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Review article

Strengths and weaknesses of common sustainability indices for multidimensional systems

Audrey L. Mayer *

Department of Biological and Environmental Sciences, Faculty of Biosciences, P.O. Box 27 (Latokartanonkaari 3), FI-00014 University of Helsinki, Finland

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Abstract

Sustainability is rapidly moving from an abstract concept to a measurable state of dynamic human-ecological systems. The large number of economic, social, and environmental indicators currently available provides an unwieldy view of system sustainability. To aid policy decisions, these indicators are therefore either presented in the context of a conceptual framework, or quantitatively aggregated into indices. Due to the quantitative nature of sustainability indices, their results may be given more weight by scientists and policy-makers. However, policy decisions can be ineffective or even counterproductive if they do not consider factors which influence index behavior: the scale of the available data and choice of system boundaries; the inclusion, transformation, and weighting of indicator data; and the aggregation method used. As previous reviews have demonstrated, sustainability indices do not rank countries consistently, even when using some of the same indicator data. Several improvements would increase the utility of sustainability indices for policy decisions, particularly the identification of biases introduced by the index methodology and data inclusion. The discrepancy of current sustainability indices due to theoretical or methodological differences supports the use of several complementary indices.

Keywords: Sustainability; Indices; Indicators; Ecological; Social; Economic; Aggregation methods

Contents

* Tel.: +358 9191 57908; fax: +358 9191 58462.
E-mail address: audrey.mayer@helsinki.fi.

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1. Introduction

1.1. What is sustainability?

Sustainability has been defined as the level of human consumption and activity which can continue into the foreseeable future, so that the systems which provide goods and services to humans persist indefinitely (WCED, 1987; US National Research Council, 1999). The practical implications of this definition are diverse, ranging from the consumption of resources with respect to their rate of renewal, the efficiency of resource use, and the equity of their use across societies and generations, with different emphases according to discipline and political ideology (Ulgiati and Brown, 1998; Parris and Kates, 2003). However, recent sustainability research has become more quantitative and includes more dimensions of sustainability simultaneously (Fig. 1), which will allow for more targeted policies to be implemented and their successes tracked more closely.

There are several different conceptual foundations currently used in quantitative sustainability research. Foundations such as Hicksian income from economics (see Section 3.3.1) and life cycles and materials flows from industrial ecology (Jelinski et al., 1992; Ehrenfeld, 2004), offer outlooks which give more emphasis to the human dimension of sustainable socioeconomic systems. A foundation based on dynamic systems and catastrophe theory increases the applicability of the research to any system regardless of type and size, as its wide variety of models can identify critical feedbacks across seemingly disparate dimensions of a system. All dynamic systems, such as ecosystems, factories, and countries, have many feedbacks and nonlinear relationships among their components. These interactions and feedbacks can result in long periods of relative stasis, punctuated by very rapid shifts to new conditions or "regimes" when systems are overwhelmed by a disturbance (Thom, 1972; Carpenter, 2003). The sustainability of human–environment systems is determined through three main characteristics: resilience to disturbances, both natural and anthropogenic; desirability to human societies; and (often implicit) temporal and spatial scale boundaries. Resilience and desirability determine policy goals, and the scale determines the system to be monitored and managed to reach those goals.

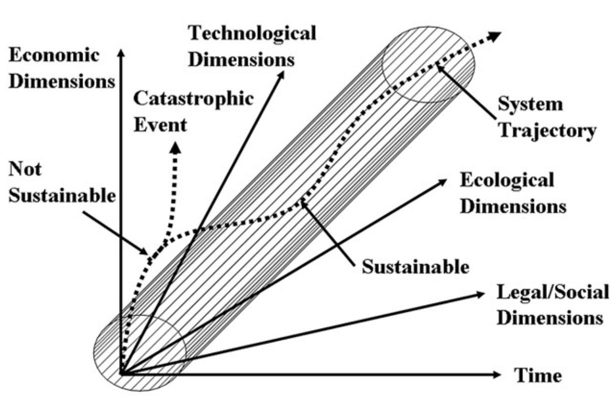

Fig. 1. The trajectory of a system, and the position of the system with respect to multidimensional sustainable boundaries, are both necessary to determine system sustainability. A system which is unsustainable in one dimension is not generally sustainable. Multiple indicators are measured for each dimension, and aggregated into an index which identifies the overall position and trajectory of the system (modified from Cabezas et al., 2003).

1.1.1. Resilience

The concept and measurement of resilience as developed in ecology was inspired by dynamic systems theory and catastrophe theory (Carpenter, 2003; Fiksel, 2006). Its use in other disciplines and application to multidimensional systems is increasing, particularly with respect to sustainable systems management (Walker et al., 2002; Mayer et al., 2004; Folke et al., 2005; Fiksel, 2006; Garmestani et al., 2006; Kinzig et al., 2006). Dynamic regimes (also called "alternative stable states", Mayer and Rietkerk, 2004) are areas of state space in which a system can persist in the presence of disturbances. The resilience of a regime is the degree to which the system can adjust to disturbances without shifting to a new regime (Holling, 1973; Grimm and Wissel, 1997; Carpenter et al., 2001). The system remains in that regime because of feedbacks between components of the system that prevent the system from straying too far. However, if a system moves into a new regime, new feedbacks will form to maintain the system in the new regime. Feedbacks in dynamic systems tend to be self-organizing (Carpenter, 2003; Rietkerk et al., 2004). Human activities which increase the sustainability of one system dimension (e.g., economic well-being) at the expense of another (e.g., ecological