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Urban sustainability assessment and ranking of cities

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ABSTRACT

With 54% of the world's population urban in 2014 it is important to assess the sustainability of cities and find systematic ways of improving it. In this paper the model SAFE (sustainability assessment by fuzzy evaluation) that was first developed to define and measure the sustainability of countries, is modified to assess the sustainability of cities worldwide. Overall sustainability is a function of two main inputs, ecological and well-being. The ecological input depends on the state of air, land and water and the well-being input on the state of the economy, education, health and civic environment of cities. SAFE uses 46 basic inputs to rank 106 cities according to sustainability. The number of inputs can be changed according to need. A sensitivity analysis identifies those basic inputs or indicators that affect sustainability the most. If such inputs are improved, the sustainability of cities improves the fastest. It turns out that European cities occupy the highest ranking positions whereas African, Asian, and South American cities the lowest. Waste generation and GHG (greenhouse gases) emissions are the main problems for cities in the developed world, whereas crime and poverty are the main problems in cities of developing countries.

1. Introduction

Urban population accounts for more than half of humanity (Satterthwaite, 2011). Cities are acquiring center stage place in human activities that range from economic to cultural. They can be seen, from a physical point of view, as enormous sources and sinks of energy and matter. To sustain their large populations they need large quantities of energy, food, water and other goods, generating in the process tremendous quantities of waste. Moreover, they require a multitude of services for their survival such as health, education, culture, policing, etc. Cities themselves are centers where such activities thrive.

Large concentrations of humans in rather limited areas raise questions about sustainability. Given the energy and matter inputs and outputs as well as the social state of affairs of a city, how sustainable is it and how can its sustainability be improved? Such questions first beg the question of what is sustainability. No definitive answer exists to date to the problem of sustainability. However, several models and approaches broach the matter from various angles in the literature. In Rockström et al. (2009) an interesting discussion on biophysical thresholds is given. Nine biophysical processes are identified that are central to human development: climate change, rate of biodiversity loss, nitrogen and phosphorus cycles, stratospheric ozone depletion, ocean acidification, freshwater use, land use change, and atmospheric aerosol loading. Boundaries are proposed for each process which, when exceeded, nonlinear — even dangerous for humans — phenomena might ensue. Already three of these processes operate outside the boundaries: climate change, biodiversity loss, and the nitrogen cycle. In a sense, humanity has embarked on an experiment of global scale in these three areas with unknown consequences that threaten the very foundations of sustainability.

An early attempt of defining and assessing sustainability is found in Wackernagel and Rees (1996), where the concept of ecological footprint of a given population is developed. The ecological footprint of a population is the land area that produces certain resources that a population consumes and assimilates certain wastes generated by the same population. Most, if not all, cities in order to flourish require ecological goods and services from large tracts of land elsewhere (Rees, 1992). Often the land needed to supply these ecological goods and services is several orders of magnitude greater than the space occupied by the city itself. Urban centers are enormous ecological sinks that appropriate the services of land sources even in remote places.

The present urban population of about 4 billion people is expected to reach 6.5 billion by 2050 (McDonnell & MacGregor-Fors, 2016). The impact of such an enormous concentration of people calls for a more integrated study not only of ecological processes but also of socioeconomic and managerial processes related to the function of cities. Phrased differently, urban sustainability ought to view urban functions from an ecological but also socioeconomic angle.

The majority of benchmarking systems use indicators to evaluate various aspects of urban performance (see, e.g., European Commission, 2015) and linear models to aggregate them. United Nation's (UN) City

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Prosperity Index (CPI; UN-Habitat, 2015) is based on 17 indicators organized in six dimensions: productivity, infrastructure development, quality of life, equity and social inclusion, environmental sustainability, and urban governance and legislation. Indicator data are first converted to dimensionless values in [0, 100] by log transformation and piecewise linearization between sustainable and unsustainable thresholds and then averaged to obtain the dimensional and overall indices. The Sustainable Cities Index (SCI; Arcadis, 2016) combines 32 indicators measuring social, environmental, and economic dimensions of sustainability, and calculates an overall sustainability index by just averaging. The Cities in Motion index (CiM; IESE Business School, 2016) evaluates a city's performance through 77 indicators grouped in ten dimensions: economy, technology, human capital, social cohesion, international outreach, environment, mobility and transportation, urban planning, public management and governance. The Global Power City Index (GPCI; Mori Memorial Foundation, 2016) assesses the attractiveness of cities to business and talent according to 70 indicators grouped in six dimensions: economy, research and development, cultural interaction, livability, environment, and accessibility. The average indicator scores in each group are summed to yield the overall index. Mercer's Quality of Living (QoL; Mercer, 2016) is based on a survey which assesses quality of living conditions according to 39 indicators grouped in ten categories: political and social environment, economy, socio-cultural environment, health, education, public services and transportation, recreation, consumer goods, housing, and natural environment. The Spatially Adjusted Liveability Index (SALI) is a recent enhancement of the Global Liveability Ranking developed by the Economist Intelligent Unit (EIU, 2016) that assesses the relative comfort for over 40 qualitative and quantitative factors across six categories: stability, healthcare, culture and environment, education, infrastructure, and spatial characteristics. Indicator scores are averaged and weighted to provide categorical and overall scores and rankings. Cities of Opportunity (CoO), was developed by PricewaterhouseCoopers (PwC, 2016), and examines 67 indicators organized in ten categories: intellectual capital and innovation; transportation and infrastructure; health, safety and security; sustainability and the natural environment; economic clout; ease of doing business; cost; demographics and liveability; and city gateway. The indicators are transformed on a common scale and summed to yield the categorical and overall scores. Grant and Chuang (2012) combine 21 existing indexes transformed on a common scale into average scores across five broad dimensions (global cities, nice cities, knowledge cities, intelligent cities, and creative cities), which are then summed to yield an overall index called Citycard.

Sustainability of cities has been examined from the point of view of multicriteria decision analysis (MCDA) in Munda (2005, 2006), where the mayor or the city council are the decision makers. It is suggested that linear aggregation models have problems of synergy or conflict among the different sustainability indicators and, therefore, non-compensatory MCDA approaches such as ELECTRE (Figueira, Mousseau, & Roy, 2005), PROMETHEE (Brans & Mareschal, 2005), and NAIDE (Munda, 1995) are more appropriate.

Other contributions study specific aspects of urban sustainability. For example, Lundin, Molander, and Morrison (1999) and Lundin and Morrison (2002) examine the sanitary and water systems, Hagshenas, Vaziri, and Gholamialam (2013) assess urban transportation in Asian cities, and Egilmez, Gumus, and Kucukvar (2015) use expert-based fuzzy MCDA to assess the environmental sustainability of 27 U.S. and Canada cities.

In this paper, we adopt the indicator approach for several reasons:

1. This approach allows for a global consideration of urban sustainability: ecological and socioeconomic. Urban viability does not only depend on ecological impact but also on the viability of infrastructure, public health and education, and policies. All these aspects are integrated into the indicator-based model we shall describe in the sequel.
2. The model we use is called SAFE (Sustainability Assessment by Fuzzy Evaluation). This model was first designed and applied to define and assess sustainability of countries and organizations (Andriantiatsaholiniaina, Kouikoglou, & Phillis, 2004; Kouloumpis, Kouikoglou, & Phillis, 2008; Phillis & Kouikoglou, 2009; Phillis, Grigoroudis, & Kouikoglou, 2011; see also www.sustainability.tuc.gr). The model can easily be adapted to the physical reality at hand, here urban sustainability, and has the ability to perform sensitivity analysis that identifies the indicators with the highest potential to improve sustainability. This last feature is absent from most existing sustainability models albeit it is of paramount importance in decision making in the context of urban sustainability.
3. Sustainability is the resultant of several dissimilar components, some of which are fraught with ambiguity or subjectivity such as political rights or corruption index. Fuzzy logic is suitable to handle ambiguous variables and derive proper conclusions in the context of sustainability. SAFE uses multistage fuzzy reasoning and statistical methods to combine such components to generate composite indices.

As observed in Gasparatos and Scolobig (2012), indicator-based models entail subjective choices of indicators, weights, normalization, and aggregation. However, given the fuzzy nature of sustainability, the lack of a rigorous definition, and the ambiguity of some of its components, subjectivity is unavoidable.

In the following sections a brief description of SAFE is given followed by its detailed adaptation to urban sustainability and a complete list of indicators, definitions, units, and sustainable regions. Data for each indicator are collected for the years 1990–2014. Whenever data are missing, an imputation procedure is used as described in Section 2.3 to generate the missing numbers. Finally SAFE is run for 106 cities the world over, primarily capitals and/or megacities. The model first assigns a number on [0, 1] to each city, 0 meaning completely unsustainable and 1 meaning completely sustainable. Then cities are ranked according to their sustainability index. Finally, a sensitivity analysis identifies those indicators that affect sustainability for each city the most. Out of 46 indicators, the first three are shown for each city in order of potential for improvement. These indicators should be improved first if sustainability is to be raised. All indicators are ranked by the model but only three are shown because of space limitations. A brief overview of SAFE follows.

2. SAFE model

2.1. Overview

The schematic structure of the SAFE model that defines and assesses urban sustainability is shown in Fig. 1. Overall urban sustainability (OSUS) has two primary components: environmental sustainability (ENVI) and societal or human sustainability (WELL-BEING). This choice reflects a global approach to sustainability in which the environment and the social system are viewed together. The environmental input has three secondary components: water quality (WATER), quality of soil and land integrity to sea level rise (LAND), and air quality (AIR), while the societal input has four secondary components: health (HEALTH), economic welfare (ECON), education (KNOW), and civic environment (CIVIC). Finally, all secondary components comprise a number of basic indicators as shown in Table 1.

The sequence of data processing has the following steps:

- Collection of available data
- Normalization on [0, 1]
- Exponential smoothing
- Data imputation
- Fuzzy assessment of sustainability
- Sensitivity analysis-decision making.

2.2. Basic indicators

The model uses a total of 46 basic indicators and assesses 106 cities. The data base of basic indicators goes as far back as 1990 and reaches the