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INTERDISCIPLINARY PERSPECTIVES ON URBAN METABOLISM

A review on the literature A working paper

The UCL Environment Institute Seminar Series Report



Interdisciplinary Perspectives on Urban Metabolism: A review on the literature

UCL Environment Institute Working Paper

27 October, 2011

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Interdisciplinary Perspectives on Urban Metabolism



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Interdisciplinary Perspectives on Urban Metabolism

Forward

This paper was commissioned as part of a project investigating the current state of research on urban metabolism at University College London (UCL) led by Vanesa Castán Broto and Adriana Allen of UCL's Development Planning Unit. The project was made possible by the support of the UCL Environment Institute, which provided a grant funding the development of both this review and a series of filmed interviews with UCL scholars working on issues related to urban metabolism. The starting point for this paper was an exploratory literature review prepared by the project initiators, which laid out the need for an interdisciplinary review of the literature on urban metabolism and the disciplines and key issues that such a review should cover (Castán Broto & Allen 2011). In developing this paper I have drawn on the ideas and literature presented in the exploratory review. In addition I am indebted to Vanesa Castán Broto and Adriana Allen for their support with and many contributions to the development of this paper. Responsibility for any errors or omissions, however, remains my own.

Executive Summary

Introduction

In recent years the concept of urban metabolism has increasingly been employed in a diverse range of disciplines as a means to analyse and theorise the city. This paper raises a number of questions about urban metabolism, its impact on urban scholarship, and how the concept is affecting understandings of the way in which environmental, social and economic factors interact to shape urban phenomena. To explore these issues, the paper reviews interpretations of and current debates around urban metabolism in five disciplines: industrial ecology, urban ecology, ecological economics, political ecology and political geography.

Urban metabolism: intellectual antecedents

Contemporary work employing the concept of urban metabolism tends to draw on either political economy or the bio-physical sciences, as well as on various branches of systems theory and the principles of thermodynamics. Marx used the concept of metabolism in *Capital* to describe the material exchanges and interdependent relationship between human society and nature, an approach which has recently been revised by political geographers and political ecologists. The biological concept of metabolism as the exchange of matter between an organism and its environment, as applied by systems ecologists to ecosystems, has influenced understandings of and approaches to urban metabolism in urban ecology, industrial ecology and ecological economics.

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Disciplinary and interdisciplinary debates in urban metabolism

The city as an ecosystem

The idea of the city as an ecosystem in the biological sense is applied most literally in the field of urban ecology, which sees the city as both a 'system' and a 'natural' entity (Marcotullio & Boyle 2003). Urban ecology has a particular focus on the implications of applying the metabolism concept to the urban realm, such that the idea that urban areas should emulate the cyclical and efficient nature of natural ecosystems is now employed in normative theories of sustainable urban planning and development (Girardet 2008; Newman & Jennings 2008). This focus on circularity, balance and order is challenged by urban ecologists studying urban metabolisms from an approach grounded in complex systems theory, who argue that rather than optimising a single set of supposedly ideal circumstances the goal should be achieving greater resilience to the inevitable internal and external shocks that will impact on an urban area (Alberti 2009).

The city as material and energy flows

The bio-physical approach of studying and quantifying urban material and energy flows, which draws on approaches in the field of industrial ecology, is the predominant interpretation of urban metabolism today (Gandy 2004). Such studies generally focus on quantifying the flow of particular materials or energy in an urban system, and on making urban areas more self-sufficient (Barles 2010, Baccini 1997, Brunner 2008). Many scholars also claim that urban metabolism studies can be tools both for identifying environmental problems and designing more efficient urban planning policies (Baccini 1997; Barles 2009; Niza *et al.* 2009). Others argue that such studies do not result in an analysis deep enough to form the basis for effective urban policy and planning interventions (Fischer-Kowalski & Hüttler 1998). One possible solution to this is to extend the metabolism model to look at links between urban and environmental quality, as well urban drivers, patterns and lifestyles and metabolic flows (Minx *et al.* 2011; Newman 1999).

Breaking the links between urbanisation, economic growth and resource consumption

Scholars from both industrial ecology and ecological economics draw on the concept of urban metabolism in developing theories of how to optimize economy - environment relations. Industrial ecologists tend to focus on finding methods to improve metabolic efficiency or reduce the amount of resources used per unit of economic output, a process usually referred to as dematerialisation or decoupling (Buttel 1997; Dunn & Steinemann 1998). While advocates of dematerialisation argue that economic growth can continue without increased environmental degradation, others see economic growth itself as the cause of this degradation (Czech & Daly 2004; Jackson 2009). Alternative solutions include Daly's idea of the steady-state economy in which economic stability occurs without growth in consumption and, more radically, de-growth or actually limiting the scale of production and consumption (Daly 1992; Martínez Alier, Pascual, *et al.* 2010).

Resignifying the city: urban metabolism and social, technical and ecological relationships

A growing cohort of scholars working across political geography and political ecology are developing new, expanded conceptions of urban metabolism as consisting of not just material and energy cycles but also of highly political physical and social processes (Heynen *et al.* 2006; Bakker 2003a). This work is contributing to a number of substantial *resignifications* of the relations between social, technical,

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economic and ecological forces in urban areas. These include moving away from a society-nature dualism to seeing the city as a process of metabolically transformed nature, even a socio-natural hybrid or a cyborg of machine and organism (Kaika & Swyngedouw 2000, Gandy 2005). This line of work also contributes to new theoretical understandings of urban infrastructure, technological networks and resource flows, drawing particular attention to their role in the metabolism of urban areas.

Urban flows and the production and reproduction of inequality

A growing body of work in political geography and political ecology looks at the role of infrastructure networks in creating and reproducing inequality in urban areas, including to what extent cities are shaped by socio-environmental flows and the networks through which they move (Bakker 2003b, Kooy & Bakker 2008, Coutard 2008). The urban dimension of conflicts around the distributional impacts of urban flows is also addressed by the environmental justice movement, which focuses on the distribution of environmental benefits and damages (Agyeman 2005; Dobson 2003; Swyngedouw & Heynen 2003). The social and distributional issues of urban flows are also a focus for ecological economists, particularly those drawing on world systems theory. These scholars link the demands of urban areas for resources with structural inequalities and ecological conflicts in the regions of the world that provide these resources (Hornborg 1998, Martinez Alier *et al.* 2010).

Governing urban flows

Closely related to debates on the impact of urban flows on inequality is the question of their governance and how they are impacted by broader social power relationships. Urban political ecologists in particular draw connections between the domination of nature and the domination of humankind, and how this can come together in urban areas (Keil & Boudreau 2006). While elites and powerful institutions may dominate the governance of urban flows, the plans and visions of those who develop and manage urban networks and the flows through them may be challenged or subverted by the daily practices of individuals and groups (Bulkeley *et al.* 2011). For this reason, to understand the way in which urban resource flows and the networks that facilitate them are actually governed requires examining daily practice and local political economies (Bulkeley *et al.* 2010, Monstadt 2007).

Conclusion

The concept of urban metabolism can be a productive and useful way to conceptualise how urban areas function. Each disciplinary interpretation has something to offer, from expanding our knowledge base about resource use in urban areas, to increasing understandings of the relationship between urban economies and the environment, to providing a critical perspective on the way in which the relations between social and natural processes produce the urban. However there are substantial differences in the extent to which different disciplinary perspectives travel from theory into practice, and urban metabolism has yet to inspire substantial cross-disciplinary engagement. Such engagement could lead to beneficial adaptations of disciplinary approaches as well as new insights and discoveries, increasing the significance of a rich and rapidly evolving field of research on the metabolisms of urban areas.

Interdisciplinary Perspectives on Urban Metabolism

Introduction

In recent years the concept of urban metabolism has increasingly been employed across a diverse range of disciplines as a means to analyse and theorise the city. The idea that urban areas operate as metabolic systems has already had a significant impact on urban scholarship, leading to reconceptualisations of the way in which environmental, social and economic factors interact to shape urban phenomena. To a certain extent, the growth in literature on urban metabolism represents a convergence in the interests of scholars across a range of disciplines. Such studies share common concerns - relationships between social and natural systems, cities and their hinterlands (both immediate and global) and sustainability and social justice in urban areas. Such studies very often also have interdisciplinary ambitions; scholars employing the concept of urban metabolism are often those working to push the boundaries of their own disciplines.

However once one begins to examine the particular disciplinary concerns driving scholars to employ the notion of urban metabolism, it begins to seem less of a coherent and interdisciplinary concept. The idea of metabolism is a fairly simple concept that many people are already familiar with and is easy to communicate (Fischer-Kowalski & Hüttler 1998). This simplicity and accessibility allows scholars to pick it up and put their own disciplinary spin on it, with the result that it ends up understood and applied in a variety of disparate ways. Urban and industrial ecologists tend to focus on the material flows within urban systems, while some ecological economists emphasise the reliance of the urban economy on natural systems. Other ecological economists focus on the role of urban metabolisms in the wider world system and the production of inequality, a concern they share with political ecologists. More recently, political geographers and political ecologists have invoked the idea of urban metabolism as a way to overcome dualistic conceptions of society and nature.

This context raises a number of questions about urban metabolism. What is the value of the term for understanding urban processes? In what ways is the concept travelling from theory into practice? Is urban metabolism leading to productive interdisciplinary engagement, or do scholars in different disciplines have little in common beyond terminology? To explore these questions, this paper will review the various interpretations of urban metabolism as well as the the current intra- and inter-disciplinary debates around the concept in five disciplines: industrial ecology, urban ecology, ecological economics, political ecology and political geography. Following a brief introduction to the history and theoretical underpinnings of the concept, the paper reviews six themes which can be found in the literature on urban metabolism.

The first theme is the idea that cities themselves can be seen as ecosystems. This view is put forward primarily by urban ecologists, who argue that natural ecosystems can be a model for urban planning and development. Debate in this area centres on whether the objective of normative interventions in urban areas should be stability or resilience. The second theme is the way in which studying urban material and energy flows informs our understanding of the city. A number of studies of urban metabolism drawing on the field of industrial ecology advocate optimising material flows to improve the environmental and economic performance of urban areas. Debates in this field focus on how to integrate social factors and spatial characteristics into these types of analyses. The metabolism of the relationship between the economy and the environment is the focus on the third theme. This section of the paper explores how industrial ecologists and ecological economists define and propose to break the link between urbanisation, economic growth and resource consumption.

The third theme explores the way in which a more critical application of the urban metabolism concept resignifies social, technical and ecological relationships in urban areas. Rejecting the functionalist

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approach of industrial and urban ecologists and building on critiques of dualistic conception of the relationship of society and nature, political geographers and political ecologists use the concept of urban metabolism to explore the complex interweaving of social and biophysical processes that occur in cities. These approaches lead in particular to a concern with the way in which urban flows produce and reproduce inequality, which is the fourth theme discussed in this paper. This theme is addressed by political ecologists through in-depth case studies of ecological conflicts, and by ecological economists through more macro-level theories. The sixth and final theme is the way in which urban flows are governed, in particular the way in which this is affected by broader social power relations. The role of politics, urban elites and neoliberal reforms in governing urban flows are all explored through studies of urban resource flows. Through the exploration of these six themes this paper aims to provide a first step towards a greater understanding of the current state of research in urban metabolism and the extent of engagement across disciplines occurring around this concept.

Urban metabolism: intellectual antecedents

The concept of metabolism emerged in the nineteenth century as a way of describing the exchange of matter between an organism and its environment, such that occurring in the process of respiration (Fischer-Kowalski & Hüttler 1998; Foster 1999). In contemporary biology, metabolism is used to describe a process that occurs in individual cells and organisms. This fairly straightforward biological concept has, almost since its genesis, been extended to apply to processes broader than the interactions between individual cells or organisms and their environment. The idea of a specifically urban metabolism is used to describe a variety of processes, including the interactions between organisms (usually humans) and their surrounding ecosystem, the interaction between an urban area and its hinterlands, and the way in which social and ecological processes interact to produce urban environments.

Two very different disciplines have influenced contemporary work employing the concept of urban metabolism, political economy and the bio-physical sciences (Gandy 2004). To explore the implications of these differences and provide a background to some of the key concepts drawn on in contemporary literature on urban metabolism this section reviews the way the concept of metabolism was taken up and extended in each discipline. In addition it introduces two other areas of theory that have had significant influence on current conceptions of urban metabolism: systems theory and thermodynamics.

Marx came to the idea of urban metabolism through the work of the nineteenth century German soil chemist Justus von Liebig. Liebig argued for addressing the contemporary problems of soil productivity and the shortage of agricultural fertilizer by creating an urban-rural metabolism whereby animal and human wastes from urban areas would be converted into fertiliser. Influenced by Liebig's work, Marx used the concept of metabolism in *Capital* to describe the relationship between humans and nature (Foster 1999). Marx used the term to refer to the material exchanges and interdependent relationship between human society and nature (Fischer-Kowalski, 1998). These exchanges occurred, he argued, through the labour process, which he described as: "a process between man and nature, a process by which man, through his own actions, mediates, regulates and controls the metabolism between himself and nature" (Marx 1976, quoted in Foster 1999, p.380).

Building on this idea of a socio-natural metabolism, Marx developed the concept of 'metabolic rift' to describe the social and environmental implications of industrial agriculture and urbanisation.

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Large-scale capitalist agriculture, he argued, led to a shift of population from rural to urban areas, creating a 'rift' in the metabolism of society as humans ceased to interact with the earth - as Liebig observed, in urban societies human waste was no longer returned to the soil. The growth in long distance trade in food and clothing made this 'metabolic rift' even more irreparable. Marx used the idea of metabolic rift "to capture the material estrangement of human beings in capitalist society from the natural conditions of their existence" (Foster 2000, p.383). Marxian conceptions of metabolism disappeared for many years before resurfacing recently in the approaches of political geographers and political ecologists, who have used them to challenge the more functionalist understandings of urban metabolism derived from ecology.

The biological concept of metabolism was taken up with enthusiasm in the discipline of ecology in the 20th century, particularly in the systems ecology pioneered in the 1960s by Eugene Odum (Odum 1963). Scholars working in this tradition took entire ecosystems as a unit of analysis, which allowed them to study and model an entity, its environment, and the interactions between them (Slocumbe 1993, p.294). Systems ecologists envisioned ecosystems as having a balanced and efficient metabolism, an idea that more recent work in ecology, in particular non-equilibrium ecology, has moved away from (White 2004). The systems ecology conception was quickly taken up by social scientists in a number of disciplines. This conception of a city, as both a system and a natural entity, has had a particular influence on understandings of and approaches to urban metabolism in urban ecology, industrial ecology and, to a lesser extent, ecological economics.

The take-up of the systems ecology approach to metabolism was also related to the influence and popularity of systems theory in the second half of the twentieth century. Systems theory encompasses a range of approaches which have their roots in the general systems theory originally developed by the biologist von Bertalanffy in the 1930s, who aimed to derive a set of general principles applicable to all systems (Von Bertalanffy 1972). The language of systems often invokes the principles of thermodynamics, originally developed by physicists in relation to energy and later extended to encompass matter as well. The first law of thermodynamics, the conservation of matter and energy, holds that energy cannot be created or destroyed. The second law of thermodynamics, the law of entropy, holds that energy and matter in the universe move inexorably towards a less ordered (or useful) state.

Reflecting their diverse approaches to urban metabolism, different disciplines draw on various types of systems theory. The use of thermodynamics has fed in particular into studies of urban metabolism in the fields of ecological economics and industrial ecology. Ecological economics and to a lesser extent political ecology draw on world systems theory, originally developed by Immanuel Wallerstein, which holds that under capitalism, some regions and states on the global "periphery" remain in a state of dependency on those in the "core" of developed nations, leading to their continual underdevelopment. Meanwhile, urban ecologists have recently begun to take their inspiration from complex systems theory, which conceives of systems as open, non-linear, hierarchically organized entities consisting of a number of agents interacting amongst themselves and with their environment (Alberti 2008).

The idea of the city itself as system has been a central metaphor for urban management in the second half of the 20th century (Marcotullio & Boyle 2003). This is quite possibly related to the increasing popularity of the idea of urban metabolism. The first explicit application of the metabolism concept to the urban realm was Wolman's study "The Metabolism of Cities," which modelled the metabolism of a hypothetical US city of one million people (Wolman 1965). Wolman's study was published at a time when concern about the impact of humans on the environment was growing. Wolman's approach, of

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modelling material and energy flows between human societies and their environment, appealed to those influenced by the discourse put forward in books such as *Limits to Growth* and *The Population Bomb* of the existence of limits to the planet's capacity to provide resources and deal with the waste of an ever-increasing human population. A wave of empirical studies of the metabolisms of various cities ensued (Boyden *et al.* 1981; Duvigneaud & Denaeyer-De Smet 1977; Hanya & Ambe 1976). After this initial wave, the popularity of the urban metabolism concept declined, only to re-emerge in the late 1990s. The work on urban metabolism developed since this re-emergence is the focus of the remainder of this paper.

Disciplinary and interdisciplinary debates in urban metabolism

The city as an ecosystem

The idea of the city itself as an ecosystem in the biological sense is applied most literally in the field of urban ecology, which sees the city as both a 'system' and a 'natural' entity (Marcotullio & Boyle 2003). Grimm *et al.* (2000) make a crucial distinction between two approaches to urban ecology: 'ecology in cities' versus 'ecology of cities.' The former are largely scientific studies of the way in which ecological patterns and processes are different in cities than in other environments, which pay minimal attention to the social realm (Marcotullio & Boyle 2003). The latter focus on how cities process energy or matter relative to their surroundings. This perspective sees the city as an ecosystem embedded in a larger system, and often employs the concept of metabolism to describe the interactions between the numerous sub-systems of an urban region.

This understanding leads to the adoption of a systems approach to the analysis of human-environment relations which, proponents argue, enables the full complexity of urban systems to be captured and interpreted effectively (Grimm *et al.* 2000; Mehmood 2010; Newman 1999). Studying the city as an ecosystem allows flows of energy, materials and information to be analysed together, along with interactions between human and non-human elements of the system (Grimm *et al.* 2000). Newman and Jennings see such a systems approach as the best way to obtain a holistic understanding of the emergent properties and complexities of living systems, by "looking at the relationships and interactions between parts, seeking to devise solutions that are integrative rather than merely reductionist" (Newman & Jennings 2008, p.92).

Urban ecology focuses perhaps more than any other discipline employing the concept of urban metabolism on the normative implications of applying the concept to the urban realm. Scholars in this field focus not just on understanding the ecology of cities but on diagnosing problems in the functioning of urban systems and developing urban planning, policy and design interventions to address these. One set of normative recommendations comes from the argument that natural ecosystems should be seen as a model for urban development. The idea that cities should mimic natural systems, however, predates the emergence of urban ecology. Organic metaphors, including metabolism, have been applied in architecture and planning since the 19th century (Mehmood 2010). The Japanese architect Kisho Kurokawa, for instance, developed a metabolist approach to urban design which envisioned cities and buildings as going through the same process of change, renewal and destruction as all other life forms. Cities, he argued, should be designed to change over time and flexible enough to enable this constant cycle of growth, transformation and death of parts without destruction of the whole (Kurokawa 1977). More recently the American architect William McDonough has advocating building cities along the principles of "cradle to cradle design," or as closed metabolic systems which

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produce no waste (McDonough & Braungart 2009; May 2008).

In recent years the idea that urban areas should emulate ecosystems has become associated with normative theories of sustainable urban planning and development (Girardet 2008; Newman & Jennings 2008). Natural systems are seen as inherently cyclical and efficient in their use of materials and energy, while urban systems tend to be more linear, consuming resources and producing waste (Dunn & Steinemann 1998). Girardet (2008) argues that the long term viability and sustainability of cities is reliant on them shifting from a linear to a circular metabolism in which outputs are recycled back into the system to become inputs. This principle of circular metabolism was the basis for the design of the Hammarby Sjöstadurban district in Stockholm, Sweden. The Hammarby model, which is routinely cited as an exemplar in sustainable urban development, proposes closing material loops through the development of integrated urban systems (City of Stockholm 2007).

This focus on circularity, balance and order is challenged by urban ecologists studying urban metabolisms from an approach grounded in complex systems theory. Their objective remains the same - to use ecologically informed urban planning interventions to increase the sustainability of urban metabolism. From a complex systems perspective, however, urban ecosystems consist of multiple interlinked subsystems in continual interaction with each other and the outside world (Alberti 1999; Alberti 2008). Rather than externalising human activity from models of ecosystems, the idea is to incorporate humans and recognise their impact on ecological processes (Alberti 1999; Grimm *et al.* 2000).

Alberti and her colleagues at the University of Washington's Urban Ecology programme, for instance, have done extensive work on developing a model that links the biophysical impacts of human-induced environmental stresses to various types of land use, human activities and management practices. The aim of the model is to allow planners to simulate the ecological impacts of urban development patterns (Alberti 1999; Alberti 2008). Grimm, Pickett and others working on the Long-Term Ecological Research Program in the United States conceive of the city as a dynamic, complex and adaptive system linking social and ecological systems (Grimm *et al.* 2000; Evans 2011).

The complex systems ecology perspective on urban metabolism challenges the idea that ecological design for urban areas should aim for stability and predictability (Alberti 2009). Rather than optimising a single set of supposedly ideal circumstances, the goal should be greater resilience to the inevitable internal and external shocks that will impact on an urban area. Such an approach does, however, carry risks - it may de-politicise urban transition, as we become reliant on scientific knowledge developed through urban ecology studies and models (Evans 2011). The use of detailed studies and models is a hallmark also of the industrial ecology approach to urban metabolism, the focus on the next section.

The city as material and energy flows

The bio-physical approach of studying and quantifying urban material and energy flows is the predominant interpretation of urban metabolism today (Gandy 2004). This approach has strong connections to the field of industrial ecology, the study of the material and energy flows and transformations of industrial systems. Industrial ecologists look for ways to optimise the "metabolism" of industrial systems through industrial symbiosis, whereby the waste output from one industry can become an input for another, providing both cost savings and environmental benefits (Dunn & Steinemann 1998). Despite the similarities between this approach and the first wave of urban

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material flow analyses (MFAs) in the 1970s, for many years industrial ecology was not applied to cities. In recent years this has begun to change, with a proliferation of industrial ecology-inspired studies of urban metabolisms (Bai 2007; Hammer & Giljum 2006; Kennedy *et al.* 2007; Schulz 2007).

Industrial ecologists share with urban ecologists a view of the city as a system, whose 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, p.44). Studies of urban metabolism done in the industrial ecology tradition generally take a largely quantitative approach, focusing on quantifying the flow of a particular material or materials, energy, or the presence of a particular substance (Barles 2010). The rationale behind this approach is that through the systematic recording of all physical flows to and from an urban area, it is possible to describe the relationship between the environment and an urban system (Minx *et al.* 2011). The challenges of such an approach are amply covered in the literature on material flow analysis, which is rife with discussion of the methodological difficulties of these sorts of studies, including the unavailability of data and the challenges of defining a boundary for an urban area (Fischer-Kowalski & Hüttler 1998; Kennedy *et al.* 2007; Minx *et al.* 2011).

Another approach to quantifying urban metabolic flows is ecological foot printing, which calculates the amount of land needed to provide the resources needed by and absorb the waste of a particular territory (Rees & Wackernagel 1995). Ecological foot printing studies can be effective in communicating the scale of the imbalance between a city's metabolism and the planet's capacity to sustain this - for instance London's ecological footprint is said to be 200 times the size of the city itself (Environment Agency 2010). A similar approach is the energetic metabolism model developed by Haberl and his colleagues at the Institute for Social Ecology at Klagenfurt University in Vienna, which attempts to comprehensively model energy flows in human societies (Haberl 2006).

Studies of urban material and energy flow are often used to identify ways to improve the environmental and economic performance of an urban area. These types of studies highlight the linear nature of urban metabolisms as a particular source of vulnerability, as this makes cities dependent on their hinterlands for resource supply and waste disposal (Brunner 2008; Dunn & Steinemann 1998). The solution, then, is to identify ways to make a city's metabolism more sustainable. But what constitutes a sustainable urban metabolism? Reflecting the use of natural systems as a model, perhaps the most frequently cited characteristic of a sustainable metabolism in industrial ecology is that it be self-sufficient, that is, not dependent upon a wider hinterland for resources or waste disposal (Baccini 1997; Brunner 2008; Niza *et al.* 2009).

Most studies of urban material and energy flows encourage the use of urban metabolism as a foundation for urban policy, and will typically conclude with a list of policy recommendations (Baccini 1997; Barles 2009; Codoban & Kennedy 2008; Kennedy *et al.* 2007; Niza *et al.* 2009). Many scholars also claim that urban metabolism studies can be tools both for identifying environmental problems and designing more efficient urban planning policies (Baccini 1997; Barles 2009; Niza *et al.* 2009). Codoban & Kennedy (2008), in their study of metabolism at the neighbourhood scale in Toronto, attempt to link the design characteristics of different types of neighbourhoods with metabolic flows. When material flow analyses are linked to policy recommendations, they usually advocate market-led solutions, such as removing subsidies, taxing resource consumption rather than labour, rather than tradition command and control environmental regulation (Fisher-Kowalski & Hüttler 1999). This can be related to the nature of the cities being studied, most of which are advanced service oriented societies in which consumers, rather than producers, are the primary source of emissions (Brunner

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2008). With millions of small emissions sources to manage, end of pipe solutions no longer work.

Others argue that such studies, while they aim to be politically relevant and lead to social change, do not result in an analysis deep enough to form the basis for effective urban policy and planning interventions (Fischer-Kowalski & Hüttler 1998). From this perspective, “urban metabolism and ecological footprint analyses have provided excellent critiques of the impact of cities on the environment, but have been weaker on providing solutions that city managers can use in their daily work” (Marcotullio & Boyle 2003, p.15). Knowledge of metabolic inflows and outflows is of little use unless we know how particular things, such as urban form, lifestyle, infrastructure lead to metabolic differences (Minx *et al.* 2011). One possible solution to this is to extend the metabolism model to look at links between urban and environmental quality, as well urban drivers, patterns and lifestyles and metabolic flows (Minx *et al.* 2011; Newman 1999).

One argument for metabolic profiles’ lack of broader relevance to the built environment is that this body of scholarship makes no reference to space, and contains no methods for doing long-term analyses (Moffatt & Kohler 2008). According to Moffatt & Kohler (2008), we need a better understanding of how spatial characteristics influence the relationship between the built environment and ecosystems. Moffatt proposes a way to do this in a report he co-authored with a team from the World Bank for the Bank’s Eco2Cities project (Suzuki *et al.* 2010). The report outlines the parameters of a “one systems approach” to planning, designing and managing urban areas, grounded in a view of the city and the urban environment as a complete system. Tactics of this approach include coordinating the planning of spatial development and infrastructure to better integrate urban form and flows. Such interventions, the report authors argue, will increase efficiency, synergy and return on investment.

Other scholars are working to better integrate social aspects of and influences on material and energy flows. In France, the field of territorial ecology attempts to integrate into an industrial ecology approach “the stakeholders and, more generally, the agents involved in material flows, questions their management methods and considers the economic and social consequences of these flows” (Barles, 2010: 443). Territorial ecologists argue that doing material flow analysis requires understanding the socio-ecological conditions that influence material flows (Barles, 2009). A similar movement exists at the Institute of Social Ecology in Vienna. Fisher-Kowalski & Hüttler (1999) prefer the term ‘society’s metabolism’ to industrial metabolism, as a way of emphasising that their approach applies to all types of societies, not just industrial societies. A society’s metabolism is the totality of the energetic and material flows required to sustain the material components of social systems (Fischer-Kowalski 1997). Drawing on environmental sociology as much as industrial ecology, for social ecologists the aim of establishing the metabolism of a society is to understand the relationship between societies and their environments. This relationship, in particular its economic and ecological aspects, is the focus of the next section.

Breaking the links between urbanisation, economic growth and resource consumption

Industrial ecologists and scholars in the related field of ecological economics use urban metabolism to describe the interrelations between the economy and the environment (Daly 1996). Of particular concern in both disciplines is the relationship between urbanisation and economic growth and the environment, in particular the depletion of natural resources and environmental damage. There is a general presumption that urbanisation and economic growth have an overall negative impact. Niza *et al.* (2009), for instance, describe urban metabolism as the process by which resources are extracted

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from the natural environment, converted into inputs into the economic system and transformed into products and material and energy flows which cause environmental damage.

One approach to explaining the underlying drivers of this link between economic growth and environmental degradation is to revive Marx’s idea of metabolic rift. For Foster (1999), the concept captures the way in which, under capitalism, humans have become estranged from the natural conditions of their existence. The metabolic rift between humans and soil created by capitalist agriculture makes human society under capitalism fundamentally unsustainable. Moore (2000), synthesising Marxist and world-systems theory, expands on Marx’s original theory. He argues that throughout history, world ecology has been repeatedly reorganised in order to deal with the rising costs of ecological exploitation that result from capitalist expansion. At each phase of world capitalist development, Moore argues, a metabolic rift has occurred. Following each rift, world ecology is reorganised, technically but also geographically, physically expanding the world economy. These reorganisations exist in a dialectical relationship with global capitalist development. Over time, the metabolic rift between town and country, and between countries, has widened and deepened.

There are a number of different theories about how best to optimize economy - environment relations. As discussed above, in most industrial ecology-inspired approaches to urban metabolism, being self-sufficient in terms of resource generation and waste disposal is considered the hallmark of a sustainable urban metabolism. Thus industrial ecologists focus on finding methods to improve metabolic efficiency or reduce the amount of resources used per unit of economic output, a process usually referred to as dematerialisation or decoupling. Achieving this requires reducing the environmental pressure embodied in a good or service and a change in production and consumption patterns leading to a reduced overall metabolism (Opschoor 1997). This approach has been applied to urban areas in material balance studies. These studies can be used to define targets both for dematerialisation and for improvements to the ecological performance of cities, something which has already been done for the cities of Stockholm and Geneva (Barles 2010).

Advocates of dematerialization make the case that technological changes and improved business practices make it possible to produce manufactured goods with less raw material, mineral and energy inputs than in the past (Buttel 1997). Dunn and Steinemann (1998), for instance, emphasise that industrial ecology demonstrates that environmentally conscious practices can be profitable, and that industrial ecology provides economic incentives to reduce environmental destruction. This focus on technological innovation highlights industrial ecology’s links to the theory of ecological modernization, which holds that economic growth and environmental protection are not mutually exclusive (Fisher & Freudenburg 2001).

Many scholars in ecological economics are similarly interested in the relationship between economic growth and resource consumption, though they do not address this issue explicitly in reference to urban areas. While many ecological economists, like industrial ecologists, use the language of systems and metabolisms, their use of these terms is usually related not to a view of an urban area as an ecosystem, but of the economy as subject to the laws of thermodynamics. The prominent ecological economist Herman Daly, for instance, describes the economy as a linear metabolic process, an “ordered system for transforming low-entropy raw materials and energy into high-entropy waste and unavailable energy” (Daly & Farley 2004, p.70). Because he sees the ecosystem and natural capital and services as finite, and the metabolism of the economy as linear, for Daly a sustainable metabolism requires a sustainable throughput. This, he argues, can only be achieved by properly valuing, and putting a price on nature’s services (Daly 2007).

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While advocates of dematerialisation argue that economic growth can continue without increased environmental degradation, others see economic growth itself as the cause of this degradation (Czech & Daly 2004; Jackson 2009). Some ecological economists believe that capital accumulation is characterised by a 'grow or die' (GOD) or 'treadmill of production' (TOP) dynamic (White 2006). Grounded in the idea that natural limits to growth exist, these theories hold that unending capital accumulation is the cause of environmental degradation.

If economic growth is the problem, then a sustainable economy would not rely on ever increasing economic growth (Jackson 2009). One solution that Daly has proposed is the idea of the steady-state economy. This involves stabilizing the economy at a fairly consistent level of throughput. Such an economy will be sustainable as it will not erode environmental carrying capacity, and technological progress will increase the ratio of GDP per unit of throughput (Czech & Daly 2004; Daly 1992). Achieving this, Jackson (2009) argues, will require a new macroeconomic model for achieving economic stability without growth in consumption.

A similar approach to addressing the link between economic growth and resource consumption is the theory of de-growth. Sustainable de-growth has been defined as "an equitable downscaling of production and consumption that increases human wellbeing and enhances ecological conditions at the local and global level, in the short and long term" (Schneider *et al.* 2010, p.512). De-growth goes beyond just efficiency improvements to limiting the scale of production and consumption. How much to downsize in order to achieve sustainability, and what might be the optimal scale for the economy are subjects of debate among de-growth advocates (Martínez Alier, Pascual, *et al.* 2010). The idea of de-growth has also been taken in disparate directions by ecological economists and social activists (Martínez Alier, Pascual, *et al.* 2010). From the social activist perspective, de-growth is not a theory but a political slogan, a movement for the reorganisation of society around conceptions of well-being that go beyond GDP (Latouche 2010). The steady-state economy and de-growth may be complementary if de-growth is pursued to a point where a steady state economy is then feasible (Kerschner 2010).

One challenge to the arguments about the relationship between the economy and the environment made by many ecological economists is whether they adequately grasp the many complexities and subtleties of socio-environmental relationships (White, 2006). The social implications of theories of how to change these relationships are also beginning to be explored, including the social and political challenges of maintaining employment levels and social stability while achieving the de-growth transition (Spangenberg 2010), the way in which reducing the economic metabolism will lead to a sense of loss among those who have to reduce their consumption (Matthey 2010), and the implications of links between consumption patterns and personal identity for de-growth (Hamilton 2010). More critical readings of theories of environmental crisis and the role of social factors in urban metabolisms are also increasingly the focus of scholars working in political geography and political ecology. The following sections turn to these critiques.

Resignifying the city: urban metabolism and social, technical and ecological relationships

In recent years, the way in which the metabolism concept is employed by urban and industrial ecologists has been challenged by a growing cohort of scholars working across political geography and political ecology. This emerging body of literature builds on critiques of dualistic conceptions of the relationship between society and nature (Harvey 1996; Smith 1984; Latour 2005; Castree 1995). Urban and industrial ecology, it is argued, uncritically present urban metabolism as a process of

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biophysical exchange, unrelated to social and historical context (Gandy 2004; Swyngedouw 2006; Monstadt 2009). Such a perspective "fails to theorise the process of urbanization as a social process of transforming and reconfiguring nature" (Swyngedouw 2006, p.35). This critique also notes that traditional (material and energy flow) metabolism studies pay little attention to political changes, see nature as static, and make no fundamental critique of the underlying capitalist economy (Keil 2005). They de-politicise the urban sphere, naturalising urban processes "so that urbanisation is no longer conceived as the outcome of historical change but rather as a cyclical dynamic alterable through technological modifications rather than by political contestation" (Gandy 2006, p.64). Even in the work of those who try to integrate the impact of social factors in their models, metabolism is still used to denote something purely material (Keil 2005). From this perspective, attempts to simply "extend" material and energy flow metabolism models to include social and economic issues do not go far enough.

New conceptions of urban metabolism are emerging from these more critical approaches which see it as consisting of more than just material cycles. Building on Marx's conception of metabolism as a metaphor to analyse human-nature relationships, these scholars are conceptualizing urban metabolism as consisting of as a number of dynamic, interconnected, and mutually transformative physical and social processes (Heynen *et al.* 2006; Bakker 2003a). Metabolism is also seen as highly political, as while it may be a process of exchanging material or energy, humans can control their input into this exchange (Zimmer 2010). In this way, metabolisms express peoples' drives, desires and imaginations (Swyngedouw 2006). By acknowledging the way in which social and environmental factors interrelate to shape urban metabolisms, as well as the political nature of these metabolisms, this more critical approach challenges the portrayal of the modern city as a static and self-regulating system (Gandy 2004; Gandy 2006). This conception of urban metabolism focuses not on a functional analogy but on the interweaving of social and biophysical processes that transform nature into commodities, and which produce new forms of nature (Gandy 2004).

The focus of these new ideas of metabolism on socio-ecological interactions, as well as their critical political stance has created scope for a number of substantial resignifications of the relations between social, technical, economic and ecological forces in urban areas. While cities have often been placed in opposition to nature (Heynen *et al.* 2006; Véron 2006), the idea of urban metabolism as consisting of multiple interconnected social and ecological processes helps move away from this society-nature dualism. This leads to a re-conceptualisation of the relationship between the urban and nature, which is succinctly expressed in Harvey's observation that there is nothing inherently unnatural about New York City (Harvey 1996). Human activity cannot be viewed as external to ecosystem function as society and nature are fundamentally interdependent, something which is most evident in urban areas, where the metabolic transformation of nature is most concentrated (Heynen *et al.* 2006). From this perspective urbanisation does not distance humans from nature, but is "a process by which new and more complex relationships of society and nature are created" (Keil 2003, p.729). Understanding urbanisation as a metabolic process conveys a sense of the interconnectedness, dynamism and transformative nature of the processes that create particular urban environments (Heynen *et al.* 2006; Swyngedouw 2006).

Closely related to a metabolic view of the urban is the idea that the city is made up of entities that cut across the categories of society and nature. This builds on Latour's (1993) idea of hybrids and Haraway's (1991) of cyborgs. If the city is a process of metabolically transformed nature, it becomes a socio-natural hybrid itself (Kaika & Swyngedouw 2000). From this perspective it is easy to see cities as collections of hybrids, such as "alleys of trees, planned by city councils and planted with the help of

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scientific knowledge in botany; urban drinking water and waste water that are treated and distributed through pipelines only to be treated again with the help of specific bacteria after us" (Zimmer 2010, p.345). The cyborg is a particular type of hybrid, one of machine and organism. In an urban context, the idea of the cyborg emphasises the interface between the body and the city, in particular the physical infrastructure which "links the human body to vast technological networks" (Gandy 2005, p.28). However Swyngedouw (2006) has proposed that the concepts of both hybrids and cyborgs may lead to reproducing the binary representation of the world that comes from a society-nature dualism, as they suggest the mixing of two ontologically distinguishable things. Nature and cities are already heterogeneous, he argues, constituted through metabolic circulations.

Leaving aside whether we should accept the concepts of hybrids and cyborgs into our ontology of the urban, their introduction has contributed to a resignification of urban infrastructure and technological networks, drawing particular attention to their role in the metabolism of urban areas. Modern urbanisation is dependent on the technological networks of urban infrastructure which have allowed cities to extend their "ecological hinterland," both for the purposes of resource extraction and waste disposal (Monstadt 2009). Through their role in structuring material metabolisms, these networks "constitute one of the most important interfaces between nature and society" (Monstadt 2009, p. 1926). The importance of this interface means that we should pay attention to the power mechanisms that occur through these flows. However this has been made more difficult, Kaika and Swyngedouw (2000) argue, by the way in which technological networks have been moved out of sight in many modern cities, blurring the relationship between nature and the city.

Seeing urban metabolism as a set of social and environmental interactions has also opened the possibility of resignifying resource flows, in particular the flow of water, as socially produced, shaped by and shaping the social relations of urbanisation (Bakker 2003a; Bakker 2003b; Kooy & Bakker 2008; Masjuan *et al.* 2008). Swyngedouw has proposed that water, through a hydro-social metabolism, can be transformed into matter that is no longer simply physical but that, in its flow through the urban fabric, also acquires a social dimension (Swyngedouw 2004). This resignification has created scope for analysis of the social dimensions of urban metabolic flows, as will be discussed below.

Urban flows and the production and reproduction of inequality

The idea that resource flows interact reflexively with the social world has created scope for analysis of the social and distributional impacts of infrastructure networks and resource flows. One result has been a growing body of work in political geography and political ecology looking at the role of infrastructure networks in creating and reproducing inequality in urban areas (Graham & S. Marvin 2001; Coutard 2008; Kooy & Bakker 2008). While such studies do not always explicitly employ the concept of urban metabolism, they are engaged with the question about to what extent urban areas are shaped by socio-environmental flows and the networks through which they move.

Water distribution networks have proved a particularly fertile area for research on urban flows and inequality. Bakker's work on the privatisation of water networks has demonstrated the extent of spatial differentiation in urban areas in terms of access to water supply (Bakker 2003b; Bakker 2007; Kooy & Bakker 2008). This spatial differentiation of access is particularly evident in the global South. In many Southern cities, urban elites benefit from a relatively plentiful and affordable water supply coming from networked infrastructure, while the urban poor typically have limited access to water supply networks, relying instead on water vendors who charge much higher prices (Bakker 2003a).

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For instance, Kooy and Bakker (2008) demonstrate that in Jakarta, fragmented urban infrastructure networks have substantial distributional impacts, creating and perpetuating inequalities along racial and class lines. Such studies support the assertion made by Allen and Bell (2011) that urban water poverty, rather than being the result of resource scarcity or poor management is socially produced and reproduced through a range of exclusive and discriminatory processes.

Thus in one city it is possible to have a number of parallel metabolisms for the same resource. This variation is enhanced by neoliberal reforms to water management, which have created a range of "alternative community water economies" which "resuscitate or develop new approaches to governing the relationship between the hydrological cycle, and socio-natural economies and politics" (Bakker 2007 pp.448). Tarr's study of the evolution of water and wastewater networks in Pittsburgh supports this argument. Just as in cities of the South, the evolution of these networks in Pittsburgh reflected class distinctions, with access to water services unevenly distributed (Tarr 2002). Masjuan *et al.*'s study of Barcelona produced similar findings: in the late nineteenth and early twentieth centuries, conflicts over water mirrored class conflicts (Masjuan *et al.* 2008).

The urban dimension of conflicts around the distributional impacts of urban flows is addressed in a different way by the environmental justice movement in the United States, which arose from a recognition that poor people tend to live in the most environmentally polluted areas (Dobson 2003; Guha & Martínez Alier 1997). While political ecologists look for the drivers of environmental inequalities in the way in which the global economic system organises socio-environmental metabolisms, the environmental justice movement, in the United States at least, focuses explicitly on the distribution of environmental benefits and damages (Agyeman 2005; Dobson 2003; Swyngedouw & Heynen 2003). From a metabolic perspective, the environmental justice movement can be seen as a reaction to the fact that the most environmentally damaging elements of the urban metabolism, such as waste incineration, are often located in poor, minority-dominated communities. Environmental justice has been critiqued as reformist, rather than radical, and as having limited generalisability as a result of dealing with particular locations (Swyngedouw & Heynen 2003). This view is challenged by Sze *et al.* (2010) who, in their study of California's management of the Sacramento-San Joaquin Delta demonstrate that the coalition of actors around this specific conflict have promoted the adoption of principles of environmental justice at a wider level.

The social and distributional issues of urban flows are also addressed by ecological economists, particularly those drawing on world systems theory. One way in which this argument has been developed is that the mechanisms generating unequal distribution can only be understood through looking at the underlying ecological conditions of human economies (Hornborg 1998, p.128). A useful concept for explaining the connection between urban flows and inequality is Ilya Prigogine's idea of dissipative structures. These are systems which, because they are not in thermodynamic equilibrium, maintain themselves by drawing in order from their environments, and discharging the disorder, or entropy. Cities, which can only maintain their structure through exchange with their environments, can be seen as such structures (Hornborg 1998). Building on this concept it is possible to link capital accumulation to the continuous demand for energy from large cities. This demand is related to the processes of market exchange and capital accumulation, as "the more energy that has been dissipated by industry today, the more new resources it will be able to purchase tomorrow" (Hornborg 1998, p.133). As both centres of capital accumulation and dissipative structures, urban areas will have an ever-increasing demand for resources from the periphery, creating structural inequality between the core and the periphery in the world system.

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While for Hornborg urban metabolisms are of interest because of the way they impact broader global systems, Martinez Alier *et al.* (2010) build on world systems theory in a slightly different way. They propose that the increase in the metabolism of cities, that is, their growing demand for resources and production of waste, is linked to the increasing number of ecological conflicts in the 'commodity frontiers,' usually located far from cities. Environmental problems and conflicts in poor countries, then, are not due to poor governance or market failure, but to a world system in which the metabolism of urban areas relies on areas beyond its boundaries for a constant supply of resources and for waste disposal. While not explicitly addressing "urban metabolisms", this argument demonstrates how conflicts around the social and environmental costs of the extraction of resources needed to maintain urban metabolic processes produce and reproduce inequality.

One attempt to bridge the broader structural arguments of ecological economics with political ecology's concern for the local implications of such underlying structural inequalities is the concept of social metabolism. Martinez Alier suggests that analysis should focus on a society's "social metabolism", or "the manner in which human societies organize their growing exchanges of energy and materials with the environment" (Martínez Alier 2009, p.153). Material flows and social metabolism, he argues, will vary between societies, and even between different classes within countries. Further, any changes in social and economic metabolisms have distributional impacts, and generally benefit some groups at the expense of others (Martínez Alier 2009). Most empirical studies of this phenomenon, however, are of rural conflicts at the point of extraction or disposal (Martínez Alier, Kallis, *et al.* 2010). One exception is a study by D'Alisa *et al.* (2010), who examine how a complex conflict around waste disposal in the metropolitan area of Campania was simplified by those in power. By creating policies based on a simplistic view of a complex metabolic issue with substantial distributional implications, politicians and public authorities increased social unrest and eroded democracy. This highlights the role of governance in shaping urban metabolisms, the focus of the next section.

Governing urban flows

Closely related to debates on the impact of urban flows on inequality is the question of their governance, in particular the way in which they are impacted by broader social power relationships. The everyday practices by which urban flows are governed, and the role of power relations in this are an area of particular interest for scholars in the sub-discipline of urban political ecology. These scholars focus on the way in which the material conditions of urban environments are controlled by and serve the interests of elites, often at the expense of marginalised populations (Swyngedouw & Heynen 2003; Heynen *et al.* 2006). The powers of ecological processes, they argue, are socially mobilised to serve particular purposes, usually associated with strategies of achieving or maintaining positions related to social power (Swyngedouw & Heynen 2003; Heynen *et al.* 2006). Urban political ecologists explore these dynamics through the use of detailed case studies, a selection of which are reviewed below.

A number of studies in urban political ecology draw connections between the domination of nature and the domination of humankind. These processes of domination can come together in urban areas (Keil & Boudreau 2006). The way in which water has been governed in Jakarta, for instance, has been driven by governmental efforts to differentiate people by race and class, creating and perpetuating inequalities (Kooy and Bakker 2008). The objectives of urban elites in particular can shape metabolisms, as Masjuan *et al.* (2008) demonstrate in their study of water networks in Barcelona. A hundred years ago water supply to the industrial sector was prioritised, often to the

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detriment of the urban classes. Reflecting a shift in the interests of elites, today one of the main objectives for the city's water network is to fulfil the growing demands of the suburban settlements. Tarr (2002), tracing the metabolisms of three resources (water, air and land) in Pittsburgh over 200 years similarly demonstrates the influence of economic, political and civic interests on the evolution of the city's metabolism.

These studies reflect an important point about metabolisms - because they exist within existing social relations, not everyone can satisfy their needs equally (Zimmer 2010). Therefore certain social classes reap the benefits of the urban metabolism more than others, as "not all actors can mobilise metabolisms in the same way" (Zimmer 2010, p.350). The varied influence of different social classes over metabolic processes in urban areas is reinforced by Bakker, Tarr and Masjuan *et al.*'s work on urban water networks, as well as by Véron's analysis of motivations for, and implications of, air-pollution policies in Delhi since the mid-1990s (Véron 2006). Such policies, he argues, are a response to the values and tastes of an increasingly influential middle class. Given that water supply and sanitation are higher priorities for urban poor than air quality, Véron proposes that the attention paid to air pollution reflects the middle-class bias of environmental groups.

Such detailed case studies also draw attention to the impact of politics on socio-environmental metabolisms and distributional issues. The physical redistribution of material flows is often accompanied by a change in the mode of social regulation accompanying flows (Keil & Boudreau 2006, Tarr 2002). Pittsburgh's sewers, for example, were built by local elected representatives to meet the demands of their more well to do constituents. Use of the new wastewater systems, and payment of the associated access fee, was then enforced by law on all citizens (Tarr 2002). Heynen (2006) uses school breakfast programmes in Milwaukee to demonstrate the connection between politics, malnutrition and social problems in deprived areas of the city. Low levels of participation in school breakfast programmes, he argues, can be linked to childhood malnutrition and lifelong health impacts. This problem is worsened by the actions of politicians unaware of the socio-ecological ramifications of reducing such programmes (Heynen 2006, p.139). Myers's (2008) study of the influence of the Finnish government sponsored Sustainable Management of Lands and Environment (SMOLE) programme on land reform in the peri-urban area of Zanzibar demonstrates the role that international aid can have in shaping urban metabolisms in the global South. Despite promises that pro-poor reform and democratic accountability would come with SMOLE, Meyers's research found that this was not the case. Pro-poor development, he concludes, will not happen without a change in the power relations and socio-cultural interests that sustain inequality.

The influence of both neoliberal reforms and international finance institutions on urban metabolism can also be seen through the privatisation of water resources (Bakker 2003a; Bakker 2003b; Bakker 2007; Allen *et al.* 2008). While private management of the water sector used to be rare, today water systems in cities in over a hundred cities in developing countries are managed by a few large companies (Bakker 2003b). The facilitation role played by international finance organisations and national governments is crucial to the functioning of the world water market. These processes of regulation and marketization can be conceived in metabolic terms, with resource regulation "the social negotiation of the metabolism of a dynamic resource landscape, and marketisation" the reregulation of the social metabolism of nature undertaken by the state" (Bakker 2003a, pp.49; 52).

While elites and powerful institutions may dominate the governance of urban flows, the plans and visions of those who develop and manage urban networks and the flows through them may be challenged or subverted by the daily practices of individuals and groups (Bulkeley *et al.* 2011). For

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this reason, to understand the way in which urban resource flows and the networks that facilitate them are actually governed requires examining daily practice and local political economies (Bulkeley *et al.* 2010, Monstadt 2007). For the urban poor in the global South, service provision often occurs through a hybrid of more formal public, public-private and private arrangements (Allen *et al.* 2008).

Conclusion

The preceding discussion has demonstrated that the concept of urban metabolism can be a productive and useful way of conceptualising the way in which urban areas function. Though it is interpreted and applied differently across disciplines, each interpretation has something to offer. MFAs and urban ecology analyses provide a valuable knowledge base which can feed into the development of social and environmental policy for urban areas. The idea that urban areas are ecological systems with their own metabolisms is contributing to our understanding of the impact of human activity, including particular types of urban planning interventions, on the natural environment. Explorations of the metabolisms of urban economies call attention to the environmental and social resources needed to maintain economic growth. Finally, more critical perspectives on urban metabolism provide a practical way of conceptualising the way in which the urban is produced through the relations between social and natural processes.

While each interpretation of urban metabolism contributes in its own way to understanding the relations between society and nature in urban areas, there are substantial differences in the extent to which these different perspectives travel from theory into practice. Urban metabolism as it is understood in industrial and urban ecology appears to have permeated urban planning and engineering practice most successfully. This may be because of the relative ease with which core disciplinary ideas, such as resource efficiency and closing material cycles, can be translated into design interventions, and the fact that they can be applied on an incremental scale through individual projects. Projects like Hammarby Sjöstad, for instance, attempt to actually apply the idea that urban areas should mimic the perceived efficiency of natural ecosystems. The practical implications of looking at urban metabolism from an ecological economics perspective, on the other hand, are more likely to require a broader social transition and hence significant social and political action - in this sense La Touche's characterisation of de-growth as a social movement seems quite apt. Critical understandings of urban metabolism also have yet to be translated into practice. This may also be because they call attention to broader structural issues such as governance and the role of institutions in perpetrating inequalities, issues which require wider social action and reform.

The literature reviewed in this paper has demonstrated that urban metabolism has significant cross-disciplinary appeal. Yet while there is some cross-disciplinary engagement, in particular between the disciplines of ecological economics and political ecology, this is largely the work of a few enterprising scholars rather than a larger movement. For the most part, scholars appear content to remain within their own disciplinary silos. Perhaps the most glaring instance of this is the lack of acknowledgement in industrial and urban ecology of the new conceptualisations of urban metabolism emerging out of geography and political ecology. Despite the proliferation of literature in this area, urban and industrial ecologists continue to use a conceptualisation of urban metabolism from which politics and power relations remain notably absent. This may ultimately limit the viability of their normative recommendations, as the implementation of dematerialisation at an urban level may

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depend as much on political support as on the particulars of material cycles.

Increased interdisciplinary engagement in urban metabolism studies would offer a number of advantages, including beneficial adaptations of disciplinary approaches. Critical perspectives could benefit from some of the ease with which industrial and urban ecology processes are absorbed into practice, while a flow of knowledge in the opposite direction could lead to an approach that better takes social and political factors into account. Working across disciplines also offers the possibility of new insights, increasing the significance of a rich and rapidly evolving field of research on the metabolisms of urban areas.

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