Industrial Ecology and the Global Impacts of Cities

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Because cities are local entities, environmental problems associated with them have long been regarded as merely local issues. We know this is no longer true. On the one hand, the environmental problems of cities have grown beyond the city limits, both with multiple dimensions and with their scale of impacts ranging from local, to regional, to global (Bai and Imura 2000; Bai 2003; McGranahan et al. 2005). On the other hand, with approximately half of world population living as urban dwellers, and with the ongoing concentration of economic activities in cities, a majority of the global environmental impacts stem from cities. Because of the ever-increasing urban population this proportion is likely to become even larger. Thus, cities are rapidly becoming a "battleground for sustainability" (Clark 2003).

Cities have not been major units of analysis in industrial ecology (IE), and industrial systems are not of much interest to urban scholars. People who are concerned about cities and those who are concerned about industrial systems generally belong to different professional groups. At least two factors exist that might provide a foundation for the two groups to work more closely together: one is methodological similarities between studying urban ecosystems and industrial ecosystems, and the other is spatial and functional linkages between cities and industry.

Cities are open systems and depend on the outside world to provide raw materials and assimilate waste to sustain their function. The input side of metabolism analysis involves characterization of various material and resource demands by a city. The output side looks at the by-products of the various urban functions and processes, and greenhouse gas (GHG) emissions are a prominent example. There is yet a third aspect or dimension that is important in the metabolism of cities: the processes and mechanisms that shape, regulate, and govern the various flows.

One of the most prominent methodological similarities is the metabolism approach, which involves conceptualizing a city or an industrial system as an organism and tracking resources that go into the system and products and wastes that leave it. In IE we often compare an industrial system to an ecosystem, with the metabolism approach being one of the fundamental tools with which to make the comparison. The same metaphor and tools have been used even earlier in studying cities. For example, the first metabolism analysis was conducted for an imaginary city of 1 million people (Wolman 1965). Some of the first metabolism analyses in real-world cities were performed under the UNESCO Man and Biosphere (MAB) Program during the 1970s and 1980s (see, for example, work by Boyden et al. 1981). The similarities, and therefore the opportunities, of working on cities have also been recognized by industrial ecologists (see, for example, work by Graedel 1999).

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When it comes to the analysis of the overall environmental impact of urban activities, other IE tools, such as life-cycle assessment (LCA), have proven to be useful (e.g., Björklund et al. 1999 and Kraines et al. 2001). A consensus now exists that a product cannot be considered green unless it has less environmental impact over its entire life cycle than a competing choice. Similar principles and analytical methods can be applied to studying cities to reveal the overall impact including the externalities of cities.

Industries are mostly located near cities, and the development of modern cities is largely due to rapid industrialization. The evidence of concurrent rapid urbanization and rapid industrialization evident in some Asian countries demonstrates such a linkage. As a result, the environmental performance of an industrial system can have significant impact on the life of urban dwellers.

The linkage has been less obvious, but important, when it runs in the other direction—between cities and the industrial system, often through urban governance. There has been a love and hate relationship between cities and industries. Cities, for example, need industries to provide jobs and revenue, but they do not want the pollution that comes with the industrial activities. So when they are able, they will get rid of polluting industries, pushing them away from city centers to suburbs or to other cities (Bai 2002). This city-industry interaction strengthens at the industrial park level (see, for example, Desrochers 2001). Cities can encourage or discourage the development of particular types of industries within their boundaries. From an ecosystem point of view, the industrial ecosystem can be considered a nested subsystem within an urban ecosystem, the former often regulated at a higher level by the latter.

Many of the regional and global environmental impacts of cities are related to either the input or the output of urban metabolism. Cities are open systems and depend on the outside world to provide raw materials and assimilate waste to sustain their function. The input side of metabolism analysis involves characterization of various material and resource demands by a city. The output side looks at the by-products of the various urban functions and processes, and GHG emissions are a prominent example. There is yet a third aspect or dimension that is important in the metabolism of cities: the processes and mechanisms that shape, regulate, and govern the various flows. The articles included in this special issue, which focuses on the global impacts of cities, without exception, highlight one of the three aspects, albeit from various viewpoints.

In the input or demand aspect, the column by Brunner (2007) provides an overview on the metabolism of a city and its global impacts. His contribution illustrates several major characteristics of the metabolism of today's cities. Especially in megacities, anthropogenic flows outweigh—literally—the geogenic flows in all materials except water and air. Most of the input into cities stays within the cities as stock materials. Due to the time lag between input and output, a growing city witnesses much more input than output, but the future amount of waste will be much larger than today. The city's function plays a significant role in its metabolic make up. In service-oriented cities, consumption-related emissions are more important than those produced by production. Recycling becomes essential in turning around the linear process of urban metabolism. For a mature city, in which the input and output tend to be similar, recycled materials will be usable to replace a large portion of material inputs from outside. For this purpose, understanding the existing stocks of key materials in an urban area is important (van Beers and Graedel 2007).

A significant body of literature on urban metabolism has become available during the past 40 years, following the pioneering work of Wolman (1965). After examining urban metabolism analyses that have been conducted in eight metropolitan regions in five continents, Kennedy and colleagues (2007) conclude that most cities exhibit increasing per capita metabolism, that is, more resources used per person. They argue that the resulting consequences of urban metabolism, such as changing ground water levels, exhaustion of local materials, heat islands, and irregular accumulation of nutrients, can have significant impact on the sustainability of cities. They further argue that an understanding of the accumulation or storage processes in the urban metabolism is thus important.

Conventional wisdom tells us that as cities grow rich, they tend to move toward a service-oriented economy and outsourcing of the manufacturing sector, resulting in a reduced material flow. It seems, however, that economic growth does not always bring about reduced input in the metabolism. Schulz (2007) provides a time series study of urban metabolism for the case of Singapore. He examines 41 years of data on the direct material flows of an exceptionally rapid example of industrialization and urban transformation, largely driven by export-oriented industrialization. Results show that the spectacular 20-fold economic growth of Singapore was associated with similar expansion of domestic material consumption—suggesting no sign of dematerialization over this period. This finding emerges despite the fact that the materials flow analysis (MFA) in this article was restricted to direct flow accounts and excluded hidden flows.

The absence of trends toward dematerialization points to the need to look at global environmental impacts of rapidly industrializing and urbanizing regions in the world, in Asia in particular. Fernández (2007) examines the material resources consumed in typical Chinese construction and outlines the emerging life-cycle issues of these recent additions to the built environment. The quality of construction, expected service lives, and durability of this most recent construction boom are discussed as part of a long-term assessment of the resource burden resulting from this massive urbanization. China currently experiences rapid urbanization, which entails rapid increases in both material and energy consumption. A recent study that examines the relationship among urbanization and the supply and demand of energy and material resources in China suggests that this China will inevitably face a long-term shortage of resources if it follows a business as usual scenario (Shen et al. 2005).

Two articles are presented on the output end of urban metabolism, examining carbon dioxide (CO_2) emissions from the residential and transport sectors, and the energy impacts of an urban park.

VandeWeghe and Kennedy (2007) examine CO_2 emissions from private transport and residential operation in Toronto, Ontario, Canada, and characterize their spatial variation. They find that, over the entire region, emissions from private auto use are on par with those from fuel use for building space heating. In lower-density suburbs, GHG emissions tend to be higher, mostly due to private car use. Although Canada has pledged to abide by the Kyoto Protocol to reduce its total emissions to 6% below 1990 levels by 2012, the energy efficiency of Canadian cities varies, and some cities are making the goal even more unattainable through relaxed building codes or urban sprawl.

Service industries are often viewed as less energy and material intensive compared with manufacturing and agricultural activities. Another common understanding of the ecosystem function of urban green spaces is that urban parks play an important role in offsetting the negative environmental impacts of urban activities, including absorbing CO_2 emissions. Urban parks may hold hope for cities to self-contain some of the output of the metabolic process by emphasizing the development of service sector industries and having more green spaces. An energy flow analysis (EFA) conducted by Oliver-Solà and colleagues (2007) of service facilities within Montjuïc Park in Barcelona, Spain, suggests that developing service sector industries is not always the answer. Even without manufacturing activities and virtually no permanent residents, the environmental impacts from the service activities in the park, which support 14.5 million visitors annually, might be significant; using energy footprint methodology, the authors calculate that the land area required to absorb the CO_2 emissions from service sector activities alone would exceed 12 times the area of the park! This disparity indicates that, depending on how urban parks are developed and used, the corollary activities to maintain the park might be "eating away" the potential ecological services that urban parks are normally considered to be providing.

As part of various processes of a complex urban system, metabolic flows are shaped by a number of intertwined factors. The solutions to reduce and maintain more sustainable metabolic flows, therefore, sometimes lie beyond the sectors that are directly involved in the cycle. Four articles in the special issue address this aspect.

Banister (2007) argues that although the potential of reduced energy intensity per capita in cities is recognized and discussed, it seems this environmental merit of urban agglomeration is yet to be realized. Furthermore, although the linkages between mobility and climate change are also recognized and efforts at governmental and individual levels in changing the situation are made, it is far from enough and the real challenge lies in substantial behavioral change. A comparison in countries of the European Union between the early 1990s and early 2000 shows that travel by car, total energy consumption in transport, and GHG emissions from transport activities have all increased significantly. Banister argues that "massive investment would be required in changing production processes for the new superefficient cars, in sourcing substantial quantities of alternative fuels, and in giving incentives to industry and individuals to use these new vehicles."

Urban forms and functional roles also weigh significantly on global impacts. Lebel and colleagues (2007) examine primarily carbon emission inventories and regional development histories in five Asian cities, namely, Manila, Jakarta, Ho Chi Minh City, New Delhi, and Chiang Mai. They argue that not only does the manner in which urban functions, such as mobility, shelter and food, are provided have major implications for carbon emissions, but each function is influenced by urban form and role in distinct ways. The linkage calls for a shift from heavily sector-focused mitigation of local GHG emissions toward an alternative, system-wide approach.

The importance of tackling global issues at local levels and the importance of government in mitigating doing so are widely recognized (Wilbanks and Kates 1999; Bulkeley and Betsill 2003). It remains difficult, however, to tackle global issues at a city level. My article, included in this issue (Bai 2007), explores the obstacles that impede cities from addressing global environmental concerns, the opportunities for removing the obstacles, and strategies to bring global issues onto the local level. I argue that many of the obstacles are reflections of contradictory perceptions, concerns, interests, and priorities, which can be presented in the form of two arguments, about scale and readiness. The close linkages between global and local environmental issues and the potential economic benefits arising from addressing global concerns at the local level may provide opportunities and incentives for cities to take earlier action. I further argue that although empirical studies in developed cities suggest that the most effective way to get municipal governments to address global concerns is by not talking about the global aspects of the issues, an overly localized policy might not always result in a net gain in a developing city setting. The article emphasizes the importance of expanding the spatial and temporal scale of concerns by city governments and managers.

As noted above, studies suggest that as cities grow richer, the predominant environmental issues change from poverty-related, to industrial pollution-related, and then to lifestyle-related ones; and the spatial scale of their impacts tends to shift from local to global (Bai and Imura 2000; Bai 2003; McGranahan et al. 2005). When examined from the sustainability point of view, the trouble is that this shift in scale does not necessarily mean a shift of a city toward a more sustainable end. After examining Southeast Asian cities, Ooi (2007) argues that the lack of a more participatory policy-making process might have influenced the failure of the shift in scale to translate into more sustainability and that the process neglects the global impacts of city activities as well.

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