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An urban metabolism and ecological footprint assessment of Metro Vancouver

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ABSTRACT

As the world urbanizes, the role of cities in determining sustainability outcomes grows in importance. Cities are the dominant form of human habitat, and most of the world's resources are either directly or indirectly consumed in cities. Sustainable city analysis and management requires understanding the demands a city places on a wider geographical area and its ecological resource base. We present a detailed, integrated urban metabolism of residential consumption and ecological footprint analysis of the Vancouver metropolitan region for the year 2006. Our overall goal is to demonstrate the application of a bottom-up ecological footprint analysis using an urban metabolism framework at a metropolitan, regional scale. Our specific objectives are: a) to quantify energy and material consumption using locally generated data and b) to relate these data to global ecological carrying capacity. Although water is the largest material flow through Metro Vancouver (424,860,000 m^3), it has the smallest ecological footprint (23,100 gha). Food (2,636,850 tonnes) contributes the largest component to the ecological footprint (4,514,400 gha) which includes crop and grazing land as well as carbon sinks required to sequester emissions from food production and distribution. Transportation fuels (3,339,000 m^3) associated with motor vehicle operation and passenger air travel comprises the second largest material flow through the region and the largest source of carbon dioxide emissions (7,577,000 tonnes). Transportation also accounts for the second largest component of the EF (2,323,200 gha). Buildings account for the largest electricity flow (17,515,150 MWh) and constitute the third largest component of the EF (1,779,240 gha). Consumables (2,400,000 tonnes) comprise the fourth largest component of the EF (1,414,440 gha). Metro Vancouver's total Ecological Footprint in 2006 was 10,071,670 gha, an area approximately 36 times larger than the region itself. The EFA reveals that cropland and carbon sinks (forested land required to sequester carbon dioxide emissions) account for 90% of Metro Vancouver's overall demand for biocapacity. The per capita ecological footprint is 4.76 gha, nearly three times the per capita global supply of biocapacity. Note that this value excludes national government services that operate outside the region and could account for up to an additional 2 gha/ca.

1. Introduction

More than 50% of the world's population live in urban regions (UNPD, 2009), and in affluent countries urbanization levels exceed 75%. Such is the case for Canada where 80% of the population lives in urban centres (Statistics Canada, 2006a). Cities and towns are perceived as the source of most states' economic wealth and the core of social and cultural activities (Jacobs, 1984). At the same time, from a biophysical perspective, cities are dissipative structures that consume vast quantities of energy and material resources (Rees, 2012, 2003). However, urban metabolism studies reveal that cities' demand for nature's goods and services is increasing over time (Browne et al., 2011; Kennedy et al., 2007; Sahely et al., 2003; Hoyer and Holden, 2003; Warren-Rhodes and Koenig, 2001; Newman and Kenworthy, 1999). This is significant because humanity's aggregate ecological footprint (Wackernagel and Rees, 1996) already exceeds the global supply of biocapacity (WWF, 2010). Humanity's ecological deficit is therefore increasing simultaneously with worldwide urbanization (Rees, 2011) even as appreciation grows that for a sustainable future, our species' demand for biocapacity must be reduced.

Urbanization has both positive and negative environmental implications. On the one hand, cities are nodes of consumption that depend utterly on a constant flow of materials and energy from around the world in order to function (Rees, 1992, 2003, 2012; Girardet, 1999; Downton, 2009). On the other hand, the economies

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of agglomeration (lower costs due to proximity of related activities)[1] and the economies of scale (lower costs due to higher volumes) associated with the city's high population density and concentration of economic activity contribute to a significant "urban sustainability multiplier" (Rees, 1997, 2009). Furthermore, the sheer wastefulness of many cities implies major opportunities for energy and material conservation. It follows that in the 21st century, cities are an appropriate focus for research into ecologically necessary, socially acceptable and politically feasible ways of reducing the overall human load on the world's ecosystems (Newman, 2006; Newman et al., 2009; Rees, 2012).

Two approaches developed in recent decades that help quantify and assess urban environmental loads are 'urban metabolism analysis' (UMA) (e.g., Wolman, 1965; Baccini, 1997; Kennedy et al., 2007) and 'ecological footprint analysis' (EFA) (Rees, 1992; Wackernagel and Rees, 1996; Chambers et al., 2000). Both use material flow analysis, predicated on the thermodynamic law of conservation of energy and the law of mass balance. Metabolism studies attempt to quantify the amounts of materials and energy that flow through a city. Analysing the material and energy metabolism of specific sectors and activities within the city allows identification of major loads and potential points of intervention for reducing urban impacts (e.g., Kennedy et al., 2010; Lenzen et al., 2003; Hendriks et al., 2000). EFA, when combined with UMA, takes the additional step of estimating the area of productive terrestrial and aquatic ecosystems required for urban metabolism to happen. This means that EFA estimates the biocapacity required to produce the energy and material resources the city consumes and to assimilate the resultant wastes (Rees, 1992; Wackernagel et al., 2006; Ewing et al., 2009). EFA also uniquely enables comparisons of demand with supply, i.e., between current urban metabolic load and available biophysical carrying capacity, both regional and global (Wackernagel and Rees, 1996; Chambers et al., 2000). For example, while world average biocapacity demand is 2.7 gha[2] per capita and global supply is only 1.8 gha per capita (WWF, 2010), the average per capita biocapacity demand in high-income cities is often much higher.

While several authors acknowledge both approaches (e.g., Hendriks et al., 2000; Sahely et al., 2003; Kennedy et al., 2007; Browne et al., 2008), most studies use only one method. Curry et al. (2011), Kennedy et al. (2010), Jones (2006), Barrett et al. (2002), Hendriks et al. (2000), Rotmans and van Asselt (2000) and Ravetz (2000) recognize UMA's usefulness in urban sustainability policy development while Collins and Flynn (2006), Mcmanus and Haughton (2006), Barrett et al. (2005), Nijkamp et al. (2004) and Holden (2004) emphasize EFA's contribution to urban policy and communication. The latter method is seen as particularly effective when local government staff is engaged in its development (Collins and Flynn, 2006; Aall and Norland, 2005).

Indeed, recently both the City of Vancouver (Vancouver, 2011) and to a lesser degree the Metro Vancouver Region (Metro Vancouver, 2007a) have indicated interest in working with EFA. It is in response to this interest, addressing local government use of EFA within a North American context, that we focus attention.

Combining UMA and EFA can build upon the strengths of each method (Curry et al., 2011). An EFA based on a UMA framework adds an additional level of insight to an already robust local-level analysis of energy and materials flows within the city. Such an approach can help local officials interpret in general terms the demands on biocapacity resulting from their city's activities and consumption by its residents. The integration of a bottom-up analysis of energy and material flows, including lifecycle assessment, to compile components of an urban metabolism and ecological footprint study can assist local governments to understand how a region's urban metabolism affects demand for ecological services.

Our objectives in this paper, therefore, are: i) to use an urban metabolism framework to quantify the energy and materials consumed by the resident population of Metro Vancouver to support their urban lifestyle patterns; and ii) to compare the ecological footprint associated with that consumption to available per capita biophysical carrying capacity globally. The study uses locally-generated, disaggregated data sources for several urban components such as: buildings, transportation, water, food, material and waste. It provides what we believe is the first integrated UMA and component based EFA study of a North American urban region. It introduces a robust data set from which to pursue further analysis pertaining to the reduction of biocapacity demand and could facilitate the integration of resource management with urban planning (Kennedy et al., 2010; Agudelo-Vera et al., 2011).

2. Evolution of ecological footprint analysis to better serve cities

To date two main approaches have been developed to calculate ecological footprints at the sub-national scale: i) an adapted compound method and ii) a component method. The compound method uses national per capita ecological footprint data that is scaled to reflect the city as much as possible (Wackernagel, 1998; Chambers et al., 2000; Ewing et al., 2010). In the crudest estimates, per capita EFs based on national data are multiplied by the population of the city in question. A more refined approach may weight certain of the national data on energy and material flows based on household consumer surveys that distinguish regional consumption preferences. Nevertheless, because it relies predominantly on national statistics, even this represents a top-down approach (e.g., Wilson and Anielski, 2005; Folke et al., 1997; Wackernagel, 1998; Onisto et al., 1998). The advantage to the compound method is that total national production, import and export data for key sectors are readily available and easier to locate than city-specific data. However, this method has limited ability to reflect the impacts of local policy and action (Levett, 1998; Chambers et al., 2000; Aall and Norland, 2005; Wilson and Grant, 2009; Xu and San Martin, 2010).

The component method starts with local data that reflect the study population's consumption activities (Wiedmann et al., 2006; Barrett et al., 2002; Chambers et al., 2000). There are two sub-approaches: a) involves (monetary) input–output analysis and; b) requires direct estimates of energy and material throughput using local data. The former prevails, particularly in Europe, because of its ability to account for the embodied energy of multiple supply chain steps (Lenzen, 2001), the ease of comparing results (Bicknell et al., 1998), and the relative expediency of data collection and calculation (Barrett et al., 2002; Xu and San Martin, 2010). We refer to this approach as the 'sub-national input–output approach' (SNIO). SNIO is based on monetary input–output economic tables whose values are secondarily converted to actual energy and material flows. It typically also connects local expenditures to carbon emissions in a further extension of conventional input–output analysis. These surrogate data are then used for ecological footprint assessment. However, money-based, economy wide input–output data do not enable: a) tracking how resources flow *within* the region, and b) distinguishing between and prioritizing different types of resource flows (Wiedmann et al., 2006). Although UMA studies can

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[1] Lower costs include reduced demand for energy and materials to service the built environment, e.g. reduced demand for transportation translates to fuel savings and less road repair and maintenance.

[2] A global hectare (gha) represents the world average biological productivity of land.