Environmental Pollution 202 (2015) 146–152

Contents lists available at ScienceDirect

Environmental Pollution

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

Urban metabolism: Measuring the city's contribution to sustainable development

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ARTICLE INFO

Article history:
Received 6 November 2014
Received in revised form
19 March 2015
Accepted 21 March 2015
Available online

Keywords:
Urban metabolism
Urban sustainability
Industrial ecology

ABSTRACT

Urban metabolism refers to the assessment of the amount of resources produced and consumed by urban ecosystems. It has become an important tool to understand how the development of one city causes impacts to the local and regional environment and to support a more sustainable urban design and planning. Therefore, the purpose of this paper was to measure the changes in material and energy use occurred in the city of Curitiba (Brazil) between the years of 2000 and 2010. Results reveal better living conditions and socioeconomic improvements derived from higher resource throughput but without complete disregard to environmental issues. Food intake, water consumption and air emissions remained at similar levels; energy use, construction materials and recycled waste were increased. The paper helps illustrate why it seems more adequate to assess the contribution a city makes to sustainable development than to evaluate if one single city is sustainable or not.

1. Introduction

Among the many challenges concerning sustainable development, one that deserves special attention is urban sustainability. The difficulty in balancing quality of life and preservation of natural resources is evident in urban areas, where expectations about the availability of employment, housing and culture exist together with hopes for pure air, mental and physical health and contact with nature. In these dominated and occupied landscapes, humans reorganize and redistribute resources in order to create opportunities, changing the functioning of ecosystems and causing environmental problems (Alberti et al., 2003).

The study of urban sustainability can be carried out through different perspectives. One that has been recognized as adequate and consistent compares the city to an ecosystem or an organism, having inputs, transformation and outputs of material and energy, i.e., a metabolism. It assumes that the maintenance of life involves the conversion of natural resources in goods, services and waste. The first time that this idea was related to an urban system was in the early 1920s, with Burgess (1925). However, the landmark paper of Urban Metabolism was developed by Abel Wolman in 1965, when he studied the impacts of material consumption and waste generation of a hypothetical American city of one million people.

Urban metabolism can be understood as "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). If we assume that sustainable development is the "development without increases in the throughput of materials and energy beyond the biosphere's capacity for regeneration and waste assimilation" (Goodland and Daly, 1996), then the urban metabolism approach represents a comprehensive framework that helps monitor the transformation occurring in cities, as well as their contributions to sustainable development (Hoornweg et al., 2012).

Studying the flows of materials and energy throughout a city became (more) useful when human activities started affecting the natural cycles of other living organisms (ab'Sáber, 2004). If city growth is achieved by increased resource throughput, then environmental issues and economic costs depend on the management of the inputs and outputs of material and energy that takes place in urban spaces (Newman, 1999). Unsustainable metabolic processes can cause the exhaustion of resources, impacting the environment in local and regional scale and turning the relationship between urban growth and natural space into a real problem.

According to Kennedy et al. (2011), an urban metabolism analysis serves four main purposes: the first one is related to the assessment of materials and energy flows throughout a city. It is a

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http://dx.doi.org/10.1016/j.envpol.2015.03.027
0269-7491/

basic accounting effort that can provide scientifically valid and representative data for urban planning. The resultant evaluation shows the efficiency in resource use, its future need, the existence of any environmental burden, the contribution of recycling and the capacity of waste treatment, enabling a better awareness of how much impact human activity (social, economic and political) is causing in the natural environment (Brunner, 2007; Holmes and Pincetl, 2012). The second application aims to quantify greenhouse gas (GHG) emissions, a metric which is part of urban metabolism itself, but it turned into an independent contribution due to its relationship to climate change. Third and fourth applications use material and energy evaluation to support decisions concerning public policy. In order to deal with problems such as pollution, sewage treatment, resource scarcity, water shortage and the formation of heat islands, different options in urban design are assessed with the aid of mathematical models, which shows the choices that best balance greater social and economic advancements with lower ecological effects (Kennedy and Hoornweg, 2012; Hoornweg et al., 2012).

Therefore, considering the growing relevance of urban metabolism studies, the purpose of this paper is to measure the changes in material and energy use occurred in Curitiba (Brazil) in the decade of 2000–2010. The gathering of data regarding this city's flows of materials and energy in ten years represents the first step to a more sophisticated analysis, and will hopefully support planning and decision-making regarding its sustainability. Besides the accounting contribution, the paper expands the comprehension of the relationship between urban regions, highlighting how industrialized cities are now more dependent on the land space available (only) beyond its geographical limits.

2. Methods

Developed over the years, urban metabolism methodology is nowadays sufficiently robust, consistent and well anchored in existing academic literature. Integrated frameworks allow the examination of energy and material flows in complex systems, shaped by various social, economic and environmental forces (Holmes and Pincetl, 2012). The specific framework adopted to assess the urban metabolism of Curitiba was proposed by Kennedy and Hoornweg (2012). They presented the basic data that should be collected in any attempt to evaluate the urban metabolism of one city or region. Requirements for Abbreviated Urban Metabolism Studies refer to inflows (water, construction materials, fossil fuels, electricity etc.) production (food, wood etc.), stocks (minerals, nutrients etc.) and outflows (air emissions, wastewater and solid waste). One of the contributions of this model is the possibility of comparison between different locations around the world, as the essential indicators are suggested along with standardized measuring units.

Considering that the main purposes are to provide a quantitative measure of Curitiba's material and energy flow and to understand the city social and economic transformation in ten years, we also included in the analysis some of the variables from the works of Newman (1999) and Kennedy et al. (2014). Newman (1999) is known for extending the metabolism model, in one of the first efforts to add social issues to urban studies, showing how resources are being used to create opportunities. He introduced variables about settlement dynamics and livability, which should be fully integrated in urban metabolism studies (Kennedy et al., 2011). Kennedy et al. (2014) used the Abbreviated Urban Metabolism framework to measure and compare almost 15 megacities. They added parameters to describe how the basic infrastructure and the services offered for households can improve living conditions in the city, reinforcing the need to measure social matters. These adjustments were considered appropriate and did not represent any methodological obstacle. They represent a more integrative approach where social and economic aspects can be examined in the context of urban metabolism (Kennedy et al., 2014).

Although urban metabolism studies have evolved over the years, some difficulties persist. The main ones, as anticipated by Wolman (1965), involve data availability and the gathering of information. One reason is that it is actually impossible to completely evaluate any urban metabolism (Brunner, 2007), as cities are present in global markets and their sustainability depend on resources available elsewhere; thus, a metabolic analysis would only be complete if it was able to identify this complex inter-municipal relationship, with the entire description of the origins and destinations of resources, produced goods and waste. In some cases, data available for the local level is less reliable than for the national level, as international transactions are better controlled (Kennedy et al., 2007; Hoornweg et al., 2012).

Another challenge is to increase proficiency in data collection and management. Hoornweg et al. (2012) advises that "data is very fragmented and not regularly collected and the studies very much adopted a 'best available data' approach". Even though Curitiba has a fairly decent official database, quality in reporting and even a department that control statistics, data was still dispersed and its gathering demanded more effort than it should be necessary. Nonetheless, we were able to contribute with a satisfactory overview of how the city has changed its resource consumption and waste production. Also, the ten-year approach represents a step further in usual urban metabolism studies, that due to (not) available data and (not) continuous monitoring, generally show only one moment (one year), reducing the possibility of comparison.

3. Case study

Curitiba is located in the south portion of Brazil, and it is the administrative capital of the state of Paraná (see Fig. 1). Officially founded in March 29th, 1693, it was first dedicated to mining, agriculture and livestock in the 17th century. Later, with the arrival of several groups of immigrants and the building of railroads connecting it to the sea, Curitiba became one of the biggest industrial production areas of the state. Nowadays, population is about 1.8 million people (the 8th most populated city in Brazil) and population density is 4027 inhabitants/km^2. Regarding its economy, Curitiba raised its Gross Domestic Product (GDP) from US$ 8 billion (2000) to about US$ 32 billion (2010), following São Paulo, Rio de Janeiro and Brasília as the 4th biggest GDP of Brazil. In the social level, the Human Development Index (HDI) went from 0.750 to 0.823 in the same period, ranking 10th in Brazil (PMC, 2014; IBGE).

Curitiba has a land area of about 435 km^2 and is located 945m above sea level. With a typical subtropical climate, the average temperature is 21 °C in the summer and 13 °C in the winter, rather cold for Brazil. The annual solar radiation in Curitiba (1481 kWh/m^2) is below cities like São Paulo (1622 kWh/m^2) and Rio de Janeiro (1694 kWh/m^2) and the average annual precipitation is about 1400 mm (Hoornweg et al., 2012; PMC, 2014; INMET, 2014). Similarly to the whole state, the main biome in Curitiba is the Atlantic Forest, and the city itself is served with 29 parks and 115 million m^2 of green areas, which makes an average of 64.5 square meters per capita (m^2/cap), above the recommended standard of 40 m^2/cap (Medeiros, 1975; Singh et al., 2010). At the same time, the building gross floor area is about 92 million m^2, being 69% of residential areas and 31% of non-residential areas.

We chose to study the urban metabolism of Curitiba for some reasons. First, the city is widely recognized for its efforts concerning sustainability. In the 1970s, instead of using vacant land to real estate speculation, the option was to create new parks and green areas, an alternative better suited for ecological preservation and