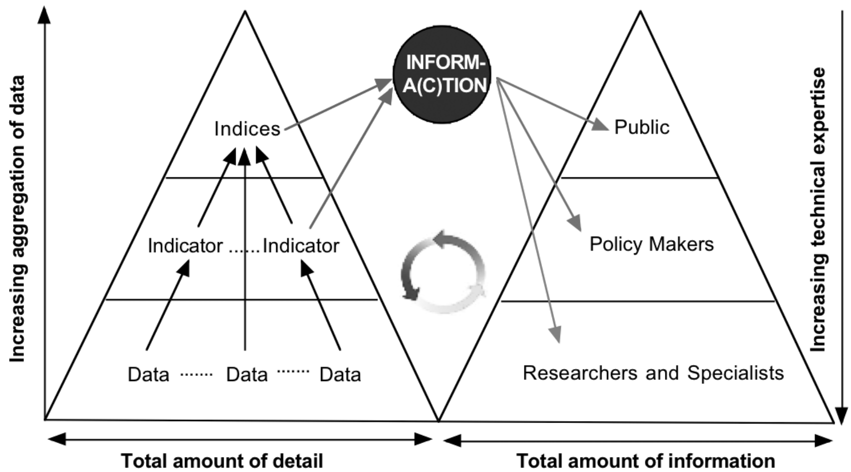



Fig. 2. Illustration of the relationship among data, indicators, indices, and information needed for sustainability actions, as well as the interactions between sustainability measures and their users and producers (based on Braat, 1991).

1991; Meadows, 1998; Bell and Morse, 2003). Such highly aggregated indices usually have the advantage of providing an overall picture of the state or performance of a system of interest in a simple and explicit way.

SIIs arguably represent the most popular approach to gauging sustainable development. Managing human–environmental systems would sustainably be impossible without using some kinds of indicators and indices. It is crucial, however, to understand that SIIs are not always objective, precise, or certain. In fact, many SIIs and the whole process of developing SIIs are to some extent subjective because of the nature of the indicators themselves (e.g., indicators representing social and cultural elements of sustainability) and our choice of specific indicators (e.g., selecting a particular indicator set over another). Also, some indicators are qualitative variables whose values are closely related to human values and perceptions. All SIIs have a degree of uncertainty that arises from the collection and analysis of data, the formulation of sustainability measures, and the unpredictable nature of the human–environmental systems. Thus, SIIs are not a panacea, but an indispensable tool for the science and practice of sustainable development. While SIIs have proven quite useful, utilizing them is still a process with many pitfalls.

## 4. Criteria and Frameworks for SIIs

### 4.1. *Criteria for selecting and evaluating indicators*

Determining what aspects of a system to monitor and what variables to use to gauge the state and performance of those aspects is critical to our understanding of sustainability. The principles and standards used in this process are reflective of our worldviews on what should be sustained and developed. Donella Meadows

(1998) said it well, "Not only do we measure what we value, we also come to value what we measure." It also seems true that the aspects that get measured are more likely to get managed and better understood by policy makers and the public. A good example of this measure–value–management phenomenon is Gross Domestic Product (GDP) or Gross National Product (GNP). Although most environmental experts understand that GDP is a poor and potentially misleading indicator of environmental and human well-being, it is still one of the most commonly used (and in many cases misused) indicators of performance by national and local governments (Wu and Wu, 2010). As the choice and use of indicators can profoundly influence our perception of the performance of a system, and as subjectivity cannot be eliminated from measuring sustainability, are there criteria that can guide us to develop more effective SIIs? There are. We discuss some commonly used ones below.

There are general guidelines and specific criteria for indicators. Among the most widely recommended are the "Bellagio Principles," a set of guidelines developed by an international group of sustainability researchers and practitioners from five continents at a conference in Bellagio, Italy, in 1996 (Hardi and Zdan, 1997). These principles can serve as instructions for sustainability assessment, including the selection and design of indicators as well as their interpretation and communication (Table 2). The Bellagio Principles focus on four aspects of sustainability assessment: clear vision and goals (Principle 1), key elements of sustainability assessment (Principles 2–5), issues of the process of assessment (Principles 6–8), and continuing capacity for assessment (Principles 9 and 10).

More specific criteria for selecting and evaluating sustainability indicators have frequently been discussed in the literature (Meadows, 1998; Bell and Morse, 2003; Hak *et al.*, 2007; UN, 2007). Commonly recognized criteria include the following aspects: an indicator set should cover the various dimensions of sustainability and their complex interactions; individual indicators should be indicative of the state and changes of the targeted aspects of sustainability; they should be informative, easy to compile from readily available and lasting data sources, understandable to lay-people, policy-relevant, predictive or leading, and hierarchical in terms of detail and scale; the methods for weighting and aggregating indicators to produce indices should be transparent and unbiased. A representative list of desired characteristics for sustainability indicators is provided in Table 3 (Guy and Kibert, 1998).

### 4.2. *Indicator frameworks*

An indicator framework is a conceptual structure based on sustainability principles and used to facilitate indicator selection, development, and interpretation. Using indicator frameworks can help us identify gaps in available data, indicator sets, and our overall understanding of the human–environmental system of concern. A number of indicator frameworks have been developed by international organizations (e.g., UNCSD, OECD) and other sources based on diverse core values and sustainable development theories (Meadows, 1998; UN, 2007; Ness *et al.*, 2007).

Table 2. The Bellagio Principles for sustainable development assessment (Hardi and Zdan, 1997).

| | Principle | Description |
|---|---|---|
| | | *Assessments of progress toward sustainable development should* |
| 1 | Guiding vision and goals | be guided by a clear vision of sustainable development and goals that define that vision |
| 2 | Holistic perspective | consider the well-being of the whole system and social, ecological, and economic sub-systems, and consider both positive and negative consequences of human activity |
| 3 | Essential elements | consider equity and disparity within the current population and between present and future generations, life-support systems, and economic development and non-market activities that contribute to human/social well-being |
| 4 | Adequate scope | adopt a time horizon long enough to capture both human and ecosystem time scales; define the space of study large enough to include not only local but also long distance impacts on people and ecosystems; and build on historic and current conditions to anticipate future conditions |
| 5 | Practical focus | have an organizing framework that links goals to indicators and assessment criteria, a limited number of key issues for analysis, a limited number of indicators, standardized measurements, and targets and reference values for indicators |
| 6 | Openness | make methods and data accessible to all, and all judgments, assumptions, and uncertainties explicit |
| 7 | Effective communication | be designed to address the needs of the audience and users; engage decision-makers; and aim for simplicity |
| 8 | Broad participation | obtain broad representation of stakeholders, and ensure the participation of decision-makers |
| 9 | Ongoing assessment | develop a capacity for repeated measurement to determine trends; be iterative, adaptive, and responsive to change and uncertainty; adjust goals, frameworks, and indicators; and promote development of collective learning and feedback to decision-making |
| 10 | Institutional capacity | clearly assign responsibility and provide ongoing support in the decision-making process; provide institutional capacity for data collection, maintenance, and documentation; and support development of local assessment capacity |

Major discrepancies among these indicator frameworks arise from the different conceptualizations of, and emphases on, key dimensions of sustainable development and their linkages, as well as the different ways of grouping and aggregating indicators. Here we discuss five types of frameworks that have been widely recognized in the literature.

#### 4.2.1. *Pressure–state–response (PSR) frameworks*

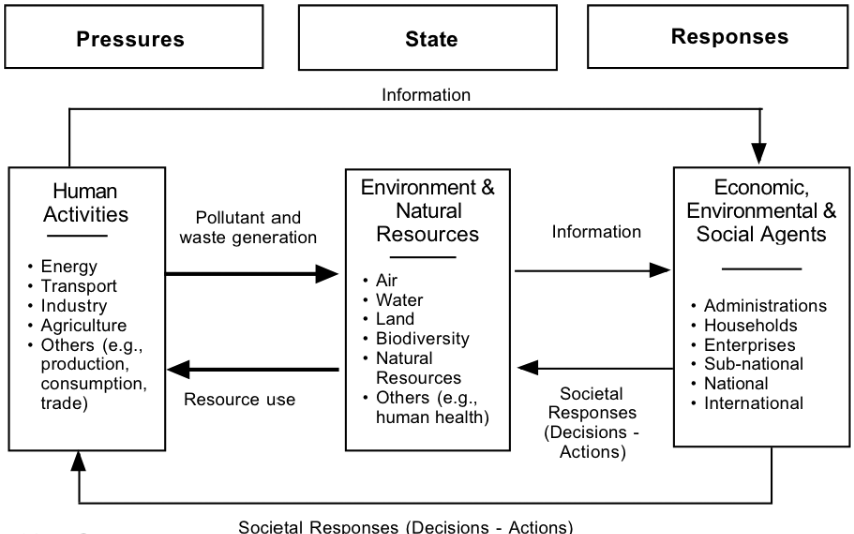
The PSR framework was one of the most popular early indicator frameworks (Fig. 3A) (OECD, 1993). Several versions of PSR frameworks have been developed by different organizations in the recent decades. The most widely recognized has been the Driving force–State–Response (DSR) framework, published in 1996, by the United

Table 3. Desired characteristics of sustainability indicators (Guy and Kibert, 1998).

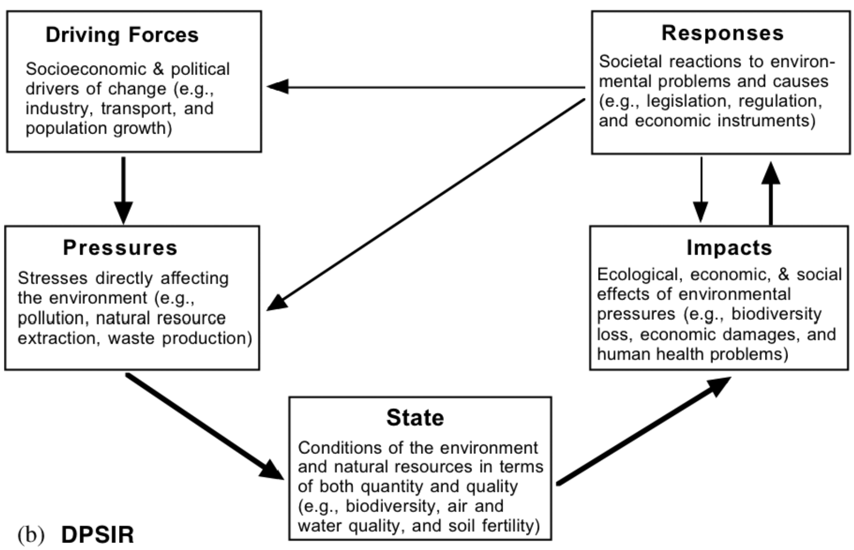
| Criteria | Corresponding questions |
|---|---|
| Community involvement | Were they developed by and acceptable to the stakeholders of the system of concern? |
| Linkage | Do they link environmental, economic, and social issues? |
| Valid | Do they measure something that is related to the state of the system? |
| Available and timely | Can the data be collected on a regular basis? |
| Stable and reliable | Are they compiled using a systematic and rigorous method? |
| Understandable | Are they simple enough to be understood by laypersons? |
| Responsive | Do they respond quickly and measurably to changes? |
| Policy relevance | Are they relevant to policy? |
| Representative | As a group, do they cover the important dimensions of the focus area? |
| Flexible | Are they important to use even if data are not readily available, considering the fact that data may be available in the future? |
| Proactive | Do they act as a warning rather than a measure of the existing state? |
| Long range | Do they focus on the long term? |
| Act locally, think globally | Do they promote sustainability at the expense of other communities, regions, or countries? |

Nations Commission on Sustainable Development (UNCSD) to guide the selection of indicators. In PSR and DSR frameworks, indicators of pressures or driving forces primarily represent anthropogenic processes that have positive or negative impacts on sustainable development. A corresponding question is: Why is the state of our environmental system changing? State indicators focus on the current conditions of the environment and natural resources in terms of both quantity and quality at a given time or during a period of time. A corresponding question then arises: What is happening to the state of our environmental system? Response indicators pertain to societal reactions to changes in the state of the environment and natural resources and the underlying drivers. This prompts another question: What are we doing about the state changes and underlying causes? An expanded version of DSR is the Driving force–Pressure–State–Impact–Response (DPSIR) framework (Fig. 3B), as used in the development of environmental indicators for North America (UNEP, 2006). To increase the relevance to policies, the DSR framework organizes all indicators of drivers, state, and responses according to four pillars of sustainable development (environment, economy, society, and institutions) and in accordance with the categories of sustainable development in Agenda 21.

The World Bank, as well as a number of other international and national organizations, has also adopted PSR-type frameworks (including the PSR, DSR, and DPSIR) in their efforts to develop sustainability indicators. Although they are conceptually appealing, the PSR frameworks have been criticized on several grounds. For example, the classification of indicators into categories such as driving force, state, and response is often ambiguous or impossible in practice because some indicators fall into more than one domain. In addition, the separation of different kinds of indicators makes it rather difficult to adequately consider the multiple




(a) **PSR**




(b) **DPSIR**

Fig. 3. Illustration of the pressure–state–response type of indicator frameworks: (A) PSR and (B) DPSIR.

causalities among indicators and the complex linkages among issues. Third, the system lacks a clear and close connection between indicators and policy issues. Because of these recognized problems, the UNCSD abandoned the DSR framework in favor of a more flexible theme-based framework that focuses more explicitly on sustainability-related issues. The PSR frameworks seem more appropriate for developing environmentally oriented indicator sets, and because of this, they will likely remain in existence (UNEP, 2006; UN, 2007).

### 4.2.2. *Theme-based frameworks*

Theme- or issue-based frameworks provide a flexible conceptual structure that organizes indicators around key themes or issues typically determined by policy relevance (UN, 2007). The best-known example has been the 2001 UNCSD theme-based framework that replaced the DSR framework (UNCSD, 2001). The UNCSD theme-based framework has a hierarchical structure: along the four dimensions of sustainable development (social, environmental, economic, and institutional), 15 themes are identified, which in turn are divided into 38 sub-themes, for which a total of 58 indicators are then identified (Fig. 4). The thematic framework has

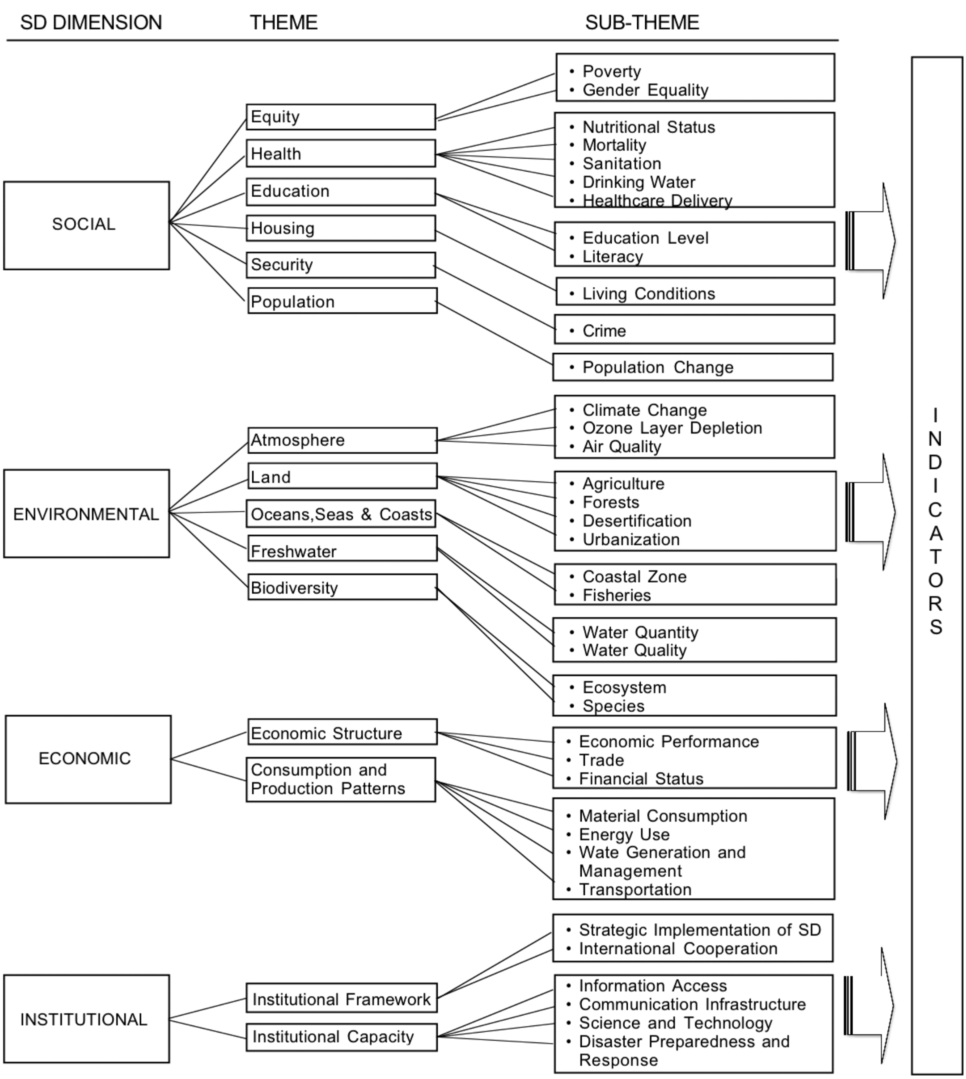



Fig. 4. Illustration of the theme-based indicator framework adopted by UNCSD in 2001.

fewer indicators, but is more policy-oriented than the DSR framework (which has 134 indicators in total).

UNCSD revised the theme-based framework again in 2007 based on evolving perspectives on indicators and the experience in applying the framework at the national and regional levels (UN, 2007). The revised UNCSD theme-based framework retains the thematic and sub-thematic structure, but further emphasizes the multi-dimensional and integrative nature of sustainable development by making the four sustainability dimensions implicit and adding crosscutting themes such as poverty and natural hazards. It also incorporates the eight Millennium Development Goals (MDGs; i.e., eradicate extreme poverty, achieve universal primary education, promote gender equality and empower women, reduce child mortality, improve maternal health, combat HIV/AIDS, malaria and other diseases, ensure environmental sustainability, and develop a global partnership) as well as the Johannesburg Plan of Implementation (UN, 2007). The 2007 UNCSD theme-based framework has 14 themes, 44 sub-themes, 50 core indicators, and a total of 96 indicators. A total of 14 themes are now poverty, governance, health, education, demographics, natural hazards, atmosphere, land, oceans, seas and coasts, freshwater, biodiversity, economic development, global economic partnership, and consumption and production patterns.

### 4.2.3. *Capital-based frameworks*

Capital frameworks attempt to calculate the wealth of a nation or a region as a function of different kinds of capital (UN, 2007). The capital approach borrows the concept of capital from economics, and expands it to include several types of capital: manufactured or built capital (all produced assets that form the human economy in a traditional sense), natural capital (the natural environment and resources), human capital (capacities of people to work, including knowledge, skills, and health), and social capital (stocks of social networks, trust, and institutional arrangements). An example of a capital-based framework is the Daly's Triangle-based system advocated by the Balaton Group, an international network of researchers and practitioners in the field of sustainable development, in which natural, built, human, and social capitals are identified (Meadows, 1998).

The different forms of capital are usually expressed in the same monetary terms, so that they can be aggregated. Sustainable development, in this context, may be interpreted differently depending on whether a strong or weak sustainability perspective is taken. Can natural capital be replaced by other types of capital at all? What natural resources and ecosystem services are substitutable? What are the limits to such substitutions? These are some of the critical questions that must be addressed when capital frameworks are used. Other challenges to using a capital framework include problems of monetizing different forms of capitals, controversies on substitutability, and issues on intra-generational equity (UN, 2007).

### 4.2.4. *Integrated accounting frameworks*

Integrated accounting frameworks refer to synthesized economic and environmental accounting systems based on national accounting methodologies. The most prominent example is the System of Integrated Environmental and Economic Accounting (SEEA), developed jointly by United Nations, European Commission, International Monetary Fund, OECD, and World Bank in 2003 (Hecht, 2006; UN, 2007). SEEA integrates environmental accounting with the standard System of National Accounts (SNA). It includes four categories of accounts: (1) physical data on material and energy flows, (2) data on environmental management and environment-related transactions, (3) accounts of environmental assets, and (4) accounts of transactions and adjustments related to the impact of the economy on the environment. Thus, instead of just producing a set of indicators, SEEA provides full accounts of environmental and economic capitals and flows. It has also been used for developing indicators and policy analysis.

However, integrated accounting frameworks such as the SEEA have not taken into consideration the social and institutional dimensions of sustainable development, although efforts to incorporate human and social capital are under way (UN, 2007). Nevertheless, the implementation of SEEA not only serves its own purposes, but also benefits the application of other indicator frameworks, particularly capital-based frameworks. Theme-based frameworks can also profit from SEEA because a consistent database facilitates the development and disaggregation of thematic indicators that can further policy analysis and design. The latest version of the UNCSD indicator framework has, therefore, strengthened its relationship with SEEA (UN, 2007).

### 4.2.5. *Bossel's orientor framework*

Bossel's orientor framework is a systems-theoretical framework for developing indicators of sustainable development (Bossel, 1977, 1999, 2001). This approach is intended to provide a holistic and comprehensive conceptual structure to guide indicator development. The framework has a nested hierarchical appearance that somewhat resembles Daly's Triangle. The orientor theory assumes that any ecological and socioeconomic system can be characterized by six fundamental environmental properties: a normal environmental state, resource scarcity, variety, variability, change, and other systems. These properties "constrain development possibilities and limit management opportunities on all spatial scales," and render "orientors," which are general categories of our key concerns, values or interests that "orient most of our decisions" (Bossel, 1999, 2001). In the context of sustainable development, Bossel (2001) described seven basic orientors as follows:

(1) *Existence*: The system must be compatible with and able to exist in the normal environmental state. The information, energy, and material inputs needed to sustain the system must be available.

(2) *Effectiveness*: The system should, on balance over the long term, be effective (not necessarily efficient) in its efforts to secure required scarce resources (information, matter, energy) and to exert influence on its environment when necessary.
(3) *Freedom of action*: The system must have the ability to cope in various ways with the challenges posed by environmental variety.
(4) *Security*: The system must be able to protect itself from the detrimental effects of environmental variability, i.e., variable, fluctuating, and unpredictable conditions outside the normal environmental state.
(5) *Adaptability*: The system should be able to learn, adapt, and self-organize to generate more appropriate responses to the challenges posed by environmental change.
(6) *Coexistence*: The system must be able to modify its behavior to respond appropriately to the behavior of the other systems in its environment.
(7) *Psychological needs*: These constitute an additional orientor for sentient beings.

For a system to achieve sustainability, these basic orientors must be satisfied; they usually cannot be measured directly, but their states of fulfillment can be inferred from appropriate indicators. A major advantage of this approach is that it "avoids the problems of incompleteness and double-counting common in ad hoc methods of indicator selection" (Bossel, 2001). Orientor-based indicators are expected to capture the essential aspects of the vitality, performance, and sustainability of human–environmental systems, and their results are typically represented as polygonal graphs known as "orientor stars" (Bossel, 1999, 2001).

## 5. Composite Indicators — Sustainability Indices

In this section, we discuss a selected set of composite sustainability indices that are usually obtained by aggregating a number of indicators selected from a specific framework. A large number of such indices exist, but we focus on a small set of the most commonly used. As discussed below, some of these indices are more sustainability-relevant than others.

### 5.1. *Green GDP*

The most popular brand of economics-based measures is the GDP. This procedure of accounting comes in many derivates, including GNP, Net National Product (NNP), and the increasingly common emendation known as "Green GDP." Although the GDP still occupies pride of place in the collection of related measures, conceptual nuances between the metrics reflect attempts to better approximate certain social and financial concerns. For instance, GNP takes into account international income transfers, and NNP is meant to accommodate the economic effects of capital depreciation. Mainly because their scope is delimited completely by the market, these traditional measurements omit many of the important goods and services that humans derive from nature. Thus, these indicators account for economic development but do not reflect actual human or environmental well-bring (Wu and Wu, 2010). Actually, empirical data show that GDP is often negatively correlated with environmental quality, and its positive correlation with social well-being measures disappears after GDP reaches a certain level. Green GDP, a newer addition to this family of indicators in the early 1990s, was developed to factor in the effects of natural resource consumption and pollution on human welfare (Wu and Wu, 2010). Green GDP is meant to correct such biases by expanding the coverage of accounting to include many, but certainly not all, of the values that people derive from nature.

### 5.2. *Human development index (HDI)*

In an effort to assess the levels of human and social development of different countries around the world, the United Nations Development Program (UNDP) created HDI. A main goal of developing HDI was to "...shift the focus of development economics from national income accounting to people centered policies" (Ul Haq, 1995). Since its inception in the 1990s, HDI has become a standard and widely reported indicator in many official reports and academic publications — most notably the UNDP's Annual Human Development Reports. The index is composed of three primary aspects: life expectancy, education, and standard of living. The education dimension is addressed using a combination of adult literacy rate and enrollment ratio, whereas the standard of living is computed from GDP per capita, adjusted for purchasing power parity. Together with life expectancy calculations, these two measurements are collated into an index taking on a value between 0 and 1 (although no country actually assumes the highest value, and only a handful of countries fall below 0.4). A major criticism of HDI is its abstraction from the environmental dimension of human welfare. As pointed out by many economists and ecologists, human welfare is inevitably a function of natural resources, and the failure to take this fact into account paints a distorted picture of development. In addition, HDI has focused only on the national and global levels of analysis.

### 5.3. *Inclusive wealth (IW) and genuine savings (GS)*

Unlike GDP and Green GDP, which are "flow" measures, IW and GS are stock-based. IW and GS derive national income and resource use data from the SEEA, designed by the United Nations. It is an emendation of the more standard SNA used in more traditional calculations of economic performance. The economic patterns of production and consumption are necessarily contingent upon the availability and configuration of the base of available resources, or capital. Thus, inter-temporal (e.g., cross-generational) transfers of economic opportunity are best represented by the value of capital stocks. The "inclusive" and "genuine" of the nomenclature derive largely from the inclusion of natural resources into economic accounting.

From this formulation, an intuitive criterion for sustainability follows: a country or region is "sustainable" over a given period if its IW or GS per capita does not decline over that time. A country can grow in both GDP and HDI while declining in wealth per capita (Arrow *et al.*, 2004). When set against this new capital-oriented development standard, and taking into account the role of natural resources, the optimism regarding the expansion of welfare is greatly tempered by much lower (often negative) values. Despite the potential for more accurate approximation of sustainability, it is not standard practice to keep stock-based measurements of economic development, and GDP and HDI still prevail as the most common development indicators at the national and regional levels.

### 5.4. *Genuine Progress Indicator (GPI) and Index of Sustainable Economic Welfare (ISEW)*

GPI and ISEW are essentially equivalent measures, with the former being more widely recognized and implemented (Lawn, 2003). Both take cues from Green GDP, amending the standard flow-based metric of economic performance to consider the role of environmental well-being. However, unlike Green GDP, which is primarily a project of augmenting the standard national accounting framework, GPI or ISEW divides economic transactions between those that make a positive contribution to human welfare and those that make a negative contribution. A classic example of the rationale underlying this dichotomy is the case of an oil spill. While an environmental disaster of this kind is surely inimical to any coherent sense of welfare, it may actually enhance GDP due to the increased number of transactions it elicits (even if they are only carried out to redress an unfortunate problem that did not have to happen in the first place). Additionally, GPI and ISEW also include imputed values of non-marketed goods and services (both social and ecological), and adjust for income distribution effects. Thus, GPI and ISEW attempt to separate the "goods" from the "bads," and provide a more holistic and sensible assessment of economic activities.

### 5.5. *Material flows accounting (MFA)*

The flow of materials through an economy can provide an insightful indication of the sustainability of the system *vis-à-vis* its resource base. Unlike Green GDP, which is also a "flow-based" measure, MFA attempts to quantify physical value in weight, not monetary value in currency (Adriaanse *et al.*, 1997; Matthews *et al.*, 2000). It monitors the weight of a number of different material flows, including production inputs and outputs, matter moved in the environment to access resources (such as excavated soil), and residual material from the production process (Hecht, 2006). This focus on the "direct ingredients" of production and consumption cuts out the "middleman" of monetary valuation. MFA produces a single metric of system performance by aggregating different material flows into the total material requirement (TMR) of a given economy. This summary indicator is meant to give a picture of the entire physical metabolism of the economic system. Although monetary accounting is still more widespread, MFA has been expanding and been carried out in a number of countries and regions (Ness *et al.*, 2007). The Statistical Office of European Communities (Eurostat), a research body tasked with *inter alia* the collection and calculation of comparative, performance-related data for European countries, developed an economy-wide MFA that is the most standardized tool for assessment (Ness *et al.*, 2007). This guideline divides material flows into three categories: input, output, and consumption. Further, within each of these categories there are levels indicating whether the flows cover domestic, foreign, and/or hidden — which are materials not included in economic accounting, such as soil erosion (Matthews *et al.*, 2000).

### 5.6. *Ecological footprint (EF)*

EF is primarily a measure of human appropriation of natural resources, and defined as the land (and water) area that would be required to support a defined human population indefinitely in terms of providing all the energy/material resources consumed and to absorb all the wastes discharged (Wackernagel and Rees, 1996). The basic unit of measurement is the "global hectare," a normalized unit capturing the average biocapacity of all hectares of all biologically productive lands in the world. Consumption patterns of natural resources, from energy to biomass, can be converted to this common metric. This simple but comprehensive measure allows us to compare our demands of the planet's ecosystems to the regenerative capacity of those ecosystems. In this sense, we can create a direct correspondence between our present standard of consumption and the capability of the biosphere to support that standard. According to recent studies using EF analysis, humanity is currently exceeding the biocapacity of the planet by approximately 20% (Wackernagel *et al.*, 2002), or we are consuming our natural capital at 1.2 times the rate at which they are being regenerated. Since its inception in the early 1990s, EF has become a widely influential indicator of human–environment impact, spawning a large body of literature and analysis. The popularity of its application may derive from the fact that it can be employed over a broad range of activities and at varying levels from individuals to the globe. However, EF analysis has not been without criticism, with much of the concerns targeted toward its abstraction from the roles played by technology, land degradation, the demarcation of spatial boundaries (Fiala, 2008; van den Bergh and Grazi, 2010; van den Bergh and Verbruggen, 1999).

### 5.7. *Happy Planet Index (HPI)*

HPI was developed, by the New Economics Foundation (http://www.happyplanetindex.org/), as an alternative to measures like HDI or GDP. Although still advocating human-oriented measures, HPI directly combines human welfare with human consumption of natural resources. Different from the standard account of welfare, which is largely defined as a simple function of consumption, HPI defines human well-being in "happy life years" — a combination of life expectation and life expectancy. The indicator is then calculated as the ratio between happy life years and environmental impact, which is measured by the EF. HPI is intended to measure "the ecological efficiency with which human well-being is delivered around the world" (New Economics Foundation, 2009).

### 5.8. *Environmental Sustainability Index (ESI) and Environmental Performance Index (EPI)*

Published between 1999 and 2005, ESI is, like MFA and EF, mainly a biophysical indicator of natural resource use by humanity. ESI was produced by the Center for Environmental Law and Policy at Yale University and Columbia University's Center for International Earth Science Information Network (ICESIN), in collaboration with the World Economic Forum and the European Commission's Joint Research Center. The computational methodology behind ESI involves combining 76 variables into 21 metrics, which are then averaged to yield a single index. ESI was succeeded by EPI, which was developed by the same institutions and has been published in 2006, 2008, and 2010 (http://sedac.ciesin.columbia.edu/es/epi/). Environmental performance, with a focus on assessing current environmental conditions, differs from the original ESI theme of gauging long-term environmental trajectory. While ESI had five assessment themes (i.e., environmental systems states, reducing environmental stress, reducing human vulnerability, institutional capacity, and global stewardship), EPI narrows its aims to two objectives: environmental health and ecosystem vitality. The change in orientation is illustrated by how the two indices differ in analyzing forest management. The 2005 ESI focused on the annual change in forest cover and percentage of total forest area certified for sustainable management. The 2008 EPI, on the other hand, simply used the change in growing stock as a proxy for management performance. EPI is supposed to provide a report of "more immediate value to policymakers" and, as of the 2010 publication, 163 countries are included in the analysis (http://sedac.ciesin.columbia.edu/es/epi/).

## 6. Conclusion

Is there a comprehensive, all-inclusive measure of sustainability, or must sustainability be measured from multiple aspects? It is not uncommon for the idea of sustainability to be subdivided into more specific, but still broad, categories such as social, ecological, and economic. However, the extents to which such classifications are valid, and the rationale for their construction as opposed to dissections that are even more specific (e.g., from social to cultural and demographic, from ecological to biophysical and geophysical), are inevitably subjective. It may be argued that in any conceptual anatomization of so general an idea as sustainability, there is no principled point at which to draw methodological standards. If cogently formed and supported by rigorous analysis, however, a certain set of metrics may be more appropriate than others for a given set of objectives or a particular region. Our review of the development of SIIs during the past several decades illustrates these points.

Depending on the organizing framework or perspective chosen, one may arrive at vastly different conclusions about the system of interest. For example, interpretations about sustainability that are drawn from Green GDP may not mean much if one rejects the premise of weak sustainability, or, more broadly, any framework of measurement centered on economic valuation. At the same time, while an indicator such as TMR is more "direct" in its treatment of underlying environmental factors, without a way to translate the effects into a language relatable to human welfare, it may be difficult to craft coherent policies. Thus, selecting and evaluating SIIs must begin with a set of guiding sustainability principles, and an understanding of the frameworks that correspond to these criteria. Only then the relevant indicators or indices can be properly contextualized and articulated for policy-making purposes.

It has been increasingly recognized that the most essential value of the term "sustainability" or "sustainable development" lies in its emphasis on unifying the relevant dimensions — of which environmental, economic, and social are common classifications. Accordingly, sustainability measures must focus on the integrative whole of human–environmental systems. As Meadows (1998) pointed out: "Sustainability indicators must be more than environmental indicators; they must be about time and/or thresholds; Development indicators should be more than growth indicators; they should be about efficiency, sufficiency, equity, and quality of life." In our efforts to operationalize sustainable development, indicators and indices are indispensable for creating scientific understanding and shaping policy. As the future unfolds, these metrics must continue to evolve in complexity and nuance to keep pace with the demands of escalating environmental and socioeconomic problems. The search for adequate and effective indicators of sustainability is an evolutionary and learning process (Meadows, 1998). This will require substantial contribution from the social and natural sciences, as well as increasing levels of participation from stakeholders of all kinds.

## References

Arrow, K., Dasgupta, P., Goulder, L., Daily, G., Ehrlich, P., Heal, G., Levin, S., Mäler, K.-G., Schneider, S., Starrett, D. and Walker, B., 2004. Are we consuming too much? *Journal of Economic Perspectives* **18**, 147–172.

Ayres, R.U., van den Bergh, J.C.J.M. and Gowdy, J.M., 1998. Viewpoint: Weak versus strong sustainability. *Tinbergen Institute Discussion Papers No 98-103/3*, Tinbergen Institute. URL: http://www.tinbergen.nl/discussionpapers/98103.pdf.

Bell, S. and Morse, S., 2003. *Measuring Sustainability: Learning by Doing*. Earthscan, London.

Bell, S. and Morse, S., 2008. *Sustainability Indicators*: *Measuring the Immeasurable*? 2nd ed. Earthscan, London.

Bossel, H., 1999. *Indicators for Sustainable Development*: *Theory, Method, Applications* (*A Report to the Balaton Group*). International Institute for Sustainable Development, Winnipeg.

Bossel, H., 2001. Assessing viability and sustainability: A systems-based approach for deriving comprehensive indicator sets. *Ecology and Society* **5**, 12. URL: http://www.consecol.org/vol15/iss12/art12/.

Braat, L., 1991. The predictive meaning of sustainability indicators. In: Kuik, O. and Verbruggen, H. (Eds), *In search of Indicators of Sustainable Development*. Kluwer Academic Publishers, Dordrecht, pp. 57–70.

Du Pisani, J.A., 2006. Sustainable development — historical roots of the concept. *Environmental Sciences* **3**, 83–96.

Gallopin, G.C., 1997. Indicators and their use: Information for decision-making. In: Moldan, B. and Billharz, S. (Eds), *Sustainability Indicators*. Wiley, New York, pp. 13–28.

Guy, G.B. and Kibert, C.J., 1998. Developing indicators of sustainability: US experience. *Building Research and Information* **26**, 39–45.

Hak, T., Moldan, B. and Dahl, A.L. (Eds.), 2007. *Sustainability Indicators*: *A Scientific Assessment*. Island Press, Washington, D.C.

Hardi, P. and Zdan, T., 1997. *Assessing Sustainable Development*: *Principles in Practice*. Internation Institute for Sustainablie Development, Winnipeg, Manitoba.

Hecht, J.E., 2006. Can indicators and accounts really measure sustainability? Considerations for the U.S. Environmental Protection Agency. *US EPA Workshop on Sustainability*. URL: http://www.epa.gov/sustainability/other_resources.htm.

Kareiva, P., Watts, S., McDonald, R. and Boucher, T., 2007. Domesticated nature: Shaping landscapes and ecosystems for human welfare. *Science* **316**, 1866–1869.

Kates, R.W., Parris, T.M. and Leiserowitz, A., 2005. What is sustainable development? Goals, indicators, values, and practice. *Environment*: *Science and Policy for Sustainable Development* **47**, 8–21.

Kidd, C.V., 1992. The evolution of sustainability. *Journal of Agricultural and Environmental Ethics* **5**, 1–26.

Lawn, P.A., 2003. A theoretical foundation to support the Index of Sustainable Economic Welfare (ISEW), Genuine Progress Indicator (GPI), and other related indexes. *Ecological Economics* **44**, 105–118.

Matthews, E., Amann, C., Bringezu, S., Fischer-Kowalski, M., Huüttler, W., Kleijn, R., Moriguchi, Y., Ottke, C., Rodenburg, E., Rogich, D., Schandl, H., Schuütz, H., van der Voet, E. and Weisz, H., 2000. *The Weight of Nations*: *Material Outflows from Industrial Economies*. World Resources Institute, Washington, D. C.

Meadows, D., (Ed.), 1998. *Indicators and Information Systems for Sustainable Development*. Sustainability Institute, Hartland Four Corners, Vermont.

Ness, B., Urbel-Piirsalu, E., Anderberg, S. and Olsson, L., 2007. Categorising tools for sustainability assessment. *Ecological Economics* **60**, 498–508.

New Economics Foundation, 2009. The (Un)Happy Planet Index 2.0. URL: http://www.happyplanetindex.org/public-data/files/happy-planet-index-2-0.pdf.

Niemi, G.J. and McDonald, M.E., 2004. Application of ecological indicators. *Annual Review of Ecology, Evolution and Systematics* **35**, 89–111.

OECD, 1993. *OECD Core Set of Indicators for Environmental Performance Reviews*. Organization for Economic Co-operation and Development, Paris.

Ul Haq, M., 1995. *Reflections on Human Development*. Oxford University Press, New York.

UN, 2007. *Indicators of Sustainable Development: Guidelines and Methodologies*, 3rd ed. United Nations, New York.

UNCSD, 2001. *Indicators of Sustainable Development: Guidelines and Methodologies*. UN Commission on Sustainable Development.

UNEP, 2006. *Environmental Indicators for North America*. United Nations Environment Programme, Washington, DC.

Wackernagel, M. and Rees, W.E., 1996. *Our Ecological Footprint: Reducing Human Impact on the Earth*. New Society Publishers, British Columbia, Canada.

Wackernagel, M., Schulz, N.B., Deumling, D., Linares, A.C., Jenkins, M., Kapos, V., Monfreda, C., Loh, J., Myers, N., Norgaard, R. and Randers, J., 2002. Tracking the ecological overshoot of the human economy. *Proceeding of the National Academy of Sciences of the United States of America* **99**, 9266–9271.

WCED, 1987. *Our Common Future*. Oxford University Press, New York.

Wu, J., 2008. Making the case for landscape ecology: An effective approach to urban sustainability. *Landscape Journal* **27**, 41–50.

Wu, J., 2010. Urban sustainability: An inevitable goal of landscape research. *Landscape Ecology* **25**, 1–4.

Wu, J. and Wu, T., 2010. Green GDP. In: *Berkshire Encyclopedia of Sustainability, Vol. II — The Business of Sustainability*. Berkshire Publishing, Great Barrington, pp. 248–250.