G Model
RECYCL-3340; No. of Pages 9
ARTICLE IN PRESS
Resources, Conservation and Recycling xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Resources, Conservation and Recycling
journal homepage: www.elsevier.com/locate/resconrec

Full length article

Socio-economic metabolism of urban construction materials: A case study of the Taipei metropolitan area

Yishin Wang, Pi-Cheng Chen, Hwong-wen Ma*, Kuang-Ly Cheng, Chih-Yu Chang

Graduate Institute of Environmental Engineering, National Taiwan University, Taiwan

ARTICLE INFO

Article history:
Received 26 January 2016
Received in revised form 28 June 2016
Accepted 14 August 2016
Available online xxx

Keywords:
Urban metabolism
Building and infrastructure
Material-flow analysis
Cement
Sand and gravel
Socioeconomic factors

ABSTRACT

Material stock is an urban issue related to urban mining. In recent years, urban metabolism issues, i.e., the determination of urban stability, have also emerged as important. The manifestation of dynamic materials in a city involves processes of importing, supply, transformation, consumption, and exporting and other activities involved in the flow of materials. Socioeconomic factors must be considered to transform study results into useful policies. This study examines cement and gravel flows in Taipei and New Taipei City to explore such concepts.

Our results show that more than 80% of the construction material use in Taipei and New Taipei City is mainly dedicated to the construction of buildings and secondarily to road improvements and road maintenance. Approximately 447 t of waste concrete is generated each year, and the consumption of cement and gravel in Taipei and New Taipei City has grown over the last decade. Factors that have heavily affected urban metabolism patterns include the slowdown of economic activities after the financial crisis of 2007–2008 and the emergence of new urban zoning laws. We find that roadwork has intensified dramatically due to road-smoothing and short-term urban construction projects, which may have been influenced by elections. This study measures flows in an urban metabolic system and examines socioeconomic factors that have led to an increase in the consumption of cement and gravel.

1. Introduction

The exploration of urban socio-economic metabolism levels has become an increasingly important topic of research. Means of alleviating environmental pressures, which are dominated by anthropogenic activities driven by urbanization, should be based on a systematic understanding of resource flows from sources to consumption, stock and sinks and through processes of transformation and circulation. In addition, dynamics of urban metabolism affected by various socio-economic factors (e.g., growing populations, changing consumption patterns, the introduction of new technologies, and variations in political and economic conditions) that can trigger interventions in urban metabolism should be considered. Analyses of how urban metabolism (UM) vitiates urban socio-economic environments represent a needed area of research in industrial ecology.

Cities require access to large reserves of construction materials for the construction of infrastructural systems and buildings to grow and develop. Such demands can in turn result in the generation of large amounts of construction and demolition waste. In a megacity, almost all material flows are dominated by anthropogenic flows. Even when pollution-abatement techniques (e.g., air-pollution control, wastewater treatment, and waste management) are applied, diffuse sources (e.g., the corrosion of urban surfaces and erosion due to vehicle-brake systems) gradually increase pollutants found in urban soils and sediments (Brunner, 2007). Large material stock densities induce strong energy and material flows (Graedel, 1999). In discussions on urban metabolism and urban sustainability indicators, the determination of inputs to urban greenhouse gas emissions and of mathematical models of urban metabolism for policy analyses have formed a basis for sustainable urban design models (Kennedy et al., 2011). Levels of construction in urban areas are presented on the country scale in terms of many types of resources. Steel, copper, wood, cement and gravel are used for construction purposes. As infrastructure and buildings typically stand for several decades after being built, these resources are stocked. Therefore, the determination of ways to manage such resources has become a complex and important issue (Simoni et al., 2015). A study in the U.S indicated that quantifying the material-intensity profiles of building stock over time and space may generate practical data from which to understand the composition of new and recycled materials entering building stock

* Corresponding author.
E-mail address: hwma@ntu.edu.tw (H.-w. Ma).

http://dx.doi.org/10.1016/j.resconrec.2016.08.019
0921-3449/

and of those leaving built environments for secondary markets. Furthermore, such an evaluation may support efforts to continue material cycles in the economy (Marcellus-Zamora et al., 2015).

As most resources in Taiwan are imported, the country easily faces resource-shortage problems. Resource-management policies should be taken more seriously in Taiwan. The construction industry is the leading consumer of material resources and is the leading generator of construction and demolition waste and associated emissions; it is also an important contributor to urban economic development. Cement and gravel materials form a large proportion of urban settings. Cement production, which is highly dependent on the availability of natural resources, will face severe resource constraints in the future and will therefore have significant environmental effects (Gao et al., 2016). The cement and cement-based materials industry is one of the key industries related to China's pollution control and resource management outcomes (Wang et al., 2016), and related problems have manifested in Taiwan. While gravel may appear easily reusable without polluting effects, it is in fact not reused well and generates excessive mining problems, which consequently have environmental effects. Therefore, the present UM study focuses on the following construction materials: cement, sand and gravel. Detailed information on material flows is needed to support the development of UM management policies.

Several studies have examined the UM of different cities with physical flow systems. Generally speaking, these UM studies have quantified material flows and stock and growth in material consumption and stocks, and they have assessed the consequences of flow and stock accumulation at several aspects, i.e., environmental, economic, and social (Zhang, 2013). Some researchers have also conducted analyses to reveal main themes emerging within interdisciplinary boundaries of urban metabolism and ways in which this concept brings forth new understandings of (1) the city as an ecosystem, (2) material and energy flows within cities, (3) economic-material relations within cities, (4) economic drivers of rural-urban relationships, (5) the reproduction of urban inequalities, and (6) attempts at resignifying cities through new understandings of socio-ecological relationships (Broto et al., 2012; Brunner, 2007).

Some previous studies have examined the relationship between UM and socioeconomic factors. Environmental footprint analyses have been used to examine the sustainability of cities and have involved studying cities within a broader geographic context (Doughty and Hammond, 2004; Hsiao et al., 2002; Huang et al., 2006). As regions extract, produce, and transform fewer materials than the countries that they are situated in, direct material inputs (DMI) for regions are lower than those of national DMIs. The multiscale approach shows that urban metabolism is strongly affected by the density and distribution of activities. For instance, the dense city center of Paris exports all locally generated waste to the other parts of the region and concentrates food consumption patterns, whereas its agricultural and urban sprawl area consumes high levels of construction materials and fuel (Barles, 2009). A case study of the Lisbon Metropolitan Area was conducted for the generation of a model that associates material flows with economic activities and spatial locations within urban areas (Rosado et al., 2014). The model determines how transitions occur, who leads transitions and what social and governance processes are best suited for the facilitation of such urban transitions. The model assesses the role of material-flow and transition analyses in describing resource flows and urban infrastructures, thus allowing one to begin to address related challenges in practical and transformative ways (Hodson, 2012). However, few studies have examined UM based on a broad range of socioeconomic statistics, which may contain specific information on relationships between physical flows and varying socioeconomic circumstances.

To gain insight into ways to shape the sustainability of UM, this study explores the driving forces in UM within a socioeconomic context. First, we present the material-flow structure of cement and gravel. We then examine the amounts of cement and gravel used and discusses major flows. We find trends by comparing resource consumption levels of each flow pattern and related socioeconomic data. Finally, the results of the case study are presented. Our results contribute new information to the field of urban metabolism through an analysis associating material flows with economic activities and material consumption patterns in urban areas.

2. Method and database

2.1. Study area and database

The Taipei metropolitan area is located in Northern Taiwan and is the most important economic center in Taiwan. It covers an area of 2224.1 km^2, accounting for 6.1% of the area of Taiwan. The area includes a population of approximately 6.7 million, accounting for 30% of Taiwan's total population.

The population of the Taipei metropolitan area has grown over the past ten years. The local economy has grown rapidly due to the expansion of urban areas and due to high rates of per capita consumption. As a result of such urbanization, nearly 80% of the population in Taiwan lives in urban areas (Huang and Hsu, 2003). The building floor area increased by approximately 170% from 2004 to 2013 in the Taipei metropolitan area. Road and transportation construction have also become more pronounced over the past ten years. Through processes of urbanization development, the consumption of natural resources has increased, producing several environmental effects. Such environmental effects not only affect urban areas, e.g., air pollution, waste and traffic problems, but also lead to resource exhaustion. The relationship between socioeconomic factors and urban resource consumption should be studied in terms of resource and urban sustainability goals.

2.2. The transitioning taipei UM for gravel and cement from 2004 to 2013

As the aim of the present work is to examine material flows and to quantify materials consumed during gravel- and cement-processing stages in cities, it is necessary to describe the primary uses of gravel and cement. The structure of consumption processes of gravel and cement for the Taipei metropolitan area is shown in Fig. 1.

In Taipei, gravel and cement are derived from two sources: from imports and from mining activities in other counties throughout Taiwan. We examined the seven main uses of gravel and cement: residence construction, road improvements and maintenance, road construction and widening, disaster-prevention engineering, mass rapid transit construction, pipe construction and bridge construction. Construction waste refers to outputs generated after use. Some of this waste is recycled and reused or is sent to landfills in Taipei or New Taipei City while another portion is exported to other counties for reuse. As there are strict regulations on the properties of construction waste to be reused, the reuse path of construction waste has not been straightened.

2.3. Data basis and determination of cement and gravel flows

To identify flows of cement and gravel, primarily appropriate statistics and scientific literature were used, including marketing reports on sand and gravel used in the Taiwan area and annual reports produced by the Taipei and New Taipei City governments. Calculating all urban construction costs to find the true value of

Please cite this article in press as: Wang, Y., et al., Socio-economic metabolism of urban construction materials: A case study of the Taipei metropolitan area. Resour Conserv Recy (2016), http://dx.doi.org/10.1016/j.resconrec.2016.08.019