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Methodological and Ideological Options

Nested open systems: An important concept for applying ecological footprint analysis to sustainable development assessment

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ABSTRACT

The calculation procedures and index interpretation of ecological footprint (EF) analysis, a method for assessing sustainable development (SD), have been continuously improved since the early 1990s. To identify potential for further improvement, this study compared the information revealed by existing EF applications for SD assessment with the core concerns of SD and found that intra-generational equity has not been appropriately addressed in the existing applications of EF analysis for SD assessment because the concept of nested open systems has been ignored. This study then argued that the concept of nested open systems should play a critical role in addressing global SD and conducting national EF analysis for SD assessment. Finally, the potential for improving EF analysis for SD assessment at the global and national scales was discussed.

1. Introduction

The process of developing indicators for sustainable development (SD) typically includes the following stages: goal/dimension setting, indicator construction, indicator application, indicator assessment, and indicator revision. Of these stages, indicator application generally attracts substantial attention when results are presented in the literature. For example, ecological footprint (EF) analysis has received substantial criticism and was the subject of a great deal of debate during the late 1990s and the early 2000s (for examples, please see Andersson and Lindroth, 2001; Ayres, 2000; Costanza, 2000; Deutsch et al., 2000; Ferguson, 1999, 2002; Haberl et al., 2001; Herendeen, 2000; van den Bergh and Verbruggen, 1999), the first decade when its applications were formally presented in the ecological economics literature. Certain criticisms have played an important role in improving the use of EF analysis as a tool for SD assessment (see Monfreda et al., 2004; Wackernagel et al., 1999a, 2004b). For example, the original interpretation of ecological deficit as overshoot at all spatial scales has been refined to mean overshoot occurring only at the global scale but not at other spatial scales (Wackernagel et al., 2004b). That is, the interpretation of the ecological deficit would depend on the spatial scale of the human society under examination.

As sustainable development indicator (SDI) applications accumulate, attention generally shifts to the assessment of existing SDIs. One line of research has focused on comparing SDIs by examining their strengths and weaknesses (for examples, see Böhringer and Jochem, 2007; Mayer, 2007; Mori and Christodoulou, 2012; Ness et al., 2007; Rametsteiner et al., 2011; Ramos and Caeiro, 2010; Singh et al., 2012) or by applying selected SDIs to a specific study area and then comparing the results (for examples, see Graymore et al., 2008; Hanley et al., 1999; Niccolucci et al., 2007; Nourry, 2008; Siche et al., 2008). Another line of research has attempted to identify efforts that can further improve a particular SDI (for examples, see Borucke et al., 2013; Haberl et al., 2001; Hueting and Reijnders, 2004; Kitzes et al., 2009; Lenzen and Murray, 2001; Uwasu and Yabar, 2011; van Vuuren and Smeets, 2000). Existing SDIs are typically developed based on the specific dimension(s) that researchers focus on in their SD concepts (Gasparatos and Scolobig, 2012), and inconsistent assessment results can be obtained when a study area is assessed using different SDIs (for examples, see Hanley et al., 1999; Mayer, 2007). The results of the first line of research can provide useful information on how the examined SDIs can complement one another in examining a defined human society or study area from different perspectives but provide little information on improving the indicators themselves.

Following the second line of research, i.e., searching for potential ways to improve SDIs, this paper suggests identifying opportunities for further improvement by comparing the information revealed by SDI applications with the essential concerns of SD. The primary reason for undertaking such a comparison is that SDIs are developed to observe and quantify sustainable development; thus, by conducting such a comparison, potential improvements can be identified. As an example, this paper examines EF analysis.

The remaining sections are organized as follows: Section 2 presents the arguments for considering the concept of a nested open system in

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assessing the SD of human societies at all spatial scales. Section 3 discusses the implications of nested open systems for the EF analysis used for SD assessment. Finally, Section 4 concludes the paper.

2. Nested open systems: an important but overlooked concept in EF analysis for SD assessment[1]

EF is an indicator for quantifying man-land relations from the perspective of human consumption and is thus a demand-side calculation method. Information generated from demand indicators alone is insufficient for an SD assessment. By introducing a comparison mechanism – comparing the demand for and the supply of *current* land biocapacity (BC), Wackernagel and Rees (1996) suggested that EF analysis could be used to assess SD in biophysical units. The results of comparing EF and BC for human society at the global scale clearly demonstrate that the Earth's biocapacity (especially in terms of its assimilation capacity[2]) has already been overshot (Wackernagel and Rees, 1996; Wackernagel et al., 1999b). This confirmation thus rejects the possibility that the Earth can sustain developing nations if they develop consumption patterns similar to those of developed nations (Wackernagel and Rees, 1996; Wackernagel and Yount, 2000) and raises concerns regarding whether current human consumption patterns and their levels can be sustained (Wackernagel and Yount, 2000). Additionally, at spatial scales smaller than the global level, the results of comparing EF and BC for a defined human society (see Haberl et al., 2001; Lenzen and Murray, 2001; van Vuuren and Smeets, 2000; Wackernagel et al., 2004a) or disaggregating EF on a local basis (see Ferng, 2011; Kissinger and Rees, 2009, 2010; McDonald and Patterson, 2004) explicitly demonstrate the mutual dependence that exists among human societies in terms of land biocapacity. These EF applications have robustly confirmed the existence of global overshoot and international dependence in biophysical terms. However, robust confirmation of these facts is insufficient for an SDI because its development and application is expected to provide information regarding what changes (or direction of change) can be made to approach SD. Furthermore, the existence of an ecological deficit/surplus for a human society at subglobal spatial scales cannot be simply interpreted as a signal indicating that the society is approaching or retreating from SD, thus raising concerns regarding the role that EF analysis plays in SD assessment at such spatial scales. For example, Canada and Australia each enjoy an ecological surplus but face the degradation or depletion of natural capital stocks (see Wackernagel and Rees, 1996: 97). These observations suggest that additional efforts are required to enhance the capability of EF analysis as a tool for SD assessment.

The interpretation of a concept, such as SD, can differ from person to person. Thus, a precondition for assessing SD is making the underlying concept observable and measurable, that is, concept operationalization. Concept operationalization can be understood as a process of logical derivation: identifying indicators that appropriately reflect the concept of interest, converting the selected indicators into variables that can be measured, and then determining decision levels (see Kumar, 1996). During this process, the selection of indicators, variables, and decision levels generally vary across researchers because of their different academic training and perspectives. Regarding the concept operationalization of SD, existing SDIs developed from different academic specializations reflect different subjects of interest, for example, pollution, natural resources and international equity, while receiving little attention in macroeconomics, are considered important factors in environmental and resource economics (Pezzey, 1992). Additionally, in contrast to environmental economists, who focus on the short-term monetary value of the environment, non-economists emphasize the importance of the long-term value of the ecosystem infrastructure, the components of which do not necessarily have market values, to SD (*ibid*).

From the perspective of substitutability, the SDIs developed thus far can be classified into two types: weak sustainability and strong sustainability (Neumayer, 2006). Weak sustainability suggests substitution between natural and human capitals, while strong sustainability allows no substitution between man-made and natural capitals (*ibid*). Additionally, strong sustainability can be further distinguished with respect to two interpretations based on substitutability: the first interpretation of strong sustainability allows substitution between different types of natural capital, while the second interpretation does not, i.e., suggesting the preservation of critical natural capitals (*ibid*).

As concept operationalization can vary across academic specializations, each of which generally specializes in discussing the issue(s) for which the aspect, scale, and level in accordance with that specialization, selecting an established criterion that is appropriate for the issue of interest is important. For example, the weak sustainability criterion has been considered applicable to issues related to production inputs, while strong sustainability is appropriate for pollution issues (*ibid*). Industrial production generally enables the use of machinery instead of human labor and the use of synthetic materials instead of natural materials; thus, weak sustainability is an appropriate criterion for issues concerning industry shortages of production factors/inputs. The environmental assimilation of carbon, nitrogen, and phosphorous through the biogeochemical cycles is the result of an array of activities with complex connections performed by living and nonliving entities, for which man-made machinery does not represent a ready substitute; thus, strong sustainability is an appropriate criterion for this type of pollution issue. The state of life-support functions reflects the integral structure of major types of land cover and land use intensity on the Earth (see Foley et al., 2005; Rockström et al., 2009; Tilman et al., 2001), thus the second interpretation of strong sustainability is an appropriate criterion to apply when discussing life-support functions.

The conceptualization of SD employed in this study is similar to that discussed in "Our Common Future", published by the World Commission on Environment and Development (WCED) in 1987. Thus, the core concerns of SD considered in this study to compare and contrast with the information revealed from EF applications were identified from "Our Common Future". The motivation for the "Our Common Future" project was that prevailing environmental degradation and resource depletion threaten/erode the ecosystem infrastructure that humanity and other forms of life depend on to sustain their lives (WCED, 1987: 2), indicating that the essential subject of concern is the state of ecosystem infrastructure. Ecosystem infrastructure consists of numerous forms of critical natural capital, each of which is not easily substituted for another (Hammer et al., 1989; Neumayer, 2006). In this context, this study suggests assessing SD based on the second interpretation of strong sustainability. Additionally, the following statements – quoted from a publication that is particularly important for researchers engaged in EF analysis,"Our Ecological Footprint: Reducing Human Impact on the Earth" (Wackernagel and Rees, 1996) – indicate that the second interpretation of strong sustainability is also a theoretical basis employed by investigators when developing EF analysis as a tool for SD assessment. Therefore, the definition of SD employed in this study refers to the second interpretation of strong sustainability.

> "Strong sustainability: the ecological bottom-line condition for sustainability" (*ibid*, p. 36)

[1] Mori and Christodoulou (2012) applied the concept of nested systems to the relationships among three dimensions; that is, physical, societal, and economic dimensions are nested rather than parallel. This implies that the survival of human society depends on well-functioning life-supporting systems, whereas economic prosperity relies on functioning social systems. This study applied the nested system concept to the relationships among spatial hierarchies (see Odum, 1996).

[2] Current estimations of ecological deficits at the global scale primarily result from excessive emissions of carbon dioxide rather than from the intensive use of land and overproductivity, which contribute to land degradation such as soil erosion. Neumayer (2006: 175) also noted that global EF would not exceed global BC if the carbon footprint were not included in the EF calculation.