Journal of Cleaner Production 130 (2016) 222–234

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Sustainable development of energy, water and environment systems index for Southeast European cities

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ARTICLE INFO

Article history:
Received 7 April 2015
Received in revised form
20 July 2015
Accepted 23 July 2015
Available online 3 August 2015

Keywords:
Composite indicator
Sustainable development
Energy
Water
Environment systems
Cities

ABSTRACT

Benchmarking the performance of cities across aspects that relate to the sustainable development of energy, water and environment systems requires an integrated approach. This paper benchmarks a sample of 12 Southeast European cities based on a composite indicator that consists of 7 dimensions and 35 main indicators. The composite indicator is namely the Sustainable Development of Energy, Water and Environment Systems (SDEWES) City Sustainability Index. The first three dimensions are energy consumption and climate, penetration of energy and carbon dioxide saving measures, and renewable energy potential and utilization. The last four dimensions are water and environmental quality, carbon dioxide emissions and industrial profile, city planning and social welfare, and research, development, innovation, and sustainability policy. The data collection process for the 12 cities integrates data from Sustainable Energy Action Plans and other sources. Data entries are normalized based on the Min–Max method and aggregated for a final ranking. Zagreb, Bucharest (District 1), and Ohrid are the top three cities. An average city receives a composite score of 2.69. Best practices are identified to allow cities to adopt well-rounded efforts to improve future performance. The SDEWES Index is useful to trigger learning, action, and collaboration among cities to transition to a more sustainable future.

1. Introduction

Benchmarking cities across aspects that relate to the sustainable development of energy, water and environment systems requires an integrated approach. Composite indicators (OECD-JRC, 2008) that can capture multiple aspects at the same time can be a useful tool in this respect. The literature provides examples of benchmarking cities in only one aspect without the use of composite indicators (Section 1.1). Other studies apply composite indicators with a limited scope and/or to a limited sample (Section 1.2). Table 1 organizes the literature based on 7 themes, indicates the scope of analysis, and marks the kinds of indicators that are used. An overview of the literature is given before proceeding to the aims of the research work.

1.1. Comparative use of indicators

As marked in Table 1, some studies involved the comparative use of quantitative (Q_T) and/or qualitative (Q_L) indicators to assess specific aspects related to cities. Composite indicators were not used in these studies. Kona et al. (2015) conducted a frequency analysis of energy per capita and CO_2 emission factors of cities that are signatories to the Covenant of Mayors (CoM). Sovacool and Brown (2010) compared the carbon footprints of 12 major metropolitan areas. Bi et al. (2011) benchmarked the energy-related CO_2 emissions of the city of Nanjing in China.

Yajie et al. (2014) compared the carbon footprint of 21 cities in China based on energy consumption and aspects of agriculture, livestock, and solid waste. Yajie et al. (2014) compared changes in the carbon metabolism of Beijing on a temporal scale based on remote sensing data and empirical coefficients. Zaman and Lehmann (2013) assessed waste management in the cities of Adelaide, San Francisco, and Stockholm. Karagiannidis et al. (2004) examined urban waste management in 14 Greek municipalities based on 4 measures. Other authors used qualitative means of assessment to evaluate the presence of various policies. Khanna et al. (2014) compared the scope of targets and measures in the low-carbon city plans of 8 pilot cities in China. Kramers et al. (2013) compared 8 cities with climate targets based on choices for target setting.

With a more multidisciplinary focus, Venkatesh et al. (2014) compared the energy-water-carbon nexus in the urban water

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http://dx.doi.org/10.1016/j.jclepro.2015.07.121
0959-6526/

Nomenclature

C	Specific Southeast European city in the sample
CI	Composite indicator, used in Table 1
c	CO_2 emissions factor, tonnes of CO_2/MWh
D	Dimensions of the SDEWES Index (D_1–D_7)
D_1	Energy Consumption and Climate Dimension
D_2	Penetration of Energy and CO_2 Saving Measures Dimension
D_3	Renewable Energy Potential and Utilization Dimension
D_4	Water and Environmental Quality Dimension
D_5	CO_2 Emissions and Industrial Profile Dimension
D_6	City Planning and Social Welfare Dimension
D_7	R&D, Innovation and Sustainability Policy Dimension
E	Final energy consumption, MWh
I	Min-Maxed values of the indicators in the SDEWES Index
i	Data inputs into the indicators prior to the Min–Max method
max	Maximum value among all cities for a given indicator
min	Minimum value among all cities for a given indicator
P	Population of the city (used in Equation (4))
Q	Quantitative (*N*) or qualitative (*L*) indicator, used in Table 1
S	Sample to which the composite indicator is applied

Greek symbols

α	Weights of the dimensions of the SDEWES Index (Equation (3))

Chemical symbols

CO_2	Carbon dioxide

Subscripts

b	Categories of buildings in the building sector ($b = 1$ to $b = 3$)
d	Industrial sector within the confines of the city
g	Public lighting sector in the city
j	Number of the Southeast European city in the sample
t	Categories of transport vehicles in the transport sector ($t = 1$ to $t = 3$)
x	Dimension number, dimensionless
y	Indicator number in the dimension (used in Equation (3))

Acronyms

ACA	Airport Carbon Accreditation
CDD	Cooling Degree Day
CHP	Combined Heat and Power
CoM	Covenant of Mayors
DH/C	District Heating and/or Cooling
EEA	European Environment Agency
GIS	Geographical Information System
HDD	Heating Degree Day
IEA	International Energy Agency
PM_{10}	Particulate matter up to 10 μm in diameter
R&D	Research and Development
SDEWES	Sustainable Development of Energy, Water and Environment Systems
SEAP	Sustainable Energy Action Plan(s)
SEE	Southeast Europe, used for SEE cities in sample
SWERA	Solar and Wind Energy Resource Assessment

systems of Nantes, Oslo, Torino, and Toronto. Kostevšek et al. (2015) developed and applied metrics to assess Locally Integrated Energy Sectors (LIES) in the district heating system of Ormož Municipality in Slovenia. The study involved 20 indicators across energy, economy, and social aspects. Zhou et al. (2015) identified a set of 33 indicators for low-carbon eco-city planning in China, such as the energy intensity of drinking water. The proposed indicators were prepared as a tool but were not applied to specific cities.

1.2. Composite indicators

Composite indicators are useful to measure multi-dimensional concepts that cannot be captured by a single indicator (Nardo et al., 2005). For example, Afgan et al. (2005, 2000) proposed, aggregated, and applied environmental, social, and economic indicators to assess cases for an island. Studies that involved the use of composite indicators (*CI*) are marked in Table 1. Keirstead (2013) used an efficiency score to determine the most energy efficient city in the UK. Out of a sample of 198 urban local administrative units, a borough of London consuming 13.9 MWh per capita was the most efficient unit (Keirstead, 2013). Alonso et al. (2015) assessed passenger transport systems in 23 European cities. Debnath et al. (2014) compared the smartness of transport systems in 26 major cities based on the extent of ICT usage to optimize traffic activities.

Miranda et al. (2014) applied a composite indicator to assess sustainable urban mobility based on the case of Curitiba (Brazil). Wilson et al. (2015) compared integrated sustainable waste management in 5 cities based on 12 indicators for physical components and the governance of waste-related aspects. Wu et al. (2015) analysed options for urban water treatment in Ningbo, China based on the priority ranking of techno-economic criteria, including emission costs. Arribas-Bel et al. (2013) analysed 35 major cities based on socio-economic power indices. The indicators included those for the number of companies with ISO 14001 certification, World Heritage sites within a 100 km area, and the number of the world's top 200 universities (Arribas-Bel et al., 2013).

The Siemens Green City Index (Siemens) benchmarked cities based on 30 indicators related to energy, waste and land use, water, air quality, environmental governance, and CO_2 emissions. Energy related indicators were limited to total energy consumption and energy intensity. The Index was applied to 30 European capital cities (e.g. Amsterdam, Berlin, Dublin, Madrid), 10 other German cities, and other cities around the world (Siemens). Trigg et al. (2010) ranked Australian cities based on 15 indicators for environmental performance, quality of life, and resilience. Green Star certified building projects was the only energy related indicator (Trigg et al., 2010).

1.3. Aim of the research work

Composite indicators are well-adapted to issues that require a multidisciplinary framework. A composite indicator that provides an integrated approach to benchmark the sustainable development of energy, water and environment systems in cities was developed by the author in Kılkış (in press). The composite indicator has the namesake of the “Sustainable Development of Energy, Water and