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Analysis

Measuring the biophysical dimension of urban sustainability

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ABSTRACT

An ecological economics perspective on urban sustainability embraces a biophysical view which emphasizes the dependence of cities on vast quantities of natural capital from various sources and spatial scales, and the generation of urban wastes which impact the local, regional and global systems. In recent years, several sets of urban sustainability indicators and indices have been developed. However, only a few consider the complex multi-scale interactions between the urban activities and the environment. Furthermore, most existing indices use a relative evaluation approach instead of an absolute approach that is needed when dealing with ecological thresholds. The paper introduces a new urban biophysical sustainability index whose framework includes: the city environmental quality, use of natural resources, and GHG emissions. Each contains topics for assessment related to local, regional and global scales and associated indicators. Standard and optimum values were determined for each indicator and a formula is provided for grading each indicator measurement. The integration of those grades allows for generation of a compound score of each topic, category, spatial scale and the entire urban biophysical sustainability performance. It then demonstrates the index in three major Israeli cities.

1. Introduction

As our world becomes increasingly urban, it is clear that human well-being and sustainability are connected to cities and the way they function (Sassen, 2011; Holden et al., 2008; Rees, 1997). An ecological economics perspective on urban sustainability embraces a biophysical view which emphasizes the dependence of cities on vast quantities of natural capital from various sources and spatial scales, and acknowledges the generation of urban wastes which impact the local (the city), regional and global systems (Newman and Jennings, 2008; Newman, 2006; Rees, 1997). Following the strong sustainability approach advanced by ecological economists (Costanza et al., 2012; Daly and Farley, 2010; Costanza, 1996), a sustainable city should meet all of the following three criteria: (1) good environmental quality within its boundaries; (2) the city does not harm the environmental quality and climate elsewhere outside its boundaries; and (3) the city operates within the limits of domestic and global ecosystems (i.e., its resource consumption is sustainable). Given these criteria, an imperative of urban governance should be the conservation of urban, regional and global natural capital assets. An important step in this direction is measuring and analyzing the interactions between cities and the environment at those geographical scales.

In recent years, several sets of urban sustainability indicators and indices have been developed (e.g. GCIF—Global City Indicators Facility, 2013; Shen et al., 2011; Berrini and Bono, 2010; Scipioni et al., 2009; Hoornweg et al., 2008; Newton, 2001; Shane and Graedel, 2000; Mega, 2000; Huang et al., 1998; Dovern et al., 2013; Dizdaroglu et al., 2012; Montero et al., 2010; Van Dijk and Mingshun, 2005). They provide information about the state of the environment and identify components of urban activity that are not environmentally sustainable. Use of these assessments contributes to better understanding of complex city–environment interactions and has the potential to increase the awareness of public and policy makers of important areas for policy and action needed for advancing sustainability (Singh et al., 2012; Fragkou, 2009; Button, 2002; Alberti, 1996).

However, a review of urban sustainability measurement literature reveals that most existing tools cannot provide a comprehensive measurement of a city's bio-physical sustainability. Hence the feedback received by city stakeholders from existing assessments is limited, representing only a partial picture of the state of urban bio-physical sustainability. Shortcomings of existing measurement tools include the following: (1) most urban sustainability assessments include indicators for only a few biophysical characteristics alongside several socio-economic ones; therefore they cannot comprehensively assess the bio-physical aspect of urban sustainability; (2) most existing assessments are relative, comparing the performance of a studied urban entity to the performance of others. Only a few refer to environmental thresholds and present absolute scores; and (3) they focus on either the state of the environment within the city boundaries (e.g., air quality index) or on local global interactions (e.g., ecological and carbon footprint assessments) rather than integrating local, regional and global interactions into the analysis.

The objective of this paper is to propose a framework for a new urban biophysical sustainability index (UBSI) that aims to tackle the abovementioned shortcomings of existing tools. It takes into account

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city–environment interactions at local, regional and global scales. Unlike other indices, the proposed index introduces absolute scores by referring to existing and desired environmental thresholds.

The following section expands on prevailing approaches to measuring urban sustainability. It then introduces the new index, explains the logic behind each component and finally, demonstrates the use of the index in three cities in Israel. The index is modular so its method and structure can be implemented in other places adjusted for local conditions and priorities.

2. Background

The research field of ecological economics has been advanced as a means to manage sustainability (Daly and Farley, 2010; Rees, 2003; Costanza, 1996). Ecological economists argue that existing measures aiming to advance sustainability are insufficient and more advanced ones are needed (Costanza et al., 2012; Rees, 2010; Victor, 2008). Ecological economics sees the economy as a fully contained sub-system of the ecosphere dependent on other species and subsystems for non-substitutable life support functions. As such, it posits that human wellbeing and sustainability depend on the sustainability of ecological systems and on conservation of natural capital. It also acknowledges that in an era in which the world economy is global, local human activities are strongly linked to natural capital and ecological services at local, regional and global scales (Kissinger et al., 2011; Koellner and van der Sleen, 2011; Giljum and Eisenmenger, 2004). Consequently, policy and planning for sustainability should take cross-scale bi-directional impacts and flows into account.

2.1. Urban Sustainability Measurement Tools

Common urban sustainability measurement tools can be divided into two major types. The first is a set of indicators that can be used to measure environmental properties (e.g. the concentrations of some air pollutants can be used to measure local air quality; the emissions of GHGs can highlight a studied entity's contribution to climate change processes). The second are indices in which several indicators are synthesized into a single metric (e.g., different air pollutants are aggregated into a single index value) (Cheng et al., 2007; Kyrkilis et al., 2007); index values can then be used to assess the ‘performance’ of different components. The conversion of indicator measurements into a single index value is done by using conversion formulas that are developed by the index creators who give equal or diverse weights to each of the index components (Singh et al., 2012; Emerson et al., 2012; Tanguay et al., 2010; Van Dijk and Mingshun, 2005).

In recent years, several urban sustainability measurement tools have been developed, including sets of indicators (e.g., GCIF—Global City Indicators Facility, 2013; Shen et al., 2011; Berrini and Bono, 2010; Scipioni et al., 2009; Hoornweg et al., 2008; Newton, 2001; Shane and Graedel, 2000; Mega, 2000; Huang et al., 1998) and indices (e.g., Dovern et al., 2013; Dizdaroglu et al., 2012; Montero et al., 2010; Van Dijk and Mingshun, 2005) (for a comprehensive review of these tools see Singh et al., 2012 and Alberti, 1996). However, as argued earlier in this manuscript, existing tools have several shortcomings which need to be addressed in order to assess comprehensively the biophysical aspects of urban sustainability.

2.1.1. Comprehensive or Selective Assessments

Most urban sustainability measurement tools include only a few biophysical indicators alongside a much larger number of socio-economic ones. For example the Dashboard of Sustainability Indicators (Scipioni et al., 2009) contains 62 indicators, of which only 6 are biophysical. Similar distributions of indicators can be found in many other urban sustainability assessment tools such as the City Development Index (UN — Habitat, 2001), Urban Sustainability Indicators (Mega, 2000), Global City Indicators (Hoornweg et al., 2008), and The Green City Index (Siemens, 2012). As a result these measurement tools do not assess the large number of environmental components required to represent urban biophysical sustainability.

2.1.2. The Scale of Urban Sustainability Measurement

Researchers have long realized the importance of scale in assessment of environmental conditions. Several definitions of *scale* have been advanced. For example: scale has been defined as the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon (e.g., Gibson et al., 2000). The Millennium Ecosystem Assessment (MEA) (2003) defined scale as the physical dimension of a phenomenon or process in space or time expressed in physical units. A common distinction in the literature is between two kinds of scales: scale of observation and scale of the phenomenon. The scale of observation is a construct based on human systems of measurement (Millennium Ecosystem Assessment (MEA), 2003). The scale of the phenomenon may be much larger than the scale of observation (i.e. certain phenomenon will be monitored within the city boundaries but the consequences of that phenomenon have impact on a much larger region). A detailed review of various dimensions of the concept is included in Millennium Ecosystem Assessment (MEA) (2003) chapters on scales (mostly Wilbanks, 2003).

In recent years various researchers have identified the need to examine cross-scale linkages among nested and complex socio-ecological systems (e.g., Kissinger et al., 2011; Cash et al., 2006; Millennium Ecosystem Assessment (MEA), 2003; Young, 2002; Gunderson and Holling, 2002; Wilbanks and Kates, 1999; Holling, 1992). Wilbanks and Kates (1999) and Kates and Wilbanks (2003) suggested that geographic scale matters in seeking an integrated understanding of global change processes, and that understanding linkages between scales is an important part of the search for knowledge.

Cities have always depended on various ecosystem services (e.g., to supply their resource needs and to sequester their wastes). This dependence has changed throughout history. While in the past human settlements relied primarily on domestic sources (i.e., areas surrounding the city), in recent decades processes of technological development and globalization together with growing urban populations have compelled cities to become increasingly reliant on global sources and sinks. Presently there is hardly a city that is not highly dependent on both domestic and overseas sources (Grimm et al., 2008; Stossel et al., 2014).

By exploring and analyzing cities' reliance on ecosystem services and resources at different spatial scales, city authorities and residents can better understand their level of dependence upon and impact on the environment, realize their vulnerability to overseas environmental changes, and consider local action and policy guidelines to increase their urban sustainability. Still most existing measurement tools focus on the state of the environment solely within city boundaries (e.g., Stossel et al., 2015; Shen et al., 2011; Montero et al., 2010; Berrini and Bono, 2010; Li et al. 2009; Scipioni et al., 2009; Donchin et al., 2006; Westfall and de Villa, 2001; Huang et al., 1998) or at best, they include reference to the city's waste generation. However while important on their own, these studies mostly ignore city's dependence and impact on ecosystem services at regional and global spatial scales. The growing awareness in recent years of local–global environmental interactions has led to the generation of some measurement tools that also consider impacts at these scales including for example, sets of indicators that include urban GHG emissions (e.g., Siemens, 2012; Moles et al., 2008; Lee and Huang, 2007).

Another group of measurement tools that consider urban reliance and impact on environmental services beyond the city boundaries include urban metabolism studies (e.g., Kennedy et al., 2007; Warren-Rhodes and Koenig, 2001), and urban ecological footprint studies (e.g., O'Regan et al., 2009; Kissinger and Haim, 2008; Walsh et al., 2006; Barrett et al., 2003; IWM — Institute of Wastes Management (Great Britain), 2002; Rees, 1992). However these tools do not consider