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ERRATUM

Erratum: Prioritizing urban sustainability solutions: coordinated approaches must incorporate scale-dependent built environment induced effects (2015 *Environ. Res. Lett.* **10** 061001)

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Due to an error in the production process, the incorrect version of figure 2 was mistakenly published on 9 June 2015. The correct version of the figure is below. This error has no bearing on the interpretation and conclusions drawn.

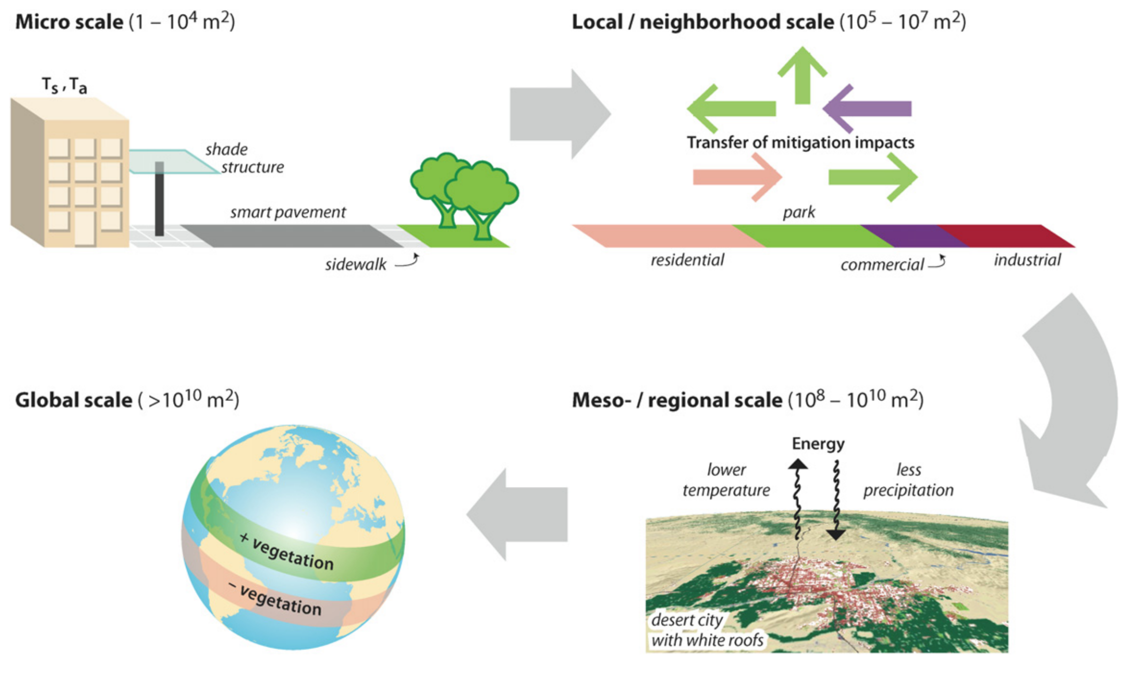

Figure 2. Geographical considerations, in terms of micro-, to local/neighborhood, to meso-/regional-, and finally global scale linkages in physical processes and aspects are often downplayed or underconsidered when implementing urban adaptation measures.

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PERSPECTIVE

Prioritizing urban sustainability solutions: coordinated approaches must incorporate scale-dependent built environment induced effects

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Abstract

Because of a projected surge of several billion urban inhabitants by mid-century, a rising urgency exists to advance local and strategically deployed measures intended to ameliorate negative consequences on urban climate (e.g., heat stress, poor air quality, energy/water availability). Here we highlight the importance of incorporating scale-dependent built environment induced solutions within the broader umbrella of urban sustainability outcomes, thereby accounting for fundamental physical principles. Contemporary and future design of settlements demands cooperative participation between planners, architects, and relevant stakeholders, with the urban and global climate community, which recognizes the complexity of the physical systems involved and is ideally fit to quantitatively examine the viability of proposed solutions. Such participatory efforts can aid the development of locally sensible approaches by integrating across the socioeconomic and climatic continuum, therefore providing opportunities facilitating comprehensive solutions that maximize benefits and limit unintended consequences.

1. Introduction

The share of urban relative to rural dwellers has rapidly surpassed the 50% threshold of global population (figure 1(a)). Anticipated increases of urban inhabitants (a surge of roughly 3 billion by mid-century compared to today) will lead to extensive conversion of natural to engineered landscapes, with recent estimates indicating likely growth of global land cover exceeding 1.5 million km^2 by 2030 [1], an area roughly equivalent to the size of Mongolia. Urban, relative to peri- or ex-urban areas, face combined challenges from directly induced regional climate modification owing to the physical infrastructure of the built environment and impacts resulting from increased global emissions of long-lived greenhouse gases [2]. Because greenhouse gas emissions continue to increase, there is mounting urgency to advance existing and develop novel strategies minimizing tradeoffs, while maximizing the benefits gained from improving the very environment more of the globe's inhabitants will reside in. We posit that novel urban solutions aimed at the provision of sustainable urban environments lie at the intersection of adaptation (i.e., adjustment in response to expected changes in climate) and mitigation (i.e., intervention aimed at anthropogenic forcing reduction) strategies, aptly incorporating essential elements of both approaches.

Current attitudes on sustainability of cities endorse the notion of high-density agglomerations [3]. This concept, centered on the presumption of reduced per capita emission of greenhouse gases, has recently given rise to large expansion campaigns. For example, Iskandar, Malaysia, a newly minted developmental region in Southeast Asia, is lauded as a sustainable metropolis of international standing with a keen eye on energy conservation, environmental awareness and preservation. Regrettably, the notion of energy conservation exclusive of built environment impacts (e.g., reduction of the sky view factor, limiting the

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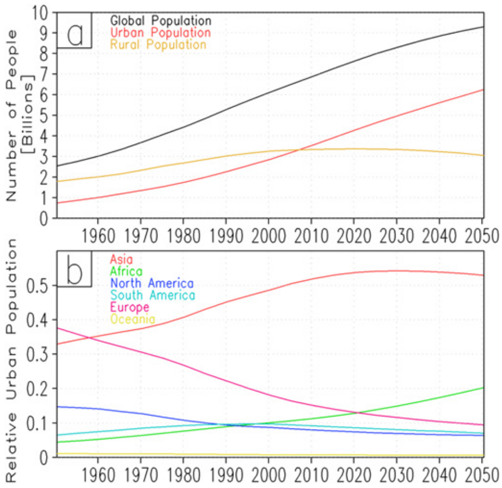

Figure 1. Historical and projected total global population (black line), urban population (red line), and rural population (dark yellow line) through 2050, in billions (**a**). Relative urban population for Asia (red line), Africa (green line), North America (blue line), South America (light blue line), Europe (pink line), and Oceania (yellow line), compared to total urban population for specified particular period of time (**b**). Source: UN.

region's ability to naturally cool itself during evening and nighttime hours will require more, not less, energy consumption) often omits fundamental physical principles. Importantly, current norms designating *high-density equals enhanced sustainability* may not offer the decisive advantage previously thought [4, 5]. Although such work has not been conducted for a necessarily diverse number of cities to reach broadly generalizable conclusions, recent evidence provides support to the notion that 'there is no easy single recipe for low-carbon lifestyles' [6] when lifecycle assessments account for lifestyle choices plus emissions related to housing energy and transportation fuels [7].

We emphasize here that urban sustainability, a term that could broadly be defined as ensuring environmental, socio-cultural, and economic dimensions of a city meeting the needs of its residents over a long-term period [8], must also incorporate direct built environment induced effects, thereby accounting for fundamental physical principles from an energy balance perspective. Prioritizing urban solutions therefore requires place-based awareness, but ought to also entail temporal aspects describing when such prioritization is expected. For example, the relative share of urban population for Asia is projected to peak around 2030, but decline subsequently, as urban populations in Africa begin growing at increasingly rapid rates (figure 1(b)). Therefore, projected changes of the urban share of population can be used as a timeline indicating when the co-evolution of urban growth and adapting/mitigating infrastructure implementation can take place—consequently, technological investments today can be utilized in several decades, henceforth, in areas where substantial urbanization is not expected for some time. This is fundamentally different relative to developed nations, where management plans for retrofitting metropolitan areas are of greater concern, necessitating economic valuation to guide strategic prioritization [9].

This perspective addresses the opportunity of choices available for urban regions to ameliorate negative consequences on urban climate (e.g., heat stress, poor air quality, energy/water availability), illustrates scale dependent benefits and tradeoffs of individual choices, and outlines necessary steps forward.

2. Limiting constraints and choices of opportunity

Commonly used approaches towards ameliorating deleterious aspects of urbanization on climate (e.g. urban warmth or air pollution) largely involve directly modifying several terms of the surface energy balance [10]. High albedo roofs increase reflectance and reduce sensible heat and stored energy in the urban fabric [11], while permeable concrete or asphalt enables reduced heat storage and larger surface evaporation [12], and green spaces simultaneously increase latent heat fluxes and increase direct shading from vegetated canopies [13]. In addition to the established methods specified, there also exists a portfolio of recently developed complementary technologies that serve dual adaptation and mitigation purposes. These technologies, which include phase change materials for storing solar energy [14], photovoltaic pavements and canopies [15], and the cogeneration of power with waste heat [16], also alter the urban surface energy and water cycles, which in turn reduce the urban heat island (UHI) intensity and building energy loads, thereby diminishing energy demand, therefore lowering greenhouse gas emissions. In addition, an indirect but essential energy saving opportunity is maximized when anthropogenic heat, an important constituent of the UHI effect [17], is utilized for cogeneration purposes.

The physical aspects underpinning the above-mentioned approaches are well known at the immediate spatial scale of application, but their multi-scale efficacy and impacts on other natural and urban systems have not been as well elucidated. The lack of theoretical knowledge is unsurprising given the inherent physical and social complexities of developing and implementing such solutions in cities. These include:

(i) The availability of developed or undeveloped spaces in urban areas. In mature cities with intensive land-use and finite space for development, little room exists for substantial variation in horizontal and vertical redevelopment. This limitation may preclude approaches that require sizeable spaces (e.g. large parks) in favor of other less space-intensive approaches utilizing urban

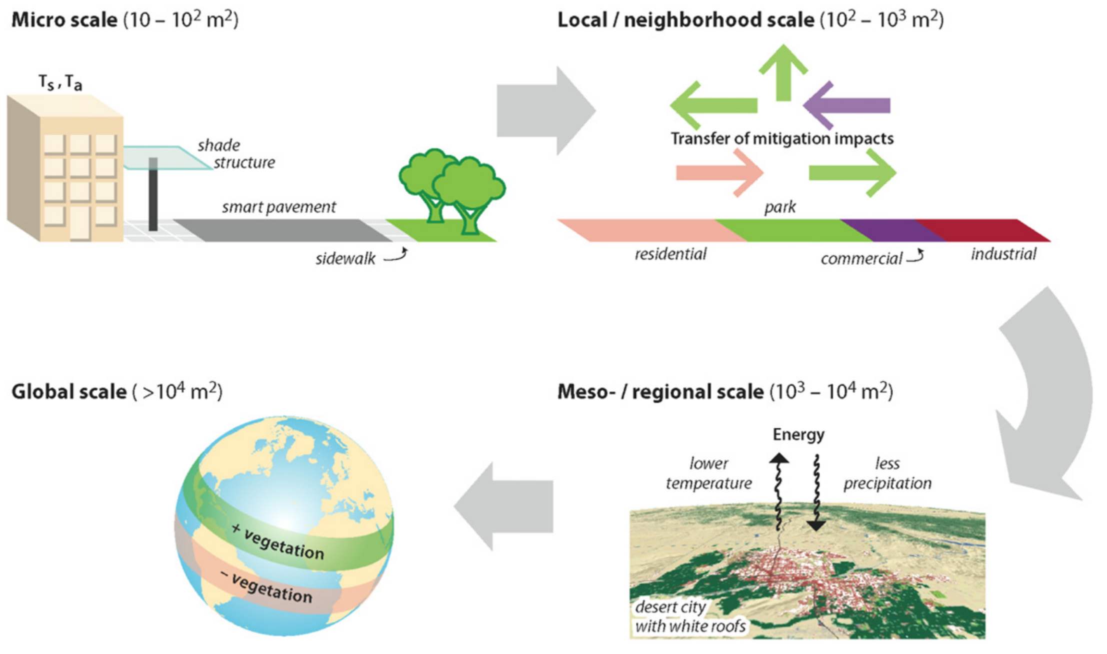

Figure 2. Geographical considerations, in terms of micro-, to local/neighborhood, to meso-/regional-, and finally global scale linkages in physical processes and aspects are often downplayed or underconsidered when implementing urban adaptation measures.

landscapes with limited functions (e.g. rooftop gardens or cool roofs).

(ii) The opportunity costs of implementing these approaches. Maintaining a dedicated space, such as an urban forest that potentially reduces urban warmth and improves air quality, may be too substantial relative to alternate land-uses that may be of greater short-term economic value. Quantifying its value under a sustainability framework is fraught with difficulty, but approaches (e.g. a cost-benefit life cycle analysis or an ecosystems services framework) assigning an economic value to the service provided can be —and have been—successfully employed in cities to inform policymakers of the sustainable value of these parks [18].

(iii) The vertical location (i.e. street- versus roof-level) and spatial extent (i.e. building or neighborhood-scale) of the approach. First, certain approaches (e.g. green roofs) will result in substantial micro-scale benefits towards selected stakeholders, particularly within or around the building rooftop. These benefits, however, are unlikely to be experienced by the majority of city residents as pedestrians at street levels, especially if not applied at sufficiently large scales. Second, the success of these methods is likely to be piecemeal without co-ordination between urban stakeholders. The spatial configuration of green spaces in the context of UHI reduction can be significant in some cities [19], and an important corollary would thus be how to maximize the potential for cooling with different configurations?

(iv) The city's larger synoptic climate context. Three examples of how urban solutions must be aware of the coupling between geographic scales of physical processes from the micro- to the global-scale (figure 2) must be considered. First, the city's regional or synoptic climate may substantially reduce the selected approach's effectiveness. Reflective roofs in cities subject to seasonal dust storms can have substantially lower albedos through deposition of fine particulate matter and other debris [20]. Second, unexpected climatological impacts at larger scales may occur. For example, high reflectivity can have adverse effects on the hydrological cycle of cities, leading to reduced regional-scale precipitation [2, 21, 22]. Third, strategies effective within specific climates may be impeded by larger sustainability contexts, such as the viability of utilizing non-native, high water-demand flora within arid environments that reduce the supply of available urban water [23, 24]. The tradeoff between localized cooling vis-à-vis water scarcity in cities susceptible to drought conditions has yet to be fully examined.

The myriad of biophysical and socio-economic complexities present in real urban environments strongly suggest that a portfolio of adaptive and mitigating strategies is likely to be a preferable option, though it remains to be seen how much, and of what, is ideal. Certainly, previous assertions endorsing one-size-fits-all type of solutions, by virtue of their neglect of multi-scale socio-economic and biophysical considerations, are not recommended [2, 25]. One narrative yet to be widely considered, however, is that of a spectrum of spatial scales (figure 2) [26]. Reflective materials, for instance, may be most effective in reducing microscale temperatures when individual building facets are considered, but lose efficiency when thermal interactions among buildings and street canyons are included at neighborhood scales. Green roofs, on the other hand, can be a promising option when implemented extensively at city scales, but its full potential can be more costly if regional scale advection is considered within the context of water-energy trade-offs.

3. Steps forward

It is understandable that urban climatologists are collaborating with other disciplines (e.g., urban planning, landscape architecture) increasingly often to enhance communication and apply knowledge towards advancing solutions to urban problems [27, 28]. Illustrative examples of interdisciplinary cooperation include: (i) comparing disciplinary theory, methods, modeling, and aspects of applications to urban design and planning, as well as (ii) sustainable policy development emphasizing enhanced coordination between stakeholders, researchers, and policymakers, and (iii) formalizing organizational structures that enable and facilitate interactions with related fields (e.g., International Association for Urban Climate, and the Board on the Urban Environment of the American Meteorological Society).

The field of ecology, for example, has been impacted heavily with new foci on urban ecology and the so-called ecological homogenization of urban USA [29]. Urbanization is a central topic in the emerging field of macrosystems ecology, which similarly has established protocols to study multi-scale drivers for ecological processes in cities. Considerable integration with knowledge in urban climate is needed in these endeavors.

While individual buildings that can be built to last for decadal- or century-time scales have considerable temporal impacts, decisions made by stakeholders concerning urban sustainability solutions also have climate-related spatial impacts. Scale considerations often impose limits on subsequent or concurrent planning decisions [27], and require extensive multidisciplinary knowledge potentially beyond individuals or uncoordinated groups involved in ad-hoc urban development. For instance, the construction of a building, which is taller relative to existing structures, would alter existing surface and near-surface temperatures, shading and wind-flow, in turn modifying thermal comfort and air quality. These impacts may preclude and limit subsequent development that potentially reduces the neighborhood's sustainability, especially when the cumulative impacts from rapid development are considered. For example, the sum of rapid development in the Pearl River Delta region in East China, by virtue of local to regional circulation changes, has been linked to deteriorating regional air quality [30]. Thus, stakeholders involved in the more sustainable design and planning of settlements should be cognizant of these issues prior to incipient stages of growth to complement strategies across spatial scales.

One way to enable this is via a centralized planning process involving contributions from interested participants aware of the limits and impacts on urban climate arising from building development. Clear and integrated communication between architects, builders, planners and other stakeholders with relevant urban climate knowledge would yield key insights into developmental approaches that maximize urban sustainability. For instance, centralized planning of the new Marina Bay Financial Centre district in Singapore utilizes several of the aforementioned urban climate adaptation strategies across building- and local-scales [31].

There remains considerable analysis, tool-building, and coordinated value-added collaboration (e.g., the World Climate Change Research Programme, tasked with improving prediction of the Earth system, omits reference to urban sustainability in its inventory of six grand challenges) that must emanate from the urban and global climate community, and related disciplines, who understand the physics of these complex systems and have the capacity to simulate desirable features and goals of the strategies noted herein. This must be a priority rather than applying limited techniques and producing quick solutions without fully comprehending outcomes that may, in reality, be inappropriate. Not all strategies should be weighted equally across all scales and regions, but judiciously analyzed to optimize what will and will not work in the climate region and within a societal needs context.

Acknowledgments

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References

[1] Seto K C, Fragkias M, Güneralp B and Reilly M K 2011 A meta-analysis of global urban land expansion *PloS one* **6** e23777
[2] Georgescu M, Morefield P E, Bierwagen B G and Weaver C P 2014 Urban adaptation can roll back warming of emerging megapolitan regions *Proc. Natl. Acad. Sci. (USA)* **111** 2909–14
[3] Glaeser E L and Kahn M E 2010 The greenness of cities: carbon dioxide emissions and urban development *J. Urban Econ.* **67** 404–18
[4] Heinonen J and Junnila S 2011 Implications of urban structure on carbon consumption in metropolitan areas *Environ. Res. Lett.* **6** 014018

[5] Echenique M H, Hargreaves A J, Mitchell G and Namdeo A 2012 Growing cities sustainably: does urban form really matter? *J. Amer. Plan. Assoc.* **78** 121–37

[6] Heinonen J, Jalas M, Juntunen J K, Ala-Mantila S and Junnila S 2013 Situated lifestyles: II. The impacts of urban density, housing type and motorization on the greenhouse gas emissions of the middle-income consumers in Finland *Environ. Res. Lett.* **8** 035050

[7] Heinonen J, Jalas M, Juntunen J K, Ala-Mantila S and Junnila S 2013 Situated lifestyles: I. How lifestyles change along with the level of urbanization and what the greenhouse gas implications are—a study of Finland *Environ. Res. Lett.* **8** 025003

[8] United Nations World Commission on Environment and Development 1987 *Our Common Future* (Oxford: Oxford University Press) (www.un-documents.net/our-common-future.pdf)

[9] Sproul J, Wan M P, Mandel B H and Rosenfeld A H 2014 Economic comparison of white, green, and black flat roofs in the United States *Energy Build.* **71** 20–7

[10] Oke T R 1988 The urban energy balance *Prog. Phys. Geogr.* **12** 471–508

[11] Akbari H, Konopacki S and Pomerantz M 1999 Cooling energy savings potential of reflective roofs for residential and commercial buildings in the United States *Energy* **24** 391–407

[12] Stempihar J J, Pourshams-Manzouri T, Kaloush K E and Rodezno M C 2012 Porous asphalt pavement temperature effects for urban heat island analysis *Transp. Res. Rec.* **2293** 123–30

[13] Dimoudi A and Nikolopoulou M 2003 Vegetation in the urban environment: microclimatic analysis and benefits *Energy Build.* **35** 69–76

[14] Santamouris M, Synnefa A and Karlessi T 2011 Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions *Sol. Energy* **85** 3085–102

[15] Golden J S, Carlson J, Kaloush K E and Phelan P 2007 A comparative study of the thermal and radiative impacts of photovoltaic canopies on pavement surface temperatures *Sol. Energy* **81** 872–83

[16] Persson U and Werner S 2012 District heating in sequential energy supply *Appl. Energy* **95** 123–31

[17] Salamanca F, Georgescu M, Mahalov A, Moustaoui M and Wang M 2014 Anthropogenic heating of the urban environment due to air conditioning *J. Geophys. Res.: Atmos.* **119** 5949–65

[18] Nowak D J, Crane D E, Stevens J C, Hoehn R E, Walton J T and Bond J 2008 A ground-based method of assessing urban forest structure and ecosystem services *Arboriculture and Urban Forestry* **34** 347–58

[19] Connors J P, Galletti C S and Chow W T L 2013 Landscape configuration and urban heat island effects: assessing the relationship between landscape characteristics and land surface temperature in Phoenix, Arizona *Landscape Ecology* **28** 271–83

[20] Getter K L and Bradley Rowe D 2006 The role of extensive green roofs in sustainable development *HortScience* **41** 1276–85

[21] Bala G and Nag B 2011 Albedo enhancement over land to counteract global warming: impacts on hydrological cycle *Clim. Dyn.* **39** 1527–42

[22] Georgescu M, Mahalov A and Moustaoui M 2012 Seasonal hydroclimatic impacts of Sun Corridor expansion *Environ. Res. Lett.* **7** 034026

[23] Coutts A M, Tapper N J, Beringer J, Loughnan M and Demuzere M 2013 Watering our cities: the capacity for water sensitive urban design to support urban cooling and improve human thermal comfort in the Australian context *Prog. Phys. Geogr.* **37** 2–28

[24] Ruddell D M and Dixon P G 2014 The energy–water nexus: are there tradeoffs between residential energy and water consumption in arid cities? *Int. J. Biometeorol.* **58** 1421–31

[25] Yang J, Wang Z H and Kaloush K E 2015 Environmental impacts of reflective materials: is high albedo a'Silver Bullet' for mitigating urban heat island? *Renew. Sustainable Energy Rev.* **47** 830–43

[26] Mills G, Cleugh H, Emmanuel R, Endlicher W, Erell E, McGranahan G, Ng E, Nickson A, Rosenthal J and Steemer K 2010 Climate information for improved planning and management of mega cities (needs perspective) *Procedia Environ. Sci.* **1** 228–46

[27] Mills G 2006 Progress towards sustainable settlements: a role for urban climatology *Theor. Appl. Climatol.* **84** 69–76

[28] Oke T R 2006 Towards better scientific communication in urban climate *Theor. Appl. Climatol.* **84** 179–90

[29] Groffman P M *et al* 2014 Ecological homogenization of urban USA *Frontiers in Ecology and the Environment* **12** 74–81

[30] Lu X, Chow K-C, Yao T, Lau A K H and Fung J C H 2010 Effects of urbanization on the land sea breeze circulation over the Pearl River Delta region in winter *Int. J. Climatol.* **30** 1089–104

[31] Urban Redevelopment Authority (URA), Singapore 2014 *Land Use Master Plan –Singapore* (www.ura.gov.sg/uol/master-plan/View-Master-Plan/master-plan-2014/master-plan.aspx)