Urban Metabolism

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Urban metabolism broadly refers to the socioecological exchange processes and transformations in cities. The concept, rooted in nineteenth-century work in biology, has in recent decades emerged as central in assessing, measuring, explaining, and addressing the nature of urban environmental change. Several schools of urban metabolism deploy the term in multiple ways: as a metaphor, a paradigm, or a methodological tool. Each school is underpinned by distinct understandings about urban natures and nature–society relations. The field of industrial ecology prioritizes a systems-framed accounting of material energy flows in what are termed urban metabolism (UM) studies, while Marxist ecologies mobilize the metaphor more loosely to highlight unequal production of urban natures. Despite diverging and contested definitions, urban metabolism remains a rich concept for discussing socioecological processes in urbanization.

For many urban metabolism studies, cities are important sites of the transformation of nature, whether understood as a biophysical base or as a hybrid socionature produced historically. Strands of UM studies have developed increasingly complex quantification and mathematical modeling to measure resource consumption and trace material energy flows within a bounded urban system. Other studies, meanwhile, recognize the need to focus on the economic, political, and ecological structures of these flows. Recent attempts propose an expanded framework that advances the transdisciplinary promise of integrating the social and biophysical processes. Urban metabolism scholars have recognized the potentials of the concept as a data-driven policy, design, and planning tool in reducing resource consumption, waste production, and greenhouse gas emissions.

The multiple, sometimes conflicting, usage of urban metabolism has led critics to question the usefulness of the term. One particular target of criticism is the organismic and biological sense of the metaphor. For many UM studies in industrial ecology, urban systems are similar to organisms that metabolize material and energy flows within the city, considered as a bounded unit where inputs and outputs are eventually transformed. As opposed to viewing cities as an organism with metabolic properties, ecologist Nancy Golubiewski (2012) proposed strengthening instead the ecosystem approach in cities. Meanwhile, urban political ecologist Matthew Gandy (2004) called for a hybrid, dialectical understanding of metabolism to emphasize the contested, historical coproduction of urban natures that the scientistic use of the term tends to obscure. Current debates and future directions show continued efforts across schools of urban metabolism to sharpen methodological toolkits, transcend disciplinary divides, and rethink inherited categories such as the "urban."

CONCEPTUAL ROOTS

While urban metabolism studies exploded in the last two decades, metabolism as a socioecological concept has deep roots going back to at least the early nineteenth

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century. Biologists and biochemists coined metabolism to refer to material exchanges within organisms and between organisms and environment. This latter meaning of metabolism was taken up by Karl Marx as a central metaphor for the material transformation of human/nonhuman nature for social reproduction. Labor mediates the socionatural metabolism radically altered under capitalist commodity relations. This sense of the term is foundational for Marxist ecologies, including the field of urban political ecology, which defines metabolism as material exchange and circulation in the production of hybrid urban socionatures (Swyngedouw 2006).

Marx also argued how urbanization and expansion of the capitalist mode of production create metabolic rifts or disruptions in the relations between human and nonhuman nature. These cleavages result in the false separation between the urban/rural and the human/nonhuman. Marxist environmental sociologists built on the concept of metabolic rift to examine the breaking down of the symbiotic ecological interdependence between town and country as a result of capitalist expansion. The ecological metabolic rifts – urban or otherwise – lead to various forms of environmental degradation. Metabolic rift ecologies, such as nutrient cycling, for example, find resonance with work in industrial ecology.

Urban metabolism in industrial ecology traces its line to Abel Wolman's (1965) seminal article, where he identified per capita inflow and outflow resource use for a hypothetical US city. With the goal of reducing consumption, his model poses urban system processes composed of inputs such as water, food, and fuel, and outputs such as waste. Wolman's work inspired subsequent industrial ecology applications of urban metabolism.

SCHOOLS OF URBAN METABOLISM

Several distinct schools of urban metabolism have emerged in the last two decades, most notable of which are systems-based industrial ecology and urban ecology, as well as Marxist-inspired urban political ecology. Industrial ecology is the most explicit in its use of the term urban metabolism as a guiding analytical tool. Urban ecology and urban political ecology employ it as conceptual proxy to refer to ecosystem transformations and production of nature in cities, respectively. Ecological economists and the Vienna school of industrial ecology, meanwhile, advance the broader concept of socioeconomic metabolism.

Industrial ecology as a study of material and energy flows associated with production and consumption activities seeks to reshape the character of environment–economy relations. The normative goal of UM studies is to contribute to the reduction of material throughput and resource consumption in cities. As such, industrial ecologists have developed frameworks such as mass-balance accounting and emergy, and a variety of methods to quantify resource flows that feed urban growth. These include material flow analysis, ecological footprinting, life cycle analysis, and other accounting tools. Most are framed through a mass-balance approach, which is an accounting of different material and energy flows based on the notion that matter is transformed (but neither created nor destroyed). Emergy or embodied energy, meanwhile, highlights how all metabolic processes are ultimately dependent on solar energy. This approach differs from mass-balance accounting by converting different measures of materials and energy into one comparable, standard unit. The emergy approach is less commonly used because of the methodological difficulties of integrating various data and measurements.

Many UM studies in industrial ecology employ material flow analysis (MFA) of particular cities. As a method, MFA gathers data on various kinds of flows entering the city from a specified outside. Urban socioeconomic activities then transform flows into stocks and elements of the built environment, and in the process produce waste. Concerns over the relationship between cities and climate change have also led to the quantification of greenhouse gas emissions using the MFA method. Challenges, however, remain in disaggregating the urban system beyond an undifferentiated black box where material energy throughput is processed.

Other methods incorporated in industrial ecology UM studies seek to extend assessment of urban environmental impacts beyond the immediate hinterland. More than just measuring input–output flows, the ecological footprint method connects urban resource consumption with pressures on land elsewhere. It describes the capacity of per unit land area to support the consumption needs in cities. Life cycle analysis meanwhile assesses cradle-to-grave impacts of urban resource use.

Vienna School industrial ecologists utilize many of these same methods to quantify what they term as socioeconomic metabolism. They differ from traditional industrial ecology in their greater emphasis on sociohistorical explanations that have shaped these flows. The term socioeconomic metabolism broadens applicability to society's transformation of biophysical elements, a process that goes beyond the urban. Ecological economists also employ socioeconomic metabolism accounting at this level of analysis to propose society's dematerialization or reduction of production and consumption.

A different tradition of urban metabolism work evolved in Marxist urban political ecology. The field's theoretical foundations lie at the intersection of urban geography (where ecology is largely absent) and political ecology (where the urban is often ignored). Geographers, sociologists, and anthropologists in this tradition attempt to interrogate and dissolve entrenched dualisms of nature/society and urban/rural, which they see as analytically and politically problematic. The field focuses on hybrid urban socionatures and a dialectical view of the city as process and relation rather than merely as a bounded space. Works in this vein emphasize the historical production of urban socionatures informed by a historical materialist approach, seeking to unveil the processes that produce capitalist urbanization. This approach differs from industrial ecology's vision of the city as a fixed unit that metabolizes resources (drawn from nature as a biophysical base) from outside the system.

Urban metabolism in urban political ecology is a looser metaphor for urban socionatural transformations, and for material and commodity circulation. Water has been the most studied flow because of its vital role in the historical development of cities, the highly political character of its governance, and the fragmented and unequal access to its distribution in many cities. The broad scope of the concept allows a wide range of empirical case studies: from circulation of diverse flows like water, food, waste, and information to the infrastructural networks and technologies that enable or constrain these flows. Urban political ecological studies share a concern for highlighting unequal access, control, and power relations that drive urban change and shape configurations of metabolism. The ultimate goals are political – to illustrate the contradictions and unsustainability of capitalist urbanization and move toward more just urban metabolic relationships and socionatures. Traditional methodological tools in the field include qualitative approaches, ethnographic fieldwork, and archival research.

Quantitative approaches have been less explored, although recent interventions seek to combine the quantitative accounting strengths of industrial ecology more explicitly with urban political ecology's tradition of historical and qualitative approaches.

Finally, urban ecologists find utility in urban metabolism as a methodological tool to trace flows rather than as an explicit paradigm or research theme. Metabolism is conceptually embedded within the ecosystem or the complex interactions among biotic and abiotic elements of the city. Instead of flows, they focus on adaptive and emergent processes that produce the ecology of cities. The dynamic and relational production of ecologies of cities share similarities with urban political ecology's core concerns of hybrid production of socionatures. Like industrial ecology, a systems framework also underpins urban ecological analysis of the city.

FUTURE DIRECTIONS

Urban metabolism remains a fertile ground for bringing scholars and policy-makers around discussions of urban environmental change. The multiple ways that it has been put into analytical use are a crucial part of its continuing appeal for many urban scholars. Calls for interdisciplinary collaborations and conversations across disciplinary divides have been premised on building on the other side's strengths. Industrial ecologists, for example, recognize the need to take power and capital seriously as a driver of processes, while an emerging group of urban political ecologists wish to take quantification of biophysical flows more seriously (Pincetl, Bunje, and Holmes 2012; Newell and Cousins 2015).

As methodological refinements of urban and socioeconomic metabolism continue in industrial ecology, urban political ecologists are rethinking fundamental categories such as the "urban." The theoretical project on "planetary urbanization" initiated by Neil Brenner and colleagues challenges the field's methodological cityism or its analytical focus on cities at the expense of urbanization as a process (Brenner 2013). It seeks to push empirical work on metabolism from socionatural transformations in cities to include transformations in noncity landscapes enrolled in the extending reach of urbanization. This challenge reconsiders what counts as urban and the methodological innovations needed to expand urban metabolism research into these landscapes.

SEE ALSO: Ecology and Cities; Planetary Urbanization; Urban Consumption; Urban Ecology; Urban Inequalities; Urban Planning; Urban Transportation

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