Focus on sustainable cities: urban solutions toward desired outcomes

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1. Introduction

Urbanization represents the single most impactful and long-lasting transformation of the Earth system since the dawn of civilization. Cities are simultaneously locations of innovation, social connectivity, and wealth, but they also create local-to-global environmental degradation and socioeconomic disparities. For example, food provision for cities has required significant land-use change and fertilizer input, has altered regional climate, biogeochemical cycles, and degraded marine and landscapes through biodiversity loss, algal blooms and fish kills. To maintain urban livelihoods and the provision of goods and services, cities require vast amounts of energy (e.g. to provide access to transport, cooling systems), which are massive producers of greenhouse gases, the main culprit of global change. Future urbanization will need to be transformative—wholly different from how we have designed, built, and powered cities and towns—so that they can be sustainable and resilient. Should current trends in urban expansion continue—low density and resource and energy intensive—urban energy use will triple between 2005 and 2050 (Creutzig et al 2015). Raw material demand will exceed what the planet can sustainably supply (UN IRP 2018) and the safe operating limits that have facilitated the rise of modern civilization will become increasingly at risk of being crossed, leading to a cascade of pressures that would pose dire consequences for and severely disrupt humanity (Rockström et al 2009).

The growth of future cities and towns—both newly developed and expansion of those already in existence, as well as how we maintain and retrofit existing urban centers—will determine whether humanity can transition to sustainability. Ideally, decisions about urbanization would be based on science and data-driven approaches that are grounded in specific places but are also generalizable (Bettencourt and West 2010). Although there are aspects of cities that are generalizable, current theories about urban systems are more conceptual in nature and there is limited work that takes into consideration the non-linear and non-local effects of urban systems. Nevertheless, scientific understanding today is sufficient to provide some level of meaningful input as regards benefits and consequences of urbanization. For example, the destruction of infrastructure and loss of life caused by Hurricane Betsy in New Orleans in 1965 led to critical knowledge that structural and social systems were necessary to safeguard the city against future tropical storms. However, ‘development outpaced available levels of protection’ (Olson 2011), minimizing the possibility of local evacuation, and eventually resulted in the devastating impacts caused by Hurricane Katrina in 2005. Some of the lessons learned post-Hurricane Betsy have yet to be incorporated post-Hurricane Katrina, diminishing the role of scientific understanding vis-à-vis the ostensible necessity for growth.

What is less known, however, is the collective and integrative effect of urbanization that cuts across disciplinary boundaries and holistically characterizes the problems that ensue, or the efficacy of solutions that are necessary, beyond the lens of any singular academic branch. For example, a frequent focus of urban climate modeling studies that examine the efficacy of temperature reduction strategies (e.g. cool and green roofs) is the ability of a particular strategy to decrease the urban heat island (UHI) (i.e. to decrease the air temperature difference between an urban and rural location). The results from such a singular focus can be misleading if it ignores other components of the urban ecosystem or lacks integration. We illustrate why by using Phoenix, AZ, as an example. Phoenix
has a negligibly small, or even negative, daytime UHI, although few would argue that the fifth largest city in the US does not have a serious urban heat burden, when maximum summertime temperatures frequently exceed 43 °C (Chow et al 2012). A focus on decreasing the UHI lacks integration by neglecting closely connected environmental and human-oriented consequences that become apparent upon examination of tradeoffs and feedbacks (Seto et al 2017, Putnam et al 2018, Broadbent et al 2021). Indeed, recent work conducted in the Californian city of Los Angeles has demonstrated that the deployment of cool (i.e. highly reflective) pavements raises concerns for the undertaking of outdoor activities (e.g. reduces walkability) as a result of increased pedestrian radiant load (Middel et al 2020). This example illustrates a second key concern related to the development of meaningful metrics that are generalizable and help pave the path toward development of urban systems theory that incorporates natural and social elements. Although the utility of a particular metric may have gained traction and become popular, as the often-utilized focus on decreasing the UHI has, it may not result in actionable science. While one may argue that it does for some cities, the lack of generalizability to the majority of cities disconnects this metric from broad societal applicability (Martilli et al 2020).

This Special Issue (SI) was focused on the discovery of urban solutions aimed at accelerating the transition to economically, socially, and environmentally resilient cities through integration of desired outcomes as an organizing framework. The SI papers collectively published, totaling one research agenda-setting perspective and 15 research studies (table 1), take an important step forward by:

(a) integrating across disciplines such as hydrology, meteorology/climatology, ecology, geomorphology, economics, environmental management, environmental sciences, geography, GIScience, and urban planning, thereby explicitly acknowledging the multifaceted qualities of sustainability that each field contributes to;

(b) developing new metrics in assessing sustainability (e.g. Chertow et al 2019, Stokes and Seto 2019, Krueger et al 2020);

(c) considering an explicit multi-scalar approach when evaluating urban sustainability solutions across temporal and spatial dimensions (Aragon et al 2019, Chakraborty et al 2019, Fan et al 2019, Jeong 2019, Meerow 2019, Pregitzer et al 2019, Carmen et al 2020, Grêt-Regamey et al 2020);

(d) examining coupled interactions between various urban system aspects, such as climate-energy, food-energy, and on industrial waste with energy production and consumption, with respect to desired sustainability outcomes through detailed scenario assessment (e.g. Lipson et al 2019, Warziniack and Brown 2019, Dukes et al 2020).

Collectively, the articles in the SI also point to four gaps in knowledge:

(a) The need for more theory—Stokes and Seto (2019) reconceptualize the urban landscape in a process-based manner that is directly connected to sustainability. The explosion in data analytical tools (e.g. machine learning, data mining), data (e.g. remote sensing, cell phone records), and computing infrastructure (e.g. parallel and cloud computing) offers an unprecedented opportunity to expand this type of analysis globally, to include other processes, and paves the way toward improved characterization and monitoring of urban areas, including large-scale urban population dynamics (e.g. Tuholske et al 2019), to guide the transition to sustainability.

(b) The need for replicability—are the results consistent across urban sites using the same methods but with different data? Pregitzer et al (2019) demonstrate the importance of improved characterization of urban forests, including their composition and structure in order to better inform both policy and management, enable provision of ecosystem services and to establish a reference against which what-if (e.g. canopy expansion) scenarios can be examined.

(c) Generalizability—are the results applicable in other urban contexts? Can inferences be made in other urban areas using results from one study? For example, how and under what conditions do the findings of Chakraborty et al (2019)—who find that poorer neighborhoods experience elevated heat exposure—apply to smaller cities around the world outside of their 25 case studies? Perhaps even more important is to understand how generalizable are the underlying conditions and processes that gave rise to these outcomes. Likewise, under what conditions can urban agriculture supply 90% of annual consumption of produce, as shown in Phoenix (Aragon et al 2019) and what are the implications for local food insecurity?

(d) Scalability—there is an urgent need for solutions to be scalable. It is valuable that some case studies in the SI demonstrate innovation and provide pathways to increase resilience, but can other cities achieve similar outcomes with significantly fewer human and financial resources?

The papers also underscore the need for rethinking the metrics we are using to measure outcomes connected to urban sustainability. For example, given the potential of ISP for reusing a city’s industrial waste and byproducts, there is an opportunity to develop metrics that examine a city’s capacity to improve resource use efficiency. Likewise, there is a need to develop and improve tools that examine a spectrum
| Paper and urban area examined | Primary discipline | Spatial scale | Temporal scale | Emergent theme for urban solutions and desired sustainability outcome |
|-------------------------------|--------------------|---------------|---------------|---------------------------------------------------------------|
| Moy de Vitry et al (2019)/NA; perspective essay | Hydrology | NA/perspective essay | | Consideration of risks embedded within smart urban water systems, and the role for future research having a dual role as both creators and critics of novel water resource solutions. |
| Carmen et al (2020)/four cities: Coimbra (Portugal), Genk (Belgium), Leipzig (Germany), and Vilnius (Lithuania) | Environmental sciences/ ecology | City-wide (regional-scale) | aBased on stakeholder survey data collected in 2019–2020 | Assessment of which ecological, economic, and social metrics are selected by cities as urban green space indicators that enhance urban resilience and sustainability. |
| Dukes et al (2020)/Baltimore City, Maryland, USA | Ecology | Census tract (local-scale) | Annual; one year (2016) | Development of new approach to examine multi-scale spatial patterns of community nitrogen footprint for urban sustainability through improved monitoring of urban food and energy consumption. |
| Gré-Regamey et al (2020)/two cities: Zurich, Switzerland; Singapore | Ecology/urban planning | Variable up to 1 km² pixels; city-wide (regional-scale) | Combination of datasets | Assessment of urban densification on urban ecosystem services, including air pollution control, water flow regulation, microclimate regulation, carbon sequestration, and recreation, for a temperate and tropical city. |
| Krueger et al (2020)/seven cities on four continents | Sustainability | City-wide (regional-scale) | Combination of datasets | Development of a new framework that integrates security, resilience, and sustainability of urban water supply systems. |
| Lipson et al (2019)/Melbourne, Australia | Meteorology/ climatology | City-wide (regional-scale) | Yearly-decadal; present day until 2100 | Examination of climate-energy interactions under various scenarios of climate, urban infrastructure and technological change to project future urban electricity and gas demand. Demonstrated utility of a generalizable mapping tool for the assessment and comparison of spatial trade-offs and synergistic ‘hotspots’ to enhance green infrastructure planning. |
| Meerow (2019)/three cities: New York City, USA; Los Angeles, USA; Manila, Philippines | Geography/ GIScience | Census tract (local-scale) | Annual; combination of yearly/multi-year datasets | Improved modeling of ex-urban hydrological sediment load in desert catchments for enhancing urban flood control structures in rapidly growing desert cities. |
| Jeong (2019)/Phoenix Metropolitan Area, USA | Hydrology/ geomorphology | City-wide (regional-scale) | Yearly-decadal; mid-20th century until present day | (Continued.) |
Table 1. (Continued.)

| Paper and urban area examined | Primary discipline | Spatial scale | Temporal scale | Emergent theme for urban solutions and desired sustainability outcome |
|-------------------------------|--------------------|---------------|----------------|---------------------------------------------------------------------|
| Fan et al (2019)/Taipei City  | Urban planning     | 250 m pixels; city-wide (regional-scale) | Annual; one year (2015) | Development of a framework for measuring compactness and urban green accessibility in a high-density transit-oriented metropolis based on the urban compactness index (UCI) and urban green accessibility index (UGAI). |
| Chakraborty et al (2019)/ 25 major cities; global distribution | Geography/GIScience | 1 × 1 km pixels (neighborhood scale) | Annual; combination of yearly/multi-year datasets | Assessment of neighborhood level urban heat exposure, using satellite and census data, for 25 global cities to characterize the extent to which poorer neighborhoods experience elevated temperatures. |
| Aragon et al (2019)/Phoenix, Arizona, USA | Geography/global studies | Building lots/rooftops (neighborhood to regional scale) | Annual; combination of yearly datasets | Contribution assessment of urban agriculture deployment over underutilized exterior spaces (i.e. unpaved vacant lots, flat rooftops, and building façades) towards city-specific sustainability goals. |
| Tuholske et al (2019) | Geography/GIScience | City-wide (regional to large-scale) | Combination of datasets from 2000, 2015, and 2016 | Utility of multiple datasets to estimate the change in Africa’s urban population between 2000 and 2015, within and between countries, and across moisture zones. |
| Pregitzer et al (2019)/New York City, USA | Ecology/GIScience | Urban plots (neighborhood scale to regional scale) | Annual; combination of yearly datasets | Enhanced scalar assessment of urban forest stands—spatial extent, structure, and composition—to accurately represent different urban forest types that inform effective policy and management. |
| Warziniack and Brown (2019)/conterminous United States | Hydrology/economics | Water basin (regional to large-scale) | Every five years: 1985–2070 | Examination of future changes in water yield and demand and their effect on the likelihood of water shortages in the absence of groundwater mining. |
| Chertow et al (2019)/Mysuru City (Mysore), India | Environmental management | City-wide (regional-scale) | Annual; combination of yearly datasets | Development of a new metric—industrial symbiosis potential—for sustainability via linking of private production and public infrastructure to improve urban resource efficiency. |
| Stokes and Seto (2019)/909 Urban Areas in the USA | Geography/GIScience | 1 × 1 km pixels (neighborhood scale) | Annual; combination of yearly datasets | Development of a new language and classification schema for urban areas based on objective measures of the built and natural environment that are comparable across and within urban areas. |

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of spatially-explicit environmental indicators, patterned after the nitrogen footprint tool (Dukes et al 2020) which permits environmental impact assessment of the aggregate activities and consumption patterns of distinct urban regions. Additionally, there is a need to develop measures of urban landscapes that link to multiple dimensions of sustainability (Grêt-Regamey et al 2020, Krueger et al 2020), including energy demand (Lipson et al 2019), flood control structures (Jeong 2019), assessment of tradeoffs and synergies that enhance urban resilience (Meerow 2019) and extend beyond the conventional focus
on land use change. Understanding how city governments plan, manage and evaluate existing urban green spaces to maximize delivery of ecological, economic, and social benefits is necessary in order to make practical contributions to urban resilience (Carmen et al. 2020). Finally, retrofitting existing cities and development of new urban clusters in a society based upon information technology offers prospects for breakthrough changes but also brings unique challenges with respect to privacy and cybersecurity (Moy de Vitry et al. 2019).

Collectively, the articles in the SI advanced the knowledge base on cities and sustainability. They also revealed considerable opportunities for future research that advance the development of pathways to urban sustainability. Especially important is the potentially critical role of innovative policy, management, and technological solutions that facilitate locally-established desired outcomes that are generalizable, integrative, and scalable. Development of new conceptual frameworks, metrics and tools, and integration across disciplinary boundaries that holistically characterize and help prioritize science and policy concerns, can help inform a convergent research agenda that paves the way to transitioning to sustainability in an urban century.

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