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Assessing the sustainability of Spanish cities considering environmental and socio-economic indicators

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A B S T R A C T

The conception of urban metabolism has considered the perspective of environmental sustainability in the framework of cities. In this context, cities can be regarded complex entities driven by material and energy flows that entail consumption of resources and production of waste materials in the pursuit of economic welfare and social progress. According to a sustainability perspective, environmental, social and economic indicators must also be integrated into urban planning processes. However, methodological advances regarding the definition and development of sustainable cities are required since a consensus of indicators, weighting and data management is still lacking. In this paper, a multi-criteria approach that combines three methodologies: Material Flow Analysis (MFA), Life Cycle Assessment (LCA) and Data Envelopment Analysis (DEA) has been developed and applied to a sample of 26 representative Spanish cities with different characteristics (i.e., population, location, demands, economy, topography and culture). The combined approach allows identifying the non-sustainable cities considering an offset of indicators from the three pillars of sustainability. With this purpose, the mentioned items are implemented in a DEA model of efficiency, being the inefficient cities with an efficiency score lower than 100% defined as non-sustainable ones. Finally, this multi-criteria method allows setting the target values for the assessed indicators (benchmarked values), which become objectives for the non-sustainable cities to evolve toward a more sustainable performance. The outcomes from the analysis have identified six cities that ranked worse, with efficiency scores ranging from 57.9% to 85.8%.

According to the targets of socio-economic indicators, attention should be paid to AROPE rate (people at risk of poverty and social exclusion), unemployment rate and number of crimes, meanwhile lower levels of electricity consumption, municipal solid waste and on-site greenhouse gases emissions are desirable from an environmental perspective. These outcomes are of potential interest for politicians, governments and inhabitants to aid in the identification of the metabolic flows and social/economic indicators to be optimized in search of sustainability.

1. Introduction

From the fifties, cities started to grow and consequently, the number of urban inhabitants is expected to rise by 30% in 2050 (Beloin-Saint-Pierre et al., 2016; Valdivia et al., 2013). Urban settlements and cities are complex systems that can be considered living organisms driven by material and energy flows. Different anthropogenic functions are performed within the urban systems to provide goods and services. Moreover, cities offer more diverse living conditions than small communities, which entail economic and social benefits in terms of educational, cultural, living and employment opportunities (Bettencourt and West, 2010; Li et al., 2016; Moore et al., 2003). Nevertheless, the contribution of cities to a remarkable number of environmental indicators such as global warming potential, resource depletion or acidification is continuously increasing (Goldstein et al., 2013). Among the different studies on urban metabolism, there is no consensus on the selection of metabolism indicators as well as the methodologies followed for the assessment of environmental sustainability (Beloin-Saint-Pierre et al., 2016; Herfray et al., 2011; Rosado et al., 2016; Russo et al., 2014). Therefore, the quantification of both material and energy flows and environmental pressures linked to cities is required to facilitate the transition into a sustainable urban development (Li et al., 2016; Rosado et al., 2016). In light of this, the

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concept of urban metabolism was introduced as a useful methodology to assess the resources demanded from cities (energy and materials) and as a platform for urban planning (Abou-Abdo et al., 2011; Pincetl et al., 2012).

According to a chronological review, there is a growing interest in the study of urban metabolism (Kennedy et al., 2011; Zhang, 2013; Beloin-Saint-Pierre et al., 2016). Many quantitative methods (e.g., flow analysis, energy assessment, input/output analysis, life cycle assessment, network analysis), as well as methodological choices (e.g., temporal and geographical scope, assessed indicators and impacts, system boundaries, etc), have been considered in the analysis.

In 1883, Karl Marx introduced the concept of urban metabolism as the study of material and energy flows, arising from urban socioeconomic activities, technical and socio-economic processes over a particular period (Kennedy et al., 2007; Abou-Abdo et al., 2011; Zhang, 2013). Nowadays, urban metabolism can be considered as an extended analogy of the biological metabolic processes (Abou-Abdo et al., 2011).

Four different flows: economic, material, process and energy are typically considered in the assessment of urban systems depending on the method chosen for environmental assessment, which may include monetary exchanges, construction materials, food, transport, electricity, fuel (Beloin-Saint-Pierre et al., 2016). On the one hand, economic and process flows involve interactions between the sectors included in an urban metabolism that are managed by economic input/output and network analysis methods (i.e., relations between nodes, such as the economic sectors). On the other hand, material and energy flows can describe the effects of urban metabolism on the environment as it can be performed by the combination of Material Flow Analysis (MFA) and Life Cycle Assessment (LCA) methods. Moreover, economic data could also be transformed into material data to determine environmental indicators; that is the example of the calculation of energy consumption from available financial information (Zhang et al., 2014). Nonetheless, urban metabolism is only focused on environmental assessment; however, the analysis of social and economic sustainability is also mandatory.

In line with this, the concept of green economy was one of the principal topics addressed in the Rio+20 conference considering that it comprises the three dimensions of sustainability; that is, the reduction of environmental pressures paying emphasis on the socioeconomic impact (Valdivia et al., 2013). This concept could be entirely extended to a city according to the definition of urban metabolism: "*the sum total of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy and elimination of waste*" (Kennedy et al., 2007), considering that cities grow in different ways depending on their social and economic structures.

Therefore, and due to the goal of maintaining both socioeconomic and environmental development, researchers, policy makers and governments must find solutions to improve the ecological environment of urban areas, with the perspective of socio-economic progress in a resource-saving and environment-friendly society (Chrysoulakis et al., 2013; Moore et al., 2013; Zhang, 2013).

Variables typically assessed by urban metabolism are water and energy consumption and waste production (Petit-Boix et al., 2017). Moreover, other major indicators such as urban density, green areas, air emissions flows, accommodation, housing availability, accessibility and proximity to essential services and facilities, education, employment, citizen security or mobility in the urban setting, should also be taken into account (Chrysoulakis et al., 2013; González et al., 2013; Pincetl et al., 2012).

Bearing in mind the reported information, the application of a multi-criteria method based on environmental, social and economic indicators could provide a comprehensive perspective for the analysis of sustainable urban systems. The integration of Data Envelopment Analysis (DEA) – a linear programming methodology to calculate the operational efficiency of multiple similar entities – into the LCA methodology has been applied to various sectors such as fishery (Avadí et al., 2014; Vázquez-Rowe et al., 2010), building (Iribarren et al., 2015), agri-food products (Iribarren et al., 2011; Mohammadi et al., 2013) and energy (Lijó et al., 2017). This joined approach allows efficiency verification while avoiding the use of average inventory data. Moreover, it has recently been proposed to integrate not only operative and environmental but also, socio-economic aspects when evaluating multiple similar units of analysis (entities) using LCA + DEA (Iribarren et al., 2016). However, the application of this combined approach in the evaluation of the sustainability of urban systems has never been performed.

Therefore, this study aims to assess the sustainability of Spanish cities considering each city as an individual metabolism or entity. An integrated-multi-criteria analysis has been defined and applied from an urban metabolism (UM) context incorporating MFA, LCA and DEA. Hence, this tool is proposed to evaluate a sample of representative Spanish cities, which will be defined as individual decision-making units (DMUs). Accordingly, the study tries to develop and apply this different framework into a field with multiple research gaps and uncertainties (Petit-Boix et al., 2017), which could help to define and drive the cities into sustainable systems.

2. Materials and methods

2.1. Description of the integrated-multi-criteria approach method

As previously reported, a city is a dynamic system, and thus, it is important to understand its energy and material flows over time. Urban metabolism is considered as the exchange and transformation of energy and materials between a city and its environment (Goldstein et al., 2013). Although several studies can be found in the literature on the identification of ecological hotspots of American and European cities (Beloin-Saint-Pierre et al., 2016; Hendriks et al., 2000; Goldstein et al., 2013; Kennedy et al., 2011, 2014; Loiseau et al., 2012), there is no available studies on Spanish cities. Besides, the consideration of socioeconomic parameters in urban systems, as well as the definition of a sustainable city, are issues that require particular attention. Cities are complex systems and there are numerous research gaps and uncertainties in both methodological and thematic terms that need to be developed (Petit-Boix et al., 2017). Therefore, the novel methodology proposed in this study could help not only to give answers some of these uncertainties but also to identify strategies to implement the sustainability concept in urban systems. Thus, environmental, economic and social indicators have been evaluated in this study using a combined multi-criteria approach based on MFA, LCA and DEA methodologies.

Material Flow Analysis (MFA). MFA is a method to support decision-making strategies in the field of resources and environmental management (Hendriks et al., 2000). It is the earliest method used in UM (Goldstein et al., 2013) and it can be used to quantify inputs (e.g., raw materials, food, fossil fuels) and outputs (atmospheric gases, heat, waste).

Life Cycle Assessment (LCA). LCA is a standardized methodology extensively used to assess environmental impacts from a product-oriented approach (ISO 14040, 2006). However, Guinée et al. (2011) proposed its application into meso-level systems, which may include groups of related products and technologies such as those in a facility, community, municipality, etc. Thus, it can be applied to analyze direct and indirect impacts from cities metabolism. When applied to urban metabolism studies, LCA is commonly combined