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Review

Cities in the age of the Anthropocene: Climate change agents and the potential for mitigation

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ABSTRACT

Cities are human creations where many of the emissions causing climate change originate. Every aspect of daily life in cities, which spans buildings, transit, food, energy, and water, relies on fossil fuels that materially contribute to climate change. This paper explores the need for research to better uncover the processes driving urbanization in order to develop novel ways to mitigate climate impacts on Earth. Areas of fruitful research include better quantification of teleconnections between cities and their hinterlands and coupling those to the socio-economic drivers and organization of those relationships; the financialization of much urban policy; understanding where cities fit in the global economic order and their role in generating economic growth, and the ways in which they are also seen as leaders of sustainability and climate actions, but constrained in so-doing by the nested and tiered layers of institutions they operate within. This paper concludes by outlining ways for cities to transition toward nurturing human well-being and reducing their impacts on planetary processes resulting in the proposed new Earth epoch – the Anthropocene.

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1. Introduction: the hallmarks of the 'Anthropocene'

The relationship between urbanization and global environmental change is now well established, along with recognition of a nexus among carbon based fuels, global environmental change, climate impacts and the emergence of industrial cities. These interactions have, in the late twentieth century, become the motors of global economic growth (Newbold et al., 2016; Seto et al., 2015; Gurney et al., 2015; McDonald et al., 2015; Kennedy et al., 2009b). This paper places current urbanization and climate impacts and their relationship to the 'Anthropocene' in a larger

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context by discussing the rise of cities as the prevailing home for humans in the twenty-first century.[1] Cities are nested in networks of production, consumption, distribution and regulations in important ways that constrain and shape their ability to be proactive actors in managing themselves. Deeper recognition of these factors sets the stage for new methods to better identify the dynamics of urban systems. Deeper concerns also motivate a need to examine the role of cities as the new homes for humans. Given that 3.6 billion people live in cities (UNDP, 2011) and urban populations will continue to grow, how cities develop in the future will affect the well-being of many. Simultaneously, the planet's health depends on how cities evolve.

First, however, we must recognize the critical relationship between urban growth and consumption of fossil fuels. The use of coal enabled the industrial revolution and a huge surge of production in factories that increasingly were located near and in cities. Coupled with the rise of capitalism (Hodgson, 2015), the conjuncture of forces was powerful. These intertwined developments enabled urbanization (as a land form) to accelerate and sweep the world. Fossil fuel energy proved powerful, transportable, and ultimately fungible into many products from petroleum to fertilizers, plastics and more. As McNeill (2000) wrote, the twentieth century was unlike any other due to the enormous inputs of fossil fuel energy. Global population rose to 6.5 billion in 2000 and is projected to reach 9 billion by 2050 (UNDP, 2011). Population growth is supported by fossil fuel energy which supplies power and technology to feed, house, and clothe more people (Zalesiewicz et al., 2011: 836).

The *great*[est] *acceleration* of global environmental change (Steffen et al., 2015) coincided with the post World War II period. Economic growth surged, enabled by greater use of inexpensive petrochemical products in more applications. Changes in the regulation of the global economy facilitated international trade, engendering a huge shift of human households into cities starting in the 1950s. Needs for Agricultural labor plummeted while agricultural productivity grew due to the application of science and technologies such as mechanical devices fueled by fossil energy. As labor redundancy grew and rural household incomes fell, people migrated to cities for jobs. Webs of new worldwide industrial metabolisms (Steffen et al., 2015), including industrial agriculture, were intrinsic to this dynamic. Post war emphasis on economic reconstruction and growth led to substantial changes in international economic rules, ushering in economic liberalization. New developments in information, technology, and skills circulated in a global space more easily, more completely, and at speeds never seen before. Thus, cities have become the motors of economic growth in the world (Storper, 2013).

Changes in governmental systems in China and other countries, along with free trade agreements, expanded economic growth in the BRIC countries (Brazil, Russia, India China) and other parts of the world. Nearly all countries, rich or poor, have experienced substantial rural to urban migration and growth of cities. While global income remains greatly unequal (with signs of increasingly large divergences across populations (Piketty, 2014)), life conditions have improved for many. Yet, cities and the urbanization process are inextricably dependent on the ability to harvest resources across the globe in inexpensive ways. Climate change, one aspect of the 'Anthropocene', is an externality of our urbanized planet. Effects are direct and attributable: land use and related pressures have reduced local biodiversity intactness across 58% of the world's land surface (Newbold et al., 2016); Vitousek et al. (1997) pointed out that 30–50% of the world's land surface has been transformed by human action. Large-scale infrastructure that moves water in time and space has degraded watersheds, aquatic ecosystems, and habitats. Human impacts are found in all parts of the planet and have been for millennia, but with population growth and fossil fuel energy, impacts are more extensive and significant for ecosystem health.

2. Why cities now?

Only recently have researchers turned their attention to the role of cities in global environmental change. While Herodotus and others (see Glacken, 1967) provided early comments of human impacts on ecosystems, George Perkins Marsh's *Man and Nature* (1865) was a pivotal publication that pointed to the significant impacts human activities could have on natural systems. Still, researchers took over a century to link urban activities themselves to environmental change, represented in part by Abel Wolman's work on the metabolism of cities. Wolman described the inflows and outflows of a hypothetical city of 1 million people, highlighting the impacts of urbanization on Earth resources (Wolman, 1965). Slowly, a general recognition that cities are at the center of biogeochemical change and the climate change challenge, has emerged.

2.1. Cities as 'things' or processes?

What is meant by city in the late twentieth and early twenty-first centuries? Keil (2003: 725) described 'the urban' as "a complex, multiscale and multidimensional process where the general and specific aspects of the human condition meet." Thus, 'the urban' should include activities such as strip mining in the Appalachian mountains for coal to create electricity for cities. These 'teleconnections' are often opaque, multiscale and multidimensional, as Keil stated, but also historically accreted and 'locked-in' (Unruh, 2000; Seto et al., 2012), making it necessary to look beyond the city to unravel path dependencies. Lefebvre (2003:57) contended that cities have exploded out of the historical space of the city to create worldwide urban society, erasing the qualitative differences between the city and the countryside (in Angelo and Wachsmuth, 2015), enlisting in their metabolisms planetary resources (see the literature on urban metabolism Kennedy et al., 2007; Pincetl et al., 2012).

The concepts of 'city' and 'urban' are slippery given their complex, differentiated and mixed land uses. Nevertheless, cities are deeply interdependent with hinterlands that reshape them as they shape and reshape themselves. While cities have always depended on hinterlands, as McNeill explained (2000) the use of fossil fuels enabled a far wider, deeper and more transformative capacity to do so. Although cities cover only 2 percent of the world's land surface, they consume over 75% of Earth's material resources (UNEP, 2013). For growing cities, large scale infrastructures are necessary, demanding materials. Müller et al. (2013) estimated that, if the developing world proceeds to construct cities with the same intensity and infrastructure observed in developed countries, the potential carbon cost is more than a third of the world's cumulative carbon budget to 2050. Between 2011–2013, China consumed more cement (6.6 gigatons (GT)) than the U.S. did between 1901 and 2000 (4.5 GT) (Smil, 2014). According to a recent

[1] *Anthropocene* as a new geologic era remains a contested concept. The author acknowledges the debate regarding its starting point and/or its legitimacy. Ruddiman, 2007, for example, posited that anthropogenic effects on greenhouse gases and global climate countered 'natural' planetary cooling due to early farming. At the same time, carbon dioxide (CO^2) monitors, ice cores and other sampling methods, have captured an unmistakable uptake in greenhouse gases with the burning of fossil fuels and industrialization, accelerating after World War II. In this paper, the author uses the term "Anthropocene" to draw attention to human-induced global environmental changes that are accelerating and likely irreversible, including groundwater depletion, CO^2 in the atmosphere, disappearance of productive agricultural lands, entire animal species and more.

United Nations Environment Programme (UNEP) assessment of global material flows, global material use has tripled over the past four decades with annual global extraction of materials growing from 22 billion tons in 1970 to 70 billion in 2010 (UNEP, 2016). These extractions exist as urbanization impacts. Accounting for the quantities and types of flows helps shed light on how 'cities' influence global environmental change, shaping the 'Anthropocene,' and externalize environmental and social costs. Going forward, a need exists to account for the expended energy and materials embedded in urban areas and their impacts.

Extended networks of power and water also serve the needs of cities. Data centers, for example, account for 2% of global greenhouse gas (GHG) emissions, a figure expected to triple in the next decade. Though not many are in 'cities' (Bawden, 2016 in Wachsmuth et al., 2016), they serve city needs. As Wachsmuth et al. (2016) pointed out, many GHG emissions inventories look at emissions only from in-city activities. As a result, the off-shoring of manufacturing of numbers of activities, including of consumption goods and the emissions resulting from that manufacturing, are not taken into account in the consumption of the city. For example, nearly 80% of the GHG emissions from the city of San Francisco are produced outside the city. Such cities seem favorable in their GHG emissions accounting as a result. Water systems that draw water from afar are similarly overlooked in the definition of cities, and are being built world-wide, causing local social environmental and environmental disruptions.

A need exists to develop better definitions of 'city' and 'the urban' in order to accurately quantify their specific impacts. Urban areas today are key to global economic development and are dependent on flows of resources. These areas contribute more than 90% to global gross value (Seto et al., 2012) and consume between 56% and 76% of global energy produced to do so (Marcotullio et al., 2013; IPCC, 2014). Both population size and affluence (for example, gross domestic product (GDP)) are significant influencers of urban GHG emissions (Kennedy et al., 2009a,b; Marcotullio et al., 2013; Solecki et al., 2015) and Earth transformation. As a result, much recent work focuses on how *cities* might mitigate their impacts and better prepare for climate impacts through adaptation and mitigation strategies. An increasing number of groups and organizations emphasize getting cities to improve their performance in these sectors, including the C-40 cities organization partly funded by the Bloomberg Foundation, Carbon Neutral Cities Alliance (CNCA), International Council for Local Environmental Initiatives (ICLEI), Asian Cities Climate Change Resilience Network (ACCCRN), Urban Climate Change Research Network (UCCRN), and the UN Habitat Cities and Climate Change Initiative (CCCI) among others These and other organizations have rallied around good practices, creating plans for transitions to reduce emissions and improve resilience. The plans show that there are economic benefits of climate action involving green growth strategies relying on best tools and practices (OECD, 2010).

2.2. Cities as global growth generators

The role of cities in global economic growth over the past two decades represents a substantial historical shift (Storper, 1995; Sassen, 2000; Scott et al., 2002; Derudder et al., 2012; Pain, 2012; Rossi, 2017). Previously, cities were leaders of national economic growth, as nations engaged in policies and subsidies for regional economic development. These policies included investing in less economically developed areas to achieve balanced nation-wide growth and prosperity (for example, the Tennessee Valley Authority). Now, cities are engaged in world-wide systems of economic exchange and financial flows (Pain, 2012). The growing importance of cities is conjoint with globalization in the late twentieth and twenty-first century. While the shift of humanity towards urban living could likely have occurred without globalization, globalization has accelerated the growth of cities in the contemporary era. Globalization contributed to a "rescaling . . . in which national domination of social practice is dissipating upwards to the global and downwards to the local" (Scott, 2001b, p.183). As a result, city regions are "active agents in shaping globalization itself" (Scott, 2001a, p.11), increasingly, the entities that nation states rely upon for economic growth. The growth of cities and the intensity of resource use directly contributes to the acceleration of climate change and impacts on Earth systems, hallmarks of the 'Anthropocene'. Clearly, many complex factors contribute to this issue, but cities generally provide higher income, rates of consumption and economic growth for their residents, all of which require resources. Beyond mere resource use, proxies related to innovation and new wealth creation (numbers of patents, number of employees in research and wealth per capita), scale with city size (Bettencourt et al., 2007 in Ernston et al., 2010). According to Bettencourt, a key driver behind urban growth is innovation, as well as economics of scale in energy consumption, leading to more efficient use of resources per capita. Cities are attractive due to the tight linkages to economic value creation, and therefore, jobs, better services such as access to medical professionals and schooling. This attractiveness, of course, depends on levels of development. For example, infant mortality shows a negative association with percent urban but increased mortality with slums as percent urban (Vlahov et al., 2007). Living conditions matter in cities for health outcomes. Thus, urban growth engenders paradoxical and contradictory tensions – generally eroding ecosystems (Ernston et al., 2010) and dependent on increased fossil fuel use, but also providing improved living conditions for humans and more efficiency.

The prominence of cities as global economic and environmental agents emerges from a constellation of changes. These changes include globalization accompanied by the rise of new forms of government and governance that have – in the west – been devolving *economic* responsibilities increasingly to localities. Widely referred to as neoliberalism, a term that has multiple meanings, this is a new economic order that emerged in the late 1970s and took hold in the 1980s (Rossi, 2017). It included the deregulation of economies, free trade agreements, the creation of the World Trade Organization in 1995, and the application of and diffusion of a market ethos and discipline (Pinson and Journel, 2016). The changes that occurred since the late 1970s deeply impacted urban landscapes, policies and governance. Paradoxically, perhaps, it has not necessarily involved a devolution of authority to cities themselves at the same time (Jessop, 1998; Jonas and Moisio, 2016). That is, a qualitative change is occurring today, making city regions integral to the 'competition state' (Cerny, 2007 in Jonas and Moisio, 2016) but within a context of the state orchestrating, steering and sustaining policy and governance processes (Jessop, 1998 in Jonas ibid). As the paper outlines below, the systems of financial accumulation that center on state and governance processes operating around urban regions (Jessop, 2016 in Jonas and Moisio, 2016) play significant roles. Some commentators have labeled this 'the special fix,' using cities and city regions to drive growth (Harvey, 1989; Brenner, 1998). They are strategic spaces for national states to participate in the global economy (Jonas, 2013) and thus how they are regulated and governed is of state (or national) interest.

2.3. Cities and financialization

A central feature of neoliberalism in the west is financialization. Financialization involves the increased role of financial motives (the belief that financial profit is the value system that creates economic growth), financial markets, financial actors and financial

institutions in the operation of domestic and international economies (Epstein, 2005) and in managing urban assets. It involves the curtailment of distributionist programs aimed to provide government funding for programs such as housing, welfare and infrastructure, toward a reduction of taxes to foster business growth and many more policies (Hackworth, 2007). Neoliberal ideas greatly influenced social policies from the early 1980s to the mid-1990s. They infused environmental policies as well, leading to market based approaches such as cap-and-trade and monetizing ecosystem services such as wetlands, trees in cities, and green infrastructure. The concept of neoliberalism has been critiqued as too Anglo-centric and is certainly more complex that what has been portrayed here. The shift in economic and governmental policy toward market-driven approaches, however, fostered greater free trade and globalization of economic activities. This shift was accompanied by a substantive change of role for governments and cities. The market ethos led to pressures for cities to become economically competitive through growth. National governments were seen as too big and slow, paralyzed by political gridlock, so, of necessity, cities became the leads. Studies have shown the positive relationship between cities and national growth and national economic development in addition to the disproportionate contribution of urban areas to national income and product (Polèse, 2005). This is largely explained in terms of agglomeration economies, which means that there are productivity gains derived from the geographical clustering of firms and people (Polèse, 2005). Given the economic importance of cities, this may lead to greater national investment in city infrastructure to support that economic activity, skewing investment toward the productive regions, and not to less competitive cities. In the United Kingdom (UK), for example, around 42% of the funds listed in the National Infrastructure Pipeline are attributed to a single English region, of which more than half are directly attributable to London – 22% of the 42% (Sheffield Political Economy Research Institute et al., 2015). These investments come at a time of fiscal austerity in the UK and many parts of the world and targeted investments toward specific competitive cities at the expense of other city-regions in that same country.

Retreat of federal or national-level leadership in many countries of the west, and budgetary pressures on national governments in developing and BRIC countries, have led cities to assume greater leadership for their own economic well-being. They have also become the policy laboratories for action on sustainability, climate change mitigation and adaptation (Evans et al., 2016; OECD, 2010). Due to their size (relatively circumscribed) and their large-scale impacts, cities are now seen as the places where impactful changes can best be made. As the CNCA explains, cities have the ability, through local regulations, urban services, city purchasing, through the implementation of eco-efficiency, smart systems, development of clean tech, and CO^2 accounting, to affect the intensity of future global climate change, and to mitigate their own environmental impacts. Since cities account for nearly three quarters of GHG emissions, the argument goes, through their reinvention, putting them on a path to a zero-carbon future, the most destructive effects of climate change will be avoided.

Thus, cities play a significant role in the 'Anthropocene', both as drivers of climate and Earth systems change and potential sites of remediation.

3. The role of cities in addressing their impacts: from urban sustainability to climate mitigation

This section provides a general overview of the myriad efforts and examples of urban sustainability, and climate mitigation initiatives across the globe. The Brundtland Commission report, Our Common Future (WCED, 1987), set the stage for sustainability thinking, suggesting that a balance between economic growth, social justice and environmental protection could be achieved. It put forward the now famous definition for sustainable development – "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The report contained a brief discussion of urban sustainability, emphasizing the need for an inclusive, democratic process to determine change at the urban level. Concern about human impacts on the environment largely motivated this initiative, but with a concern about inclusiveness and democracy in so doing. In the late 1980s and 1990s, despite knowledge about climate change, the focus emphasized sustainability and sustainable development, without the climate dimension.

During the preparatory meetings for the URBAN21 Conference (Berlin, July 2000) the following definition was developed to define sustainable urban development:

> *"Improving the quality of life in a city, including ecological, cultural, political, institutional, social and economic components without leaving a burden on the future generations. A burden which is the result of a reduced natural capital and an excessive local debt. Our aim is that the flow principle, that is based on an equilibrium of material and energy and also financial input/output, plays a crucial role in all future decisions upon the development of urban areas."*

The urban sustainability agenda clearly articulated the case for cities to lead the way for mitigating human impacts on the environment. With cities the new home for the majority of human populations, the logic is that with the right set of technological innovations, green designs, and participatory initiatives, they can lead toward a more sustainable planet (Beatley and Manning, 1998; Ravitz, 2000; Birch and Wachter, 2008; Yarnella and Levine, 2011; Isenhour et al., 2015). Krueger (2017), however, insightfully noted the origins of urban sustainable development are not found in, nor motivated by, urban concerns, *per se*. Rather urban sustainable development comes out of a larger context of human-environment relationships, specifically to those outlined in the planetary scarcity and growth debates of the 1970s and 80s. Urban sustainability may have been a logical expansion of the concept, but hardly operationalizable since cities have always relied on distal resources.

Currently, hundreds of city and regional sustainability plans across the world have been created. The plans guide cities to reduce resource use and pollution and mitigate their environmental impacts through greening, better transportation policies, and reduction of water and energy inputs as well as waste generation. More recently, there has been a merging and blending of plans for urban sustainability and climate action planning. Both raise complex questions about boundaries – where the city begins and ends – and how it might curtail its larger impacts.

For the Brundtland Commission, sustainability included human (and economic) development and values such as the respect of different cultures, gender equality, participation in decision making processes, access to education and health services. These concerns have been less central to many city sustainability and climate plans, triggering, more recently, the rise of a climate justice movement. More common are plans for urban greening, the harnessing of nature in the city itself, as well as for energy transitions toward low carbon sources of energy (Bulkeley et al., 2011).

The CNCA (https://www.usdn.org/uploads/cms/documents/cncaframework_deepdecarb.pdf, released December 2015), described above, provides a good example of an initiative that shows the overlap between urban sustainability and climate mitigation initiatives. This initiative calls for transformative changes in energy systems, transportation networks, commerce centers,

neighborhoods and even governance practices. The CNCA considers these changes essential to meeting the challenge of cutting GHG emissions by at least 80% by 2050 — the goal of the global cities that make up the CNCA. Planning documents outline and suggest ways for cities to decarbonize imported electricity and increase local production of renewable energy while reducing demand. The plans emphasize changing urban transportation systems to shift to a radically different mode share, including modern, affordable, accessible mobility choices. The CNCA also advocates for creating a path for the 'market dominance' of clean technologies and fuels, as well as the creation of complete, connected, regionalized mobility systems and the reduction of solid waste. The initiative gives less emphasis to the third leg of the stool – equity. Notably, the Alliance is staffed by the Urban Sustainability Directors Network (USDN) in partnership with the Innovation Network for Communities (INC) and C40 Cities Climate Leadership Group (C40), and is supported by The Kresge Foundation, Barr Foundation, Summit Foundation, Rockefeller Brothers Fund, V. Kann Rasmussen Foundation, MacArthur Foundation and Bullitt Foundation – non-state actors. The involvement of non-state actors has become a common feature of governance as local and state funding has declined. It is an intrinsic feature of neo-liberalism.

3.1. Obstacles for cities: scalar dependencies and system lock-in

Aside from funding, other scalar dependencies pose obstacles. Cities rely on systems that function and interconnect at global, national, regional and urban scales. Such systems are nested, tiered and often integrated and/or interdependent: they are constituted spatially (Bridge et al., 2013) and regulated at different governmental levels as well. The energy sector provides a highly illustrative example. Cities throughout the globe depend on geopolitical and geo-economic factors associated with the multinational ownership of oil, gas and electricity companies whose transactions are regulated by international treaties and conventions, make it apparent that transitioning to low carbon futures at the city-level implies deep transformations, either in ownership of energy systems, or in regulatory regimes at the international scale. Further, the intertwined system of the production and use of conventional fossil fuels poses significant infrastructure change challenges that can also apply to other important infrastructures deployed in cities, but embedded in nested scales (Cousins and Newell, 2015).

Electricity grid and pipeline infrastructure networks transmit and deliver these resources, overseen by a complex network of institutions. In the United States, for example, electricity grids are regulated at multiple levels of government. At the macro level, the Federal Energy Regulatory Commission (FERC), responsible for rates and service standards for most bulk power transmission, licenses hydro and nuclear power plants and is responsible for reliability standards set by the North American Electric Reliability Corporation (NERC). Regional entities then take regulation to the next geographical scale. The Western Electricity Coordinating Council (WECC) promotes bulk electric system reliability in the Western Interconnection area. Its responsibility is to balance sources of power from regional providers such as dams and power plants. States themselves may or may not have entities that coordinate power distribution and reliability, but then there are state, regional and local utilities that nest into this larger system. Some of the utilities are private, some are public, but they are all tied into an electricity grid whose power cascades down to buildings through a well-developed and organized grid system (Pincetl et al., 2016).

Within this system, the transition to a low carbon, or zero carbon electricity system is, technologically, politically and economically hinged to the regulation of the grid at these different scalar levels. How the FERC, NERC, WECC and state regulatory agencies decide tariffs, fees, rates and develop other regulations, deeply influence the transition, potentially precluding alternatives. The requirements for certain grid capacities and structure, for example, may bar or slow a low carbon future because renewables cannot be integrated into the existing system. This example, one of many (as for example the role of financial circuits in transitions to alternative infrastructures or state-level policies that impede regional collaboration), illustrates the dependence of cities on larger scale systems they do not control.

System lock-in and dominance by large socio-technical systems with major embedded historic investments must be factored into any analysis of city/urban initiatives to mitigate GHG emissions (whether power supplies, supply chains that support their metabolisms, or other resource appropriation). The South-to-North water transfer project of the Chinese government, for example, is a mega-project that is channeling fresh water from the Yangtze River in southern China to the industrialized north through three canal systems, including to Beijing and Tianjin. This project is estimated to displace over 300,000 people to urban areas. Long term, sustainability, not only in terms of the ability of the Yangtze to continue to be a water source in the place of origin, but for Beijing and other cities, is uncertain. Beijing is a recipient of this project; it is also the nation's capital. Supplying water to the capital is politically and economically important even though the long-term consequences for the hinterlands may be significant (Cartier, 2015). Cities are, due to structuring decisions, interdependent with their hinterlands, which then may restrict the ability of cities themselves to change course. In addition, the Chinese government determines where further urban development will take place and establishes free trade zones (for example, in Shanghai). A continuum exists from the Chinese situation to countries with not much governance – as found in very weak state countries in Africa – and where urban policies may be more directly linked to international development agencies. Overall, however, cities are enmeshed in complex networks that deeply affect their ability to innovate.

City change is contingent on political, economic, and social rules, codes, conventions, treaties and other structuring frameworks that exist at multiple, interacting and interdependent scales. It is not that cities are powerless in affecting their own destinies as discussed above; it simply means that they are constrained and it is essential to catalogue, measure and describe their structural situation. The degree of constraint will vary from country to country, as will the legal purview of cities. No city is an island, and the limitations imposed by the wider system must be understood for cities to be able to affect not only the direction of climate change, but also to reorganize themselves.

Philanthropy and carbon neutral and sustainable city plans fall short of addressing the governance of cities or how to improve revenues where state subsidies and infrastructural investments have been curtailed under 'neoliberalism.' Plans do little to reverse the deepening inequality both within and between cities, particularly in the west. For other places, such as China, where the state has supported and indeed, directed, urban growth in multiple and complex ways including land policy, such factors may not be in play. In China, the emphasis is on *urbanization*, and in the longer term, it is not clear whether it will reduce overall Chinese environmental impacts as modelers such as Bettancourt et al. (2007) have shown as a global trend.

3.2. The question of justice for cities in the 'Anthropocene'

Much work remains toward understanding how social justice or equity in an urban context relates to climate or sustainability. Is the

issue of inequality one of urban economic structure? Is urban inequality a derived outcome of national social and economic policy? Can it be redressed through sustainability or climate policy? These issues are significant for cities in the 'Anthopocene' given rising income inequality and the challenges facing cities in developing countries (Davis, 2006). Decades of development planning have not redressed the relentless inequality of megacities and the vulnerability of the poor who end up building in flood plains, on precarious hill sides and more (Davis, 2006; Isenhour et al. 2015). As Davis pointed out, part of the neoliberal shift are the structural adjustment programs of the World Bank and the International Monetary Fund which have required borrowers to cut back on public expenditures and taxation. Much the same approach was recently taken by the European Union (EU) toward Greece and Portugal. Climate justice is a critical aspect of the challenges facing cities in the 'Anthropocene' as it is clear that with income inequality comes more vulnerability for the poor.

According to Bulkeley et al. (2014a), the operation and constitution of [global political and economic] power must be engaged through the "socio-materiality" of cities. This involves recognizing different forms of inequality and the ways in which climate change might affect structuring contexts such as infrastructure (Bulkeley et al., 2014b). Factors such as carbon dependence in land use patterns, energy systems, transportation infrastructure and local, state and national politics also greatly shape the ability of localities to influence their futures due to lock-in. Further, cities and regions have differential incentives, capacities and capabilities to reduce carbon emissions and invest in a low-carbon future (While et al., 2010).

Not only will significant reductions in carbon emissions require governments to find new ways of engaging with citizens (Dobson, 2003 in While et al., 2010), but many policies and programs needed for such a shift are likely to transcend the city. These programs will likely require funding beyond the fiscal capacities of cities themselves. As McDonald et al. (2014) discussed, financially limited cities continue to be the least able to finance needed infrastructures. Poor cities are the most challenged. But all cities are only able to meet their needs relative to a larger context of international and national levels of government and governance, fiscal regimes and economic agreements, hierarchical regulatory policies and interlocking scales of energy and materials flows and infrastructures. With reduced incomes due to financialization, and increasingly stagnant economic growth, the costly building of low carbon infrastructure transcends individual cities' capacities. Current global economic stagnation and constrained national budgets raise the question of how cities will be able to finance these systems. McDonald et al. suggest that cities in the least developed countries should be targets for international aid and investment, but international aid institutions and investment funds have suffered budget cuts as Davis (op cit) pointed out. Funding change is a conundrum in a neoliberal era.

4. Going forward: coupled analyses

How to, then, understand, quantify and address the complex and contradictory role of cities in the Anthropocene? Their processes and growth are undergirded by social, cultural, economic and political forces, as outlined above, but their impacts are biophysical as they are dependent on Earth systems and resources. The challenge is to better understand both – the social factors and the biophysical impacts – and to then develop coupled analysis, showing feedbacks and interactions (Liu et al., 2015).

While much work has documented Earth impacts of human activity, more needs to be done on cities specifically. Urban metabolism analyses have helped to better identify and quantify the flows of resources and materials into cities and, in some rare cases with enough granularity, to develop specific policy responses for curbing flows (Newman, 1999; Porse et al., 2016; Kennedy et al., 2011; Pincetl et al., 2015a,b). Waste flows have also been characterized, although the quantification of flows has been hampered by lack of specific data at various scales and in different places (Murphy et al., 2013). To date, urban metabolism analyses have been patchy and opportunistic as data availability is a major barrier. Characterizing city resource use, greenhouse and other climate change gases, and the patterns of use across urban regions depends on sufficient data. Using urban metabolism to discover inequalities across urban landscapes such as electricity and natural gas use, water use and building infrastructure among many other characteristics is also insufficiently explored (Chester et al., 2012).

Industrial ecologists have contributed pioneering work in this field, but lack of sufficient and granular data is limiting. In addition, better agreement on methods and on the overlap and potential integration of methods could help put together material flows analysis, life cycle and supply chain analysis and ultimately urban metabolism (Kennedy et al., 2007, 2006, 2011; Pincetl et al., 2015a, b). The biggest challenge, however, is developing the institutional/regulatory regime counterpart to the material quantification of urban metabolism studies. Yet, ability to identify organizational structures at various scales and the ways in which they constrain and orient cities and urbanization would greatly improve understanding of how cities are involved in environmental change. This knowledge, coupled with quantifying the flows of Earth materials, would also increase understanding of the potential role of cities in mitigating human impacts. The structure of markets and free trade, the organization of credit and the ability of cities to access funding, environmental regulation and rules for international loans and repayments, all impact how cities maintain themselves and the urbanization process. They shape the social conditions under which people live in cities and how inequality is structured. The organization of different governmental systems, their rules, codes and procedures, the nested and tiered levels of authority and public participation also shape how cities and the hinterlands they depend upon, function and their ability to change. These are deeply linked to the constraints for sustainability or climate agendas. Better data, both on flows and institutional/regulatory regimes, could lead to targeting policy shifts that lessen urban environmental and climate impacts and do not exacerbate inequality.

Research on human systems and how they organize remains all too often detached from their environmental impacts and exclusive to the human systems themselves; this is a classic problem in disciplinary focus. But understanding how cities are intrinsically embedded in Earth systems change requires a focus on complex interactions, the feedbacks of current fiscalization and regulations as well as how economic competition is concentrated in cities. Thus, for example, the flow of coal for urban power supply from Australia to Japan, the EU and Brazil does not simply reflect abundant Australian coal supplies. It is also constituted by the financial flows behind the flow of coal (). How these are constituted and function are equally important to understand and document as they serve as drivers of the system. To address this trade-circuit that has substantial climate and environmental impacts, it would be useful to know how the flows were made easier and more economic – what social institutions were involved. The quantification of CO^2 impacts of coal burning can be quantified, yet the quantification and description of the human systems that produces these flows remains sketchy.

Such a research agenda is, admittedly, daunting, complex, and most of all, interdisciplinary (Bostic and Howey, 2017). Socio-economic and political drivers operate at different scales, as shown above, and their organization differs across the globe. Yet, relying on quantification of impacts alone will not provide insights into the

hierarchy of drivers, their scalar relationships, and the place of the 'city' within global change.

5. Cities and the 'Anthropocene'

Consensus is growing that Earth is moving into another epoch, called the 'Anthropocene.' out of the Holocene which lasted about 12,000 years. One characteristic of the Holocene was its relatively stable climate, which produced predictable and consistent conditions for life as we know it today. It was distinguished by certain biogeochemical cycles, including the hydrologic, nitrogen, phosphorus and carbon cycles, favorable to human life, that our new, human induced epoch is disrupting. This will have yet untold consequences on many aspects of life on Earth as well as human activities, from agriculture to urbanization and energy use. It might be useful, then, to consider more deeply how humans as planetary agents, are ultimately inextricably interdependent with these Earth forces and the life forms that have ensued.

With humans now predominantly city dwellers and the primary agents in climate change, cities are the places to start examining the future. What are cities for? This question is rarely asked but is assumed. The question, however, opens up opportunity to explore their function and how, humans as primarily urban dwellers, wish to live in them. Although such a question relates to social values and norms, it is critical to the function of cities going forward, and to the quality of life of urban residents.

While it is not evident how cities can transcend the global entanglements and path dependencies upon which they depend for their sustenance, their course today is clearly unsustainable for current planetary life. Vast supply chains bring Earth materials and resources to cities which cities then embed in their infrastructures at an ever-growing rate to keep up with urban populations. Beyond providing humans urban infrastructures of all types, cities today have focused on creating wealth as the pathway for their survival and residents' well-being. This increased wealth is translated into increased consumption and daily life improvements for many people in developing countries. Amartya Sen (1999) linked economic opportunities, political freedoms, social facilities, transparency guarantees and protective security as crucial instrumental freedoms. But as Chakrabarty (2008) described, though richer and mainly Western nations have played an historic role in emitting GHG emissions, wealth and individual well-being created in cities continues to be built on the burning of fossil fuels and extraction of resources.

Insufficient recognition of some of the conditions for the existence of institutions central to the idea of modernity, such as the generosity of the Holocene, is remarked upon by Chakrabarty (2008). He pointed out that historical contingency and accidents have led humans to industrial civilization (p. 217). He echoed E.O. Wilson's recommendation that humans must better understand themselves as a *species*, and that this will help to visualize human well-being (1996). Is industrial civilization – and cities as people have developed them – the sole way to achieve human well-being? Humans need to go beyond mechanistic plans for making cities carbon neutral that are now formulaic and limited, to consider what they wish to achieve as a species relative to ourselves, and as urban residents.

This will involve stepping back and considering how humans are connected to the history of life on this planet, different life-forms, and planetary shifts. Such shifts may open up alternative paths, away from cities as workshops of the world, toward cities as the home of humans where well-being is sought. The trajectory of humans as a species is entirely dependent on Earth systems. The unalterably disrupted biogeochemical patterns and systems, largely through the use of fossil fuels that have enabled today's cities, calls for rethinking the evolution of cities going forward. This includes grappling with the fact that cities are not entirely of their own making and that larger global networks must be examined to reduce impacts.

Jamieson (2014) argued for a need to develop *ethical* means to live with climate change, while working to mitigate the worst long term impacts, an ethics for the Anthropocene.' This task involves recognizing that, even in the era of the 'Anthropocene,' humans are entirely dependent on planetary systems, resources and life forms beyond the human. Jamieson called for the idea of nature as a partner. An ethics for the 'Anthropocene' would rely on nourishing and cultivating particular human character traits, such as cooperation, simplicity and mindfulness. This contrasts with efficiency, growth and GDP. Foundationally, a new ethics is based on the realization that humans find meaning in their lives in the context of human inter-relationships, with other animals, the rest of nature and the world generally (Jamieson, p 184).

Living well in cities is about imagining what is important for joy as well as material well-being. It is about reflecting and debating how much is enough and what work looks like. It also includes reimagining agriculture and the role of proximate hinterlands. Perhaps an exercise in thinking about how systems could be organized without fossil fuel energy and including full cost accounting might trigger ideas about how to change cities beyond the types of laundry list recommendations that have become so prevalent. Does it involve, as Graedel (2011) evocatively suggested, curtailing resource inputs into cities and turning to the riches already embedded in cities and their waste flows, and mining them? Recovery, separation, sorting and processing are all work, work to reuse and repurpose that requires skill, inventiveness and creativity. Many cities now have large amounts of embedded materials. "Every kilogram recovered and reused displaces a kilogram that must be mined and processed with all the environmental, social and economic implications those actions entail (pg. 49)." This would involve improving designs so products could be mined for their materials, spurring innovation. Full cost accounting would make these reused materials very valuable as the virgin ones ought to reflect the impacts of their extraction and often, scarcity.

Tools for new accounting exist: life cycle analysis, material flows analysis, urban metabolism. These can help in revealing how cities are made up of Earth resources and the impacts of city waste streams. But more challenging is to imagine a new set of global relationships that are about providing people with what they need to live well, that is not consumption based and recognizes nature as partner. Jobs and GDP today are predicated on consumption. What other ways can cities be organized for human well-being is then the question for the twenty-first Century and the era of the 'Anthropocene.'

6. Conclusion

The research agenda for cities in the 'Anthropocene' is multi-dimensional and complex. It requires much greater and deeper collaborations among the different biophysical and social sciences so that connections can be made that elucidate how human activities affect Earth systems and the feedbacks that ensue, including on humans themselves. How humans organize their activities, and the prevalent belief systems and social organizations that govern those activities, structure how cities grow and function. These are topics that need greater coupling to human impacts on biogeochemical cycles. Global economic forces and the growth of cities are conjoint in this era. They are also inextricably dependent on cheap fossil fuels that are the main driver of climate change. It is that coupling that must be better unpacked due to the many impacts this juggernaut creates. Cities are the nexus that binds it all together. Therefore, a need exists for greater

investigation of teleconnections between cities and their hinterlands by linking just material/resource flows. The impacts of those flows and the financial and institutional arrangements that facilitate and direct them must also be explored as Liu et al. (2015) laid out. The role of cities as the new habitat of humans and drivers of Earth change, is intrinsic to that investigation. At the same time, such investigations go beyond quantification and description. Better understanding of this complex coupled system will not necessarily lead to change. It is also necessary to develop ethics, ethical precepts to nourish certain human traits such as cooperation, simplicity and mindfulness, of treating nature as a partner on the planet, and treating fellow humans with dignity. Such investigations are about pathways toward uncoupling economic growth from well-being (recognizing the need to greatly improve living conditions in many cities of the world) and moving toward healing, and ultimately of rethinking the role of cities in the twenty-first century.

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