frontiers in Sustainable Cities

PERSPECTIVE
published: 03 February 2022
doi: 10.3389/frsc.2021.807735

Insights in Urban Resource Management: A Comprehensive Understanding of Unexplored Patterns

Amalia Zucaro[1]*, *Gabriella Maselli*[2]* and *Sergio Ulgiati*[3,4]*

[1] Division Resource Efficency, Department for Sustainability, Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Research Centre of Portici (NA), Naples, Italy, [2] Department of Civil Engineering, University of Salerno, Fisciano, Italy, [3] Department of Science and Technology, Parthenope University of Napoli, Naples, Italy, [4] School of Environment, Beijing Normal University, Beijing, China

Edited by:
Feni Agostinho,
Paulista University, Brazil

Reviewed by:
Walter Alberto Pengue,
National University of General Sarmiento, Argentina
William W. Braham,
University of Pennsylvania, United States

***Correspondence:**
Amalia Zucaro
amalia.zucaro@enea.it
Gabriella Maselli
gmaselli@unisa.it
Sergio Ulgiati
sergio.ulgiati@uniparthenope.it

Specialty section:
This article was submitted to Urban Resource Management, a section of the journal Frontiers in Sustainable Cities

Received: 02 November 2021
Accepted: 27 December 2021
Published: 03 February 2022

Citation:
Zucaro A, Maselli G and Ulgiati S (2022) Insights in Urban Resource Management: A Comprehensive Understanding of Unexplored Patterns.
Front. Sustain. Cities 3:807735.
doi: 10.3389/frsc.2021.807735

In the last few decades, the rapid urbanisation process has led to an exponential growth of resource use, making increasingly difficult to ensure the principles of sustainability within urban systems. Similar to living organisms, cities have always required resources and energy to survive. However, technological development and population growth have consequently led to increasing urban inflows and outflows, in so deeply altering the relations of cities with the environment as a source and a sink. Examples include the extraction of minerals for built environment and industrial processes providing manufactured goods; the conversion of fossil energy into electricity for buildings and fuel for vehicles; the use of natural resources (e.g., land or water) to support urban expansion activities. In a planet with limited resources, the challenge should not be to find new resources but to improve the way we use them and the lifestyles that they support, or in other words, to plan strategies to generate more value and higher quality of life with fewer inputs. It is well-known that cities depend on imports of external resources; however, they also benefit from internal resources and ecosystem services. Based on this framework, an urgent effort is needed to explore crucial urban issues that have not yet been adequately investigated. A strategic resource management is needed to actually move towards sustainable cities. In particular, a special focus should be placed on: (i) to monitor and properly manage the city's resources and energy systems within the metaphor of "urban metabolism;" (ii) to define innovative approaches, actions and strategies that ensure the sustainable management of non-renewable urban resources; (iii) to protect and restore urban ecosystem services as valuable renewable resources, and finally (iv) to envisage participatory governance processes for the appropriate allocation of resources to the common well-being.

Keywords: urban resource management, urban metabolism, sustainable resource use, circular economy, well-being

INTRODUCTION

Cities and more generally urban areas are growing very rapidly. The urban population currently accounts for more than 55% of the world's population, and this figure is expected to rise to 68% by 2050 (United Nations, Department of Economic and Social Affairs, Population Division, 2019a). In addition, it is predicted that by 2030 there will be 43 megacities worldwide, i.e., urban complexes with at least ten million inhabitants (United Nations, Department of Economic and Social Affairs, Population Division, 2019b). According to Marvuglia et al. (2020), while urban areas cover only 0.4–0.9% of global land area, they are host to more than half of the global population and are responsible for around three quarters of global final energy use as well as related carbon dioxide emissions. Like living organisms, cities require huge amounts of natural resources, raw materials, food, energy, and goods to sustain the activities of their inhabitants (European Environmental Agency, 2015). The United Nations Environment Programme (UNEP) reported that further urbanisation could increase the annual consumption of raw materials (fuels, minerals, biotic resources) to almost 90 billion tonnes by 2050, a 125% increase from 40 billion tonnes in 2010 (International Resource Panel, IRP, 2018).

According to the European Environment Agency (2006), several factors can be identified as driving urban growth: macroeconomic factors, such as economic growth, integration, and globalisation; microeconomic factors, like rising living standards, but also high land prices in city centres compared to agricultural land; social and demographic factors, including the increase in household formation and the change in housing preferences. However, it should be considered that in some countries rapid urbanisation is closely related to the implementation of village relocation and urbanisation schemes, which imposed continuous and large-scale rural expropriation and land transfer (Lu et al., 2018) and exercised unified rural planning (Huang et al., 2018).

As a result of these multiple actions, the processes of densification and urbanisation are accelerating resources depletion and the degradation of urban ecosystems (Galli et al., 2020). Just to mention a few prominent examples, (i) a large number of cities in China are reported to be suffering from severe water shortage problem (Guan et al., 2018); (ii) Jakarta (Indonesia) is experiencing a resource crisis due to human-induced problems such as intense population density, traffic congestion, water pollution, as well as serious challenges induced by climate change (Shen et al., 2020); (iii) developing countries such as Bangladesh are undergoing dramatic changes in land cover/land use due to population densification (Kafy et al., 2021).

Another emblematic case is represented by Latin American cities. As urban centres such as Mexico City and São Paulo have expanded, they have "swallowed up" smaller neighbouring cities, but the latter have remained outside the jurisdiction of the larger city. The phenomenon of geophagia, by which we identify the consumption of land for urban activities, has also involved Buenos Aires. It is alarming to observe how the process of expansion of the urban frontier has taken place at the expense of natural and semi-natural ecosystems (Morello et al., 2000). Ji et al. (2020) point out that a shocking gap between supply and demand for arable land emerged during the process of industrialisation and urbanisation and they estimate for Shanghai the imbalances between demand for arable land relative to supply, and inflows of incorporated arable land relative to outflows.

These examples show that issues related to urban sprawl and growth are more relevant than ever. However, we feel that some topics are not yet sufficiently investigated. Thus, in the following sections, after providing an outline of the perspectives and factors driving the urbanisation process, we aim to suggest several unresolved issues to be explored in order to invite scientists, students, stakeholders to propose actions, strategies and approaches that can guide towards sustainable urban development.

INCREASING URBANISATION AND RESOURCE CONVERGENCE

In more general terms, about 70–75% of total natural resources are consumed within urban areas (Tan et al., 2021) and the expected increase of population, associated with increasing resource use, will hardly allow to meet the basic sustainability principles within urban systems. The aim cannot be, of course, to keep the present irreversible urban deterioration, but to properly converge renewable and non-renewable resource flows from the surrounding rural areas into the city and implement feedback actions from cities to the rural surroundings, in order to achieve a win-win rural-urban interplay. It is therefore urgent and crucial to understand how to address the issue of increasing urbanisation and, at the same time, the issues of (i) direct resource convergence to cities, (ii) indirect resource demand by processes that ultimately deliver products to cities, (iii) environmental degradation generated by supply side chains, and finally (iv) unavoidable resource scarcity in the presence of growing demand for goods and services by growing population in urban systems.

Disregarding such much needed focus on the variety of the attraction patterns of urban systems and the environmental impacts associated to their continuous growth within a resource-limited planet may lead to hard-to-deal-with problems in the very near future.

Examples of resource concentration may be, among others:

(i) fossil energy extraction, refinement, conversion to electricity and use in urbans houses and vehicles;
(ii) minerals extraction to built environment and industrial processes (cement, metals, clay, sand, and gravel, among others), among which the recent expansion of batteries for electric cars;
(iii) rare earth minerals in support to electronic devices (smartphones, tables, computers and more) also called as critical raw materials;
(iv) land use, in support to food production, livestock, urban expansion, industrial parks, mobility infrastructures (highways, high speed trains, etc);

(v) water use, in support to agriculture, mining, industry, households;
(vi) waste management through collection, recovery, recycling (urban mining);
(vii) ecosystem services provided by urban vegetation.

Concentration of resources is constrained by their limited availability as well as the huge social and environmental problems created by extraction, transport and processing. Moreover, concentration to (the richest) cities (or richest fractions of urban populations) is likely to subtract resources from potential development and well-being of rural areas and smaller urban centres. In a planet with limited resources, the challenge is to design strategies to generate more value and more services with fewer inputs, perhaps also increasing our awareness that not all wants are needs. This means that, in order to move in the direction of the "sustainable city," available resources must be managed strategically to satisfy very basic and crucial needs (qualitative growth) of both large and small urban centres as well as rural areas, while at the same time disregarding the illusion of unlimited growth on finite resources.

URBAN RESOURCE MANAGEMENT. IS "EFFICIENCY" THE KEYWORD?

Resource Management (RM) is a key factor for Sustainable Development (SD), which in turn must guide Urban Planning (UP) (Agudelo-Vera et al., 2011). The concept of urban resource management has no formal definition. However, according to Agudelo-Vera et al. (2011) it should be referred to "the conscious handling of natural resources–energy and materials–and the utilisation of infrastructure and technology to meet human needs; including extraction, transformation, consumption or use and disposal of resources." In response to increasing resource competition such as the use of land, drinking water, energy, or ecosystem services, Krellenberg et al. (2016) introduce the concept of "resource efficient city." The latter deals with the link between the increasing proportion of city dwellers and the intensive use of resources. It addresses a more equitable and sustainable pattern of living and consumption, as the way in which resources are used (e.g., in terms of the water-energy nexus) and transformed. In other words, a resource-efficient city can be defined as a city that minimises the extraction of raw materials, waste production and energy consumption, while at the same time safeguarding ecosystems and ecosystem services (Dodman et al., 2017). Some studies (e.g., Tan et al., 2021) move beyond the efficiency concept, raising an issue of effectiveness, namely understanding "the hotspots of imports in cities to redirect resources to where they are most needed, based on the system overall resource effectiveness to maximise the use of all resources available."

Similar to all living organisms, cities and human economies operate according to Lotka's Maximum Power Principle (MPP), i.e., "in processes of self-organisation, systems develop those parts, processes and relationships that maximise useful power" (Lotka, 1922a,b). Under maximum power and natural selection constraints, maximum efficiency, as defined by classical thermodynamics, is no longer the goal. When environmental conditions change, the response of a system adapts by optimising, and not necessarily maximising, its efficiency to maintain maximum power (Odum and Odum, 2006). It means that cities grow as self-organising organisms: they manage to increase their power and their ability to attract resources and maximise their output. According to Lotka's Maximum Power Principle, when resources are abundant, maximum power is achieved by competing for the largest possible amount of resources, no matter the efficiency (we may just remember that the Watt steam machine had, at the beginning, efficiencies around 1–2%, yet it was the starting tool of the industrial revolution in the U.K. thanks to abundant and cheap coal storages). Instead, when resources become scarce, maximum power is achieved by increasing efficiency through collaboration with other players and urban systems.

URBAN WELL-BEING VS. SHRINKING RESOURCE BASIS

As mentioned above, a city is generally regarded as a complex open, non-linear, adaptive, and resilient system, which demands large amounts of energy and resources (Shen et al., 2020). Thus, an urban system is not only dependent on its close neighbourhoods but also absorbs resources from very far outside areas, thus competing with other urban systems worldwide and challenging the carrying capacity of the Earth's life support system (John et al., 2019). So, the problem is how to improve the quality of life of an increasing number of citizens and make an urban system sustainable even with a shrinking amount of resources. The solution is neither simple nor unique. To meet this challenge, an important step is to describe the city's energy resources and systems within the "urban metabolism" (UM) metaphor (Wolman, 1965; Odum, 1996). The UM approach includes all the physical stocks and flows of energy and matter that constitute the material basis of a city and creates at the same time awareness of decreasing availability vs. increased demand. In this framework, UM assessments become fundamental tools to inform evidence-based and resource-conscious urban planning and design, allowing a comprehensive understanding of the urban dynamics, to enable a better management of resource flows (Céspedes Restrepo and Morales-Pinzón, 2018; Ulgiati and Zucaro, 2019). This means, in the first place, contemplating simultaneously multiple actions-strategies by different actors and at different scales: from the individual building to the neighbourhood, from the city to the region. The challenge is to integrate possible actions to consider the whole system and the interactions between its individual parts. According to the International Resource Panel, IRP (2018), an appropriate and comprehensive understanding of the connexions and interactions among one or more infrastructure sectors–such as construction and buildings, energy supply, water and wastewater treatment, waste management, travel behaviour and transportation–can provide benefits for sustainability and increased resilience. Secondly, specific solutions need to be designed for each city: an effective path to sustainability must be built on a place-based approach that reflects the characteristics of the individual city in terms of natural, social, and economic capital.

THE NEED FOR INNOVATIVE AND INTEGRATED STRATEGIES

What specific actions and strategies should be implemented is hard to say. According to the Environment Protection Authority Victoria (Environmental Protection Agency Victoria, 2020), it is possible to identify a group of objectives that are currently key to making an urban system resource oriented. These objectives relate to: (i) *decreasing and manage waste*, to provide a wide range of options that are both environmentally and financially effective and efficient; (ii) *selecting resources*, by using materials and designing processes that produce less waste; (iii) *decreasing non-renewable energy use*, with actions to maximise daylight, shifting to renewables (e.g., replace electric heaters with solar heaters), reducing CO_2-emitting devices; (iv) *preserving freshwater*, by reducing excess use and contamination risks by toxic materials; (v) *improving information*, by monitoring energy and other resources consumption; and (vi) *reducing odours and air emissions*. Clearly, these are closely related objectives that must be pursued simultaneously and with integrated strategies. For example, water-energy consumption nexus (WEN) and food-water-energy nexus (FWEN) approaches can provide important insights for sustainable water planning (Fan et al., 2019). Further, minimising waste is undoubtedly crucial, but it cannot be the only way to address the waste issue. When waste cannot be avoided, recovering materials and energy from waste, as well as remanufacturing and recycling into usable products can be a second-step strategy on the way towards sustainable waste management. "Managing waste" by giving resources a second life translates into reducing pressure on the environment, limiting negative impacts on human health and promoting economic growth by fostering circular economy patterns.

To achieve appropriate resource management in cities, in addition to monitoring and managing urban metabolism, an appropriate design and interplay of the components of the urban system is also a crucial issue that must be addressed. According to Ramaswami et al. (2012), the urban system design derives from the mutual interactions of three sub-components: (a) natural capital, (b) engineered infrastructures, and (c) the actors and institutions that regulate these infrastructures.

Natural capital, which may at least translate into urban green areas within and around the city, is a strategic importance aspect as it allows urban pollution to be uptaken and limited, benefiting human life and biodiversity. In fact, nature conservation strategies and maximisation of space for urban forests would philtre pollutants from urban metabolism and improve human livelihoods (Endreny et al., 2017).

Engineered infrastructures of an urban system—also known as the "grey" infrastructure system—include the built environment, from buildings to utilities, from roads to other civil transport structures. It does not only determine the spatial extent of the city and the urban patterns, but plays a crucial role in urban sustainability, as "physical social well-being" (Dong et al., 2018). In this regard, models such as the "15-min city" (Moreno et al., 2021), relaunched by the Mayor of Paris Anne Hidalgo, may positively influence the achievement of more sustainable lifestyles. The idea is to transform the metropolis into a place where citizens can reach any service and satisfy their needs (from culture to shopping) in a few minutes, on foot or by bicycle, made possible by decreased distances among living, working and leisure sites, as well as implementation of suitable infrastructure. Such a city model could become instrumental in the regeneration of urban neighbourhoods. Indeed, this new vision of a compact city, in addition to fostering social cohesion, is capable of significantly improving the urban metabolism. On the contrary, uncontrolled expansion of the built environment most often leads to misuse of resources, soil sealing, fragmentation of natural systems, urban-rural imbalance and increased consumption of energy and materials. For this reason, particular attention should be paid to the development of an appropriate infrastructural system and to the choice of building types that achieve optimal use of space and resource use. In this respect, Pomponi et al. (2021) have shown that higher urban environments increase life cycle greenhouse gas emissions by 154% and low-density urban environments increase land consumption by 142%. These studies show that opting for one building type over another is crucial for sustainable urbanisation Urban planners and local governments should undertake integrated strategies and resource-oriented policies on different spatial and temporal scales.

Finally, societal structure and dynamics play a key role in the path to urban sustainability. Indeed, through its lifestyles, values and behaviours, civil society can guide decision-makers to implement efficient integrated urban planning.

VALORIZATION OF URBAN ECOSYSTEM SERVICES

Although we recognise the need to carefully manage the energy and material resources converging towards urban systems, we are also aware that cities can themselves be resource producers and generators of ecosystem services, most often disregarded: "*When human valuations do not measure the real contributions of natural ecosystems, as is currently the case, ecosystems are not protected, and the larger systems produce less when the natural ecosystems are lost to development*" (Odum and Odum, 2000). In this context, the creation and restoration of natural areas, forests and urban parks, as well as spaces for agriculture within the city, are undoubtedly key initiatives for sustainable urban planning.

Therefore, a key strategy to improve the liveability, health and resilience of growing cities is to invest in the restoration of urban ecosystem services that are generated in a diverse set of habitats, including: green spaces, such as parks, urban forests, gardens and courtyards; and blue spaces, including streams, lakes, rainwater retention ponds, artificial wetlands (Elmqvist et al., 2015). Networks of green and blue areas, both in suburban and urban areas as well as directly integrated into homes through green roofs and green walls, can provide a wide range of benefits, classified according to MEA (2005): (a) *provisioning services* such as water, food, fibre, timber, and genetic resources; (b) *regulating services* including climate regulation, flooding, disease control, water quality and waste treatment; (c) *cultural services* such as recreation, spiritual fulfilment and aesthetic enjoyment; and (d) *supporting services* such as soil formation, pollination and nutrient cycling. It is crucial that urban systems self-organise in a way to maximise these services, instead of having to rely on energy-driven technology.

In addition to green and blue spaces, also urban agriculture and agroecology can contribute to a diverse set of ecosystem services (Nicklay et al., 2020). Urbanisation, geophagy, and the expansion of cities into rural areas are bringing about a radical change in food systems and agricultural production. Thus, applying agroecological principles to urban agriculture initiatives (farms, community gardens, and home and hydroponic gardens) may become an important strategy to support goals such as food access, racial/environmental/food justice, climate adaptation and mitigation, and stormwater management (Recknagel et al., 2016). In summary, awareness of the importance of natural capital and ecosystem services in the city could mean harnessing degraded urban areas and allocating them to a different narrative, subjecting them to restoration and even expansion.

EXPLORING THE UNEXPLORED

From the issues introduced above, it clearly emerges that while cities are among the main contributors to energy and material consumption, they may have a high potential for achieving resource efficiency and effectiveness as well as innovative sufficiency patterns, that allow well-being within sustainable development. It is crucial to focus on these aspects and suggest how to reduce resource consumption, how to decrease the environmental burden, how to create a new balance between human-controlled systems and natural systems and rural-urban interplay. The main issue is not (only) finding new resources, but improving the use of existing ones and the lifestyles that they support, by defining strategies for better urban management and governance through new systemic narratives in which systems act to match action and information with their goals (Gonella et al., 2019). In this regard, it should be noted that the scientific community has contributed to the development of techniques and implementation of urban resource assessment tools using the UM framework. These include material flow analysis, ecological network analysis, emergy accounting, life cycle assessment, food-water-energy nexus and input-output analyses to manage material production, and consumption in cities. Several important urban issues have not yet been sufficiently investigated and many questions/problems remain unanswered and unsolved. Waste management, ecosystem services, and community sharing of basic resources are clear examples. In fact, few studies have been implemented to comprehensively address emerging problems related to the quality of resource use and the circularity of resource flows in urban systems (Tan et al., 2021). A second issue mainly concerns the definition of: (i) innovative and integrated approaches for the strategic management of urban resource flows; (ii) urban problem-solving approaches to address issues such as resource recovery from waste, nature restoration in cities to ensure ecosystem services, geophagy and urban-rural imbalance; (iii) actions for more efficient and effective use of existing technologies; (iv) strategies to extend the life of urban resources and to make cities become producers of resources and ecosystem services; (v) economic models to support urban decision-making concerning, for instance, the optimal allocation of resources to urban green spaces or the recovery of urban unused areas so that they are converted to the highest and best use; (vi) fair governance initiatives so as to ensure equitable access to goods, natural resources and services.

In a nutshell, no path to sustainable development would be possible without first analysing the urban system overall, i.e., considering the interrelationships between its sub-systems and the specific characteristics of cities, such as social and economic and natural resources. Finally, only through participatory governance processes based on dialogue between stakeholders is it possible to plan actions and intervention strategies that ensure the appropriate use and management of urban resources.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

AZ, GM, and SU contributed to conception and design of the study. All authors provided a significant contribution to the paper and contributed to manuscript revision, read, and approved the submitted version.

REFERENCES

Agudelo-Vera, C. M., Mels, A. R., Keesman, K. J., and Rijnaarts, H. H. M. (2011). Resource management as a key factor for sustainable urban planning. *J. Environ. Manage.* 92, 2295–2303. doi: 10.1016/j.jenvman.2011.05.016

Céspedes Restrepo, J. D., and Morales-Pinzón, T. (2018). Urban metabolism and sustainability: precedents, genesis and research perspectives. *Resour. Conserv. Recycl.* 131, 216–224. doi: 10.1016/j.resconrec.2017.12.023

Dodman, D., Diep, L., and Colenbrander, S. (2017). Making the case for the nexus between resilience and resource efficiency at the city scale. *Int. J. Urban Sustain. Dev.* 9, 97–106. doi: 10.1080/19463138.2017.1345740

Dong, L., Wang, Y., Scipioni, A., Park, H. S., and Ren, J. (2018). Recent progress on innovative urban infrastructures system towards sustainable resource management. *Resour. Conserv. Recycl.* 128, 355–359. doi: 10.1016/j.resconrec.2017.02.020

Elmqvist, T., Setäl,ä, H., Handel, S. N., van der Ploeg, S., Aronson, J., Blignaut, J. N., et al. (2015). Benefits of restoring ecosystem services in urban areas, *Curr. Opin. Environ. Sust.* 14, 101–108. doi: 10.1016/j.cosust.2015.05.001

Endreny, T., Santagata, R., Perna, A., De Stefano, C., Rallo, R. F., and Ulgiati, S. (2017). Implementing and managing urban forests: a much needed conservation strategy to increase ecosystem services and urban wellbeing. *Ecol. Model.* 360, 328–335. doi: 10.1016/j.ecolmodel.2017.07.016

Environmental Protection Agency Victoria. (2020). *Resources Efficient Strategies Reshapes the Future of Urban Fabric*. Available online at: https://www.planradar.com/gb/resources-efficient-strategies-in-urban-design/

European Environment Agency (2006). *Urban Sprawl in Europe–The Ignored Challenge. EEA Report No 10/2006.* Copenhagen: European Environment Agency.

European Environmental Agency (2015). *Urban Sustainability Issues — What Is a Resource-Efficient City? EEA Technical Report No 23/2015.* Luxembourg: Publications Office of the European Union.

Fan, J. L., Kong, L. S., Wang, H., and Zhang, X. (2019). A water-energy nexus review from the perspective of urban metabolism. *Ecol. Modell.* 392, 128–136. doi: 10.1016/j.ecolmodel.2018.11.019

Galli, A., Iha, K., Moreno Pires, S., Mancini, M. S., Alves, A., Zokai, G., et al. (2020). Assessing the ecological footprint and biocapacity of Portuguese cities: critical results for environmental awareness and local management. *Cities* 96:102442. doi: 10.1016/j.cities.2019.102442

Gonella, F., Almeida, C. M. V. B., Fiorentino, G., Handayani, K., Span,ò, F., Testoni, R., et al. (2019). Is technology optimism justified? A discussion towards a comprehensive narrative. *J. Clean. Prod.* 223, 456–465. doi: 10.1016/j.jclepro.2019.03.126

Guan, X., Wei, H., Lu, S., Dai, Q., and Su, H. (2018). Assessment on the urbanization strategy in China: achievements, challenges and reflections. *Habit. Int.* 71, 97–109. doi: 10.1016/j.habitatint.2017.11.009

Huang, Q., Jiajun, X., Hua, Q., and Xinyu, G. (2018). Understanding land use and rural development in the national scheme of village relocation and urbanization in China: a case study of two villages in Jiangsu Province. *Sustainability* 10:3227. doi: 10.3390/su10093227

International Resource Panel, IRP (2018). *The Weight of Cities: Resource Requirements of Future Urbanization*, eds Swilling, M., Hajer, M., Baynes, T., Bergesen, J., Labbé, F., Musango, J. K., Ramaswami, A., Robinson, B., Salat, S., Suh, S., Currie, P., Fang, A., Hanson, A. Kruit, K., Reiner, M., Smit, S., and Tabory, S. A Report by the International Resource Panel. United Nations Environment Programme, Nairobi, Kenya.

Ji, X., Han, M., and Ulgiati, S. (2020). Optimal allocation of direct and embodied arable land associated to urban economy: understanding the options deriving from economic globalization. *Land Use Policy* 91:104392. doi: 10.1016/j.landusepol.2019.104392

John, B., Luederitz, C., Lang, D. J., and von Wehrden, H. (2019). Toward sustainable urban metabolisms. From system understanding to system transformation. *Ecol. Econ.* 157, 402–414. doi: 10.1016/j.ecolecon.2018.12.007

Kafy, A. A., Faisal, A. A., Raikwar, V., Rakib, A. A., Kona, M. A., and Ferdousi, J. (2021). Geospatial approach for developing an integrated water resource management plan in Rajshahi, Bangladesh. *Environ. Chall.* 4:100139. doi: 10.1016/j.envc.2021.100139

Krellenberg, K., Koch, F., and Kabisch, S. (2016). Urban sustainability transformations in lights of resource efficiency and resilient city concepts. *Curr. Opin. Environ. Sustain.* 22, 51–56. doi: 10.1016/j.cosust.2017.04.001

Lotka, A. J. (1922a). Contribution to the energetics of evolution. *Proc. Natl. Acad. Sci. U.S.A.* 8, 147–151. doi: 10.1073/pnas.8.6.147

Lotka, A. J. (1922b). Natural selection as a physical principle. *Proc. Natl. Acad. Sci. U.S.A.* 8, 151–154. doi: 10.1073/pnas.8.6.151

Lu, N., Wei, H., Fan, W., Xu, Z., Wang, X., Xing, K., et al. (2018). Multiple influences of land transfer in the integration of Beijing-Tianjin-Hebei region in China. *Ecol. Indic.* 90, 101–111. doi: 10.1016/j.ecolind.2018.02.057

Marvuglia, A., Havinga, L., Heidrich, O., Fonseca, J., Gaitani, N., and Reckien, D. (2020). Advances and challenges in assessing urban sustainability: an advanced bibliometric review. *Renew. Sust. Energ. Rev.* 124:109788. doi: 10.1016/j.rser.2020.109788

MEA (2005). *Millennium Ecosystem Assessment, Ecosystems and Human Well-being: Synthesis.* Washington, DC: Island Press. Available online at: https://www.millenniumassessment.org/en/index.html

Morello, J., Buzai, G., Baxendale, C., Rodriguez, A., Matteucci, S., Godagnone, R., et al. (2000). Urbanization and the consumption of fertile land and other ecological changes: the case of buenos aires. *Environ. Urban.* 12, 119–131. doi: 10.1177/095624780001200210

Moreno, C., Allam, Z., Chabaud, D., Gall, C., and Pratlong, F. (2021). Introducing the "15-Minute City": sustainability, resilience and place identity in future post-pandemic cities. *Smart Cities* 4, 93–111. doi: 10.3390/smartcities4010006

Nicklay, J. A., Cadieux, K. V., Rogers, M. A., Jelinski, N. A., LaBine, K., and Small, G. E. (2020). Facilitating spaces of urban agroecology: a learning framework for community-university partnerships. *Front. Sustain. Food Syst.* 4:143. doi: 10.3389/fsufs.2020.00143

Odum, H. T. (1996). *Environmental Accounting: Emergy and Environmental Decision Making*. New York, NY: Wiley-Inderscience.

Odum, H. T., and Odum, E. C. (2006), The prosperous way down. *Energy* 31, 21–32. doi: 10.1016/j.energy.2004.05.012

Odum, H. T., and Odum, E. P. (2000). The energetic basis for valuation of ecosystem services. *Ecosystems* 3, 21–23. doi: 10.1007/s100210000005

Pomponi, F., Saint, R., Arehart, J. H., Gharavi, N., and D'Amico, B. (2021). Decoupling density from tallness in analysing the life cycle greenhouse gas emissions of cities. *NPJ Urban. Sustain.* 1:33. doi: 10.1038/s42949-021-00034-w

Ramaswami, A., Weible, C., Main, D., Heikkila, T., Siddiki, S., Duvall, A., et al. (2012). A social-ecological-infrastructural systems framework for interdisciplinary study of sustainable city systems. *J. Ind. Ecol.* 16, 801–813. doi: 10.1111/j.1530-9290.2012.00566.x

Recknagel, C., Patton, B., and Hugunin, P. (2016). *Urban Agriculture in Minnesota: A Report to the Minnesota Legislature*. St. Paul, MN: Minnesota Department of Agriculture.

Shen, L., Shu, T., Liao, X., Yang, N., Ren, Y., Zhu, M., et al. (2020). A new method to evaluate urban resources environment carrying capacity from the load-and-carrier perspective. *Resour. Conserv. Recycl.* 154:104616. doi: 10.1016/j.resconrec.2019.104616

Tan, L. M., Arbabi, H., Tingley, D. D., Brockway, P. E., and Mayfield, M. (2021). Mapping resource effectiveness across urban systems. *Urban Sustain.* 1:20. doi: 10.1038/s42949-020-00009-3

Ulgiati, S., and Zucaro, A. (2019). Challenges in urban metabolism: sustainability and well-being in cities. *Front. Sustain. Cities* 1:1. doi: 10.3389/frsc.2019.00001

United Nations, Department of Economic and Social Affairs, Population Division (2019a). *World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420).* New York, NY: United Nations.

United Nations, Department of Economic and Social Affairs, Population Division (2019b). *World Population Prospects 2019: Highlights (ST/ESA/SER.A/423).* New York, NY: United Nations.

Wolman, A. (1965). The metabolism of cities. *Sci. Am.* 213, 178–190. doi: 10.1038/scientificamerican0965-178

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.