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Intersections of Jane Jacobs' Conditions for Diversity and Low-Carbon Urban Systems: A Look at Four Global Cities

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Abstract

Countless cities are rapidly developing across the globe, pressing the need for clear urban planning and design recommendations geared towards sustainability. This article examines the intersections of Jane Jacobs' four conditions for diversity with low-carbon and low-energy use urban systems in four cities around the world: Lyon (France), Chicago (United-States), Kolkata (India), and Singapore (Singapore). After reviewing Jacobs' four conditions for diversity, we introduce the four cities and describe their historical development context. We then present a framework to study the cities along three dimensions: *population and density*, *infrastructure development/use*, and *climate and landscape*. These cities differ in many respects and their analysis is instructive for many other cities around the globe. Jacobs' conditions are present in all of them, manifested in different ways and to varying degrees. Overall we find that the adoption of Jacobs' conditions seems to align well with concepts of low-carbon urban systems, with their focus on walkability, transit-oriented design, and more efficient land use (i.e., smaller unit sizes). Transportation sector emissions seems to demonstrate a stronger influence from the presence of Jacobs' conditions, while the link was less pronounced in the building sector. Kolkata, a low-income, developing world city, seems to possess many of Jacobs' conditions, while exhibiting low per capita emissions - maintaining both of these during its economic expansion will take careful consideration. Greenhouse gas mitigation, however, is inherently an *in situ* problem and the first task must therefore be to gain local knowledge of an area before developing strategies to lower its carbon footprint.

Introduction

Although it was written more than 50 years ago, Jane Jacobs' seminal work, "The Death and Life of Great American Cities" (Jacobs, 1961), remains an insightful and important text to this day. Jacobs is seen as one of the key proponents of shifting away from modern urban form. Indeed, she was a staunch critic of master planning, suburban expansion, and single-use planning schemes, which had been pioneered by Ebenezer Howard and Le Corbusier and championed to varying degrees by a number of influential 20th century designers including Lewis Mumford and Frank Lloyd Wright (Jacobs, 1961; Breheny, 1996). Jacobs' opposition to these approaches stemmed from her view that cities are self-organizing complex systems and should be encouraged to develop according to micro-scale social and market forces. The current shift towards more compact, walkable, transit-oriented, and mixed-use developments suggests that urban decision makers have accepted her (and her like-minded contemporaries') theories on urban growth and decay.

A great deal of overlap exists between prominent notions of urban sustainability and Jacobs' ideas for creating vibrant cities. For example, in the development of Litman's (2014) indicators for sustainable transportation, planning objectives such as land use mix, walkability/bikeability, and quality of road/street environments appear alongside per capita transport energy consumption and transportation emissions (nitrogen oxides, volatile organic compounds, particulate matter, etc). Moreover, current notions of how to reduce energy demand and mitigate greenhouse gas (GHG) emissions also align with Jacobs' ideas of a diverse and economically successful urban area (Seto et al. 2014; Otkay, 2012; Kennedy, 2011; Talen, 2011; Jabareen, 2006). Indeed some quantitative analysis has been conducted in this regard; for example, Ewing et al (2013) found that mixed-use developments built to LEED-ND (Leadership in Energy and Environmental Design - New Development) standards have been estimated to reduce per capita vehicle-kilometers traveled (VKT) by 24-60%. Porter (2009) suggests that a 12% reduction in national transportation-related GHGs through aggressive implementation of compact land use approaches (i.e., transit-oriented development). In addition to the GHG savings, considerable cost savings can be associated with these types of approaches, with Mashayekh et al. (2011) suggesting that compact, mixed-use brownfield development save residents \$3,500 - 4,000 USD per year in driving time, fuel, and external air pollution.

Established cities face substantial challenges in reducing their GHG emissions, with current projections for low-carbon technology adoption being insufficient to meet long-term mitigation targets (Mohareb and Kennedy 2014). This inherently suggests that behavior (i.e., energy demand reduction) approaches to mitigation are also important, many of which are underpinned by changes in urban form and spatial planning (Seto et al. 2014). In this article, we restrict our analysis of urban sustainability to this important issue of low-carbon urban systems. There is a strong correlation between energy demand and GHG emissions, since fossil fuels provided an estimated 86% of energy demand

within cities in 2006 (IEA, 2008; see Table 8.2, p.183). As a result, urban GHGs and urban energy use are henceforth used interchangeably in the context of their quantification and mitigation. For this work, we argue that Jacobs' ideas represent a *means/process*, in the form of planning objectives, to achieving reductions in urban GHG emissions. Central to Jacobs' conception of what makes a functional, vibrant city, are the four "conditions for diversity" (these will henceforth be referred to as "Jacobs' conditions", as a shorthand), which we will review later.

Jacobs' conditions, however, are not universal in their application, and as we will see, are manifested in many different ways. It follows that dealing with urban GHG mitigation is inherently an *in situ* problem (i.e., context-sensitive), requiring tailored solutions for each city; approaches to reduce GHG emissions in Chicago (US) would not necessarily work in Kolkata (India). Analyzing the commonalities between low-energy/low-carbon cities on the one hand, and vibrant and diverse cities on the other hand is paramount, as countless cities from emerging countries are rapidly expanding and are faced with the challenge of developing in a way that both enhances economic prosperity while keeping adverse environmental and social impacts low.

In this article, we look at the profiles of four cities worldwide that vary vastly in their urban development, and that either have benefited or can benefit from adapting or nurturing Jacobs' conditions. These cities are Lyon (France), Chicago (United States), Kolkata (India), and Singapore (Singapore). They are selected because they developed in different eras and under different conditions (economic, climatic, and political), which has resulted in unique urban forms and varying degrees of adherence to Jacobs' four conditions. The breadth of comparison provided through the selection of these differing urban contexts provides insight into individual cities' unique challenges in mitigating their climate impacts, as well as the different ways Jacobs' conditions are exhibited. Given the differing positions in their stage of development and the history of their growth, the challenges these cities face in reducing GHG emissions can be instructive to a broader urban audience when considered together. Moreover, the authors have personally lived in these four cities, which enables us to discuss certain features that can be hard to measure (although our focus is primarily on quantitative analysis).

The article is structured as follows. First, Jacobs' conditions for diversity are reviewed. Second, the four cities are introduced, and their individual histories are discussed. Third, the framework for comparing four world cities against Jacobs' conditions is detailed, which is based on three dimensions: Population and Density, Infrastructure Development/Use, Climate and Landscape. Finally, a discussion of the perceived intersection of Jacobs' conditions and low-carbon cities is presented. Through the comparison of the four urban profiles, the purpose of this paper is to relate Jacobs' conditions with urban GHG mitigation and determine how cities can further learn from Jacobs' conditions to substantially deviate from a development path that exacerbates climate change.

Jane Jacobs' Four Conditions of Diversity

Central to Jacobs' (1961) description of what makes a city (or its component neighborhoods) successful is an "intricate and close-grained diversity of uses that give each other constant mutual support" (p.14). Essentially, a well-functioning urban space allows continual opportunities for a variety of different uses and types of interactions; this provides it with safety ("eyes on the street"), economic activity, and general vibrancy throughout the day. Jacobs' work embraces urban complexity, which is groundbreaking, as it demonstrates that urban planning provides an application for what was a new science at the time. In order for a city to be sufficiently diverse (and its function sufficiently complex), four conditions of diversity must be present:

1. Multiple uses, encouraging pedestrian traffic that *persistently* uses streets for a variety of reasons, and for as many hours of the day as possible;
2. Short blocks to find different paths, allowing exploration en route to any given destination;
3. Mixture of building ages, so that differing rents can be charged, allowing for tenants from a broader economic spectrum;
4. Sufficient density of people, both residents and non-residents, using the streets for a multitude of reasons.

The first condition focuses on the ability for areas of cities to attract people operating on different schedules, so that each successive/overlapping wave of users can provide the services that residents and visitors inherently provide for vitality and security; specifically, these services include driving economic activity and delivering indirect neighborhood policing through their presence ("eyes on the street"). Users are drawn in by *primary diversity* (residences, businesses, certain retail clusters), which then stimulates further economic activity through *secondary diversity* (food service, retailers and other services) that serves the needs of those anchored by primary diversity. This condition naturally favors active transportation modes (walking and cycling).

The second condition for diversity stipulates that in order to ensure a constant flow of pedestrian traffic through an area, small blocks are required. The rationale behind this is that short blocks offer wider options of way-finding for users seeking to traverse a given area. This free flow of street users prevents stagnant zones that are unable to attract passive activity; in the absence of activity, Jacobs suggests economic decay can occur (due to lack of walk-in clientele), thus increasing the potential for crime and decreasing the sense of safety. Short blocks can directly encourage pedestrian activity and discourage car use (Lotfi and Koohsari 2011; Yin 2013; Ewing and Cervero, 2010).

The third condition for diversity suggests that a mixture of building ages offers the opportunity for an assortment of users to occupy them. New buildings and their

associated higher rents typically house high-yield businesses. Jacobs suggests these types of businesses can be limited to chain restaurants/retailers, financial sector operations, and supermarkets. Niche enterprises that would provide novel services to emerging consumer groups require older buildings with lower rents. These buildings are the incubators necessary for small businesses and organizations to develop and thrive. While the implications for sustainability are indirect, this condition promotes heterogeneity (unlike residential sprawl, which favors homogeneity in the physical, economic, and demographic sense); this can further encourage active transportation.

Jacobs' final condition for diversity is one that she suggests is well established: the need for a sufficient concentration of people/businesses to provide the users of a mixture of primary and secondary diversity. It is necessary that density not be pursued for the sake of density alone, and that the other three conditions are considered in conjunction. Examples of urban developments that do not incorporate the other three conditions are single-use housing projects, which can have high density yet fail to produce the desired economic vibrancy because they are standardized monoculture (with respect to use, building age, and character). Jacobs sees the optimal residential density being somewhere between 100-200 units per net acre of residential land.

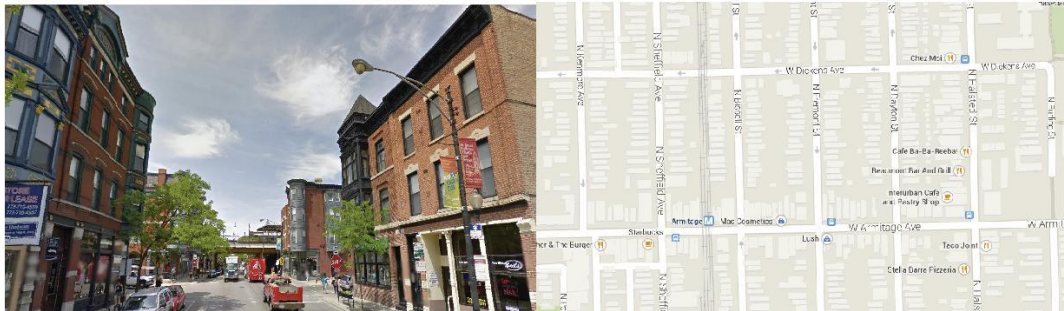
Increased density has two notable impacts on the sustainability of cities: lower transportation energy and lower energy requirements for lighting and space conditioning (i.e. reduced floor area per unit/capita). A further benefit around density promotion is the mitigation of the urban heat island; some studies have shown that low density urban form can lead to a greater heat island effect per housing unit due to a decrease in surface albedo from the conversion of forested areas to lawns (Ko, 2013). This can lead to a reduction in cooling energy demand per unit of housing, building urban resilience to extreme heat events.

The theories Jacobs put forward on the conditions that contribute to a vibrant urban center have been adopted in planning discourse internationally (Grant, 2002; Oktay, 2004; King, 2013). Jacobs herself recognized the contribution made by her theory on generating diversity, stating: "The necessity for these four conditions is the most important point this book has to make" (p.151). Naturally, most cities tend to possess neighborhoods that share some or all of these conditions. Figure 1 shows such neighborhoods for each of the four cities being assessed here (with a sample street view on the left-hand side and a map view on the right-hand-side). Nevertheless, not only are the data that illuminate whether or not Jacobs' conditions are observed in a city difficult to obtain (especially urban-scale data on the mixture of building ages), these conditions can be manifested in many different ways. For example, the urban form providing the population density in Figure 1b) from Chicago is different from that in Figure 1d) from Singapore. The analysis provided below attempts to substantiate a relationship between Jacobs' conditions and urban GHG mitigation through the exploration of four different case study cities.

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a) Lyon



b) Chicago



c) Kolkata



d) Singapore

Figure 1: Neighborhoods exhibiting some or all of Jacobs' conditions. Source for Lyon, Chicago and Singapore: Google Street View and Google Maps; Source for Kolkata: personal photo and Google Map.

The Four Cities

The four cities studied in this article are: Lyon (France), Chicago (US), Kolkata (India), and Singapore (Singapore). In this section, we offer a historical account of each city to provide context for the GHG analysis and comparison to Jacobs' conditions in following sections. This is paramount since a city's development context is an important factor influencing its land-use. Therefore, while arguing for more compact land-use in Chicago, for instance, may be sensible and achievable, it is more challenging in the historically rich city of Lyon, with its UNESCO (United Nations Educational, Scientific, and Cultural Organization) recognized buildings. Similarly, arguing for a mixture of building ages in Singapore is not practical, considering most of the land was developed after it gained independence from Malaysia in the 1960s. Table 1 lists various characteristics from each city that has influenced their growth, urban form and infrastructure development, differing sufficiently to make their comparison with Jacobs' conditions unique. These factors provide each city with unique characteristics, which dictate the types of policies and infrastructure projects that can be carried out locally towards GHG mitigation. Table 2 offers detailed indicators about each city. These indicators pertain to all aspects of this work, including the three dimensions that are discussed below.

Table 1: Characteristics influencing urban form and development in the four cities studied

Characteristic	Lyon	Chicago	Kolkata	Singapore
Year founded	43 BCE	1837 CE	1690 CE	1819 CE
Development Status	Developed economy	Developed economy	Emerging economy	Developed economy
Infrastructure Status	Historic & modern infrastructure	Modern infrastructure	Historic & modern infrastructure	Modern infrastructure
Population Dynamics	Stable population	Stable population	Growing population	Growing population
Governance Status	Established democracy	Established democracy	Recently independent	Recently independent

Table 2: Summary of metrics related to dimensions for comparing Jacobs' conditions for diversity and GHG emissions for Lyon, France

City	Population ¹ (2008)	Population Density ¹ (per km ²)	Decades of Peak Population Quartiles ²	Mode Share ³ (2008)	Average Road Density (km/km ²) ⁴	HDD ⁵	CDD ⁶	Climate ⁷	Hot Months ⁸	Annual Wet Days ⁹
Lyon	1,269,257 (Lyon) 1,516,061 (Grand Lyon)	9,874 (Lyon) 2,460 (Grand Lyon)	1 st -pre-1840 2 nd -1890s 3 rd - 1960s 4 th - 2000s	- Private: 58% - Public: 25% - Walking: 10% - Two-wheels: 4%	9.87	2473	454	Humid Subtropical	0	145
Chicago	2,695,598 (Chicago) 5,194,675 (Cook County)	7,360 (Chicago) 3,414 (Cook County)	1 st -1890s 2 nd -1910s 3 rd - 1940s 4 th - 1970s	- Private: 73% - Public: 10% - Walk: 14% - Bike: 1% - Other: 2%	10.18	3353	654	Humid Continental	0	124
Kolkata	4,496,694	24,306	1 st -1920s 2 nd -1940s 3 rd - 1980s 4 th - 2000s	Public - 82% Private - 2% Walk - 16%	8.22 ¹⁰	96	3244	Tropical wet-and- dry	8	84
Singapore	5,399,200	7,428	1 st - 1960s 2 nd -1980s 3 rd - 1990s 4 th - 2010s	- Private: 29% - Public: 44% - Walk: 22% - Bike: 1% - Taxi: 4%	6.75	0	3571	Tropical wet-and- dry	8	84

¹Sources: Lyon & Grand Lyon (UrbaLyon, 2011), Chicago & Cook County (US Census, 2013), Singapore (SingStat, 2011), Kolkata (Census of India, 2011); ² These refer to the decades in which mark the division of the quartiles of the peak population (25% of peak, 50% of peak, etc.) observed in Figure 2; ³Sources: Grand Lyon – UrbaLyon (2011), Cook County – Journey to work only – CMAP (2010), Kolkata (WWF, 2010), Singapore (LTA, 2011); ⁴See Figure 3; ⁵HDD: Heating Degree Days; ⁶CDD: Cooling Degree Days; Source: www.degreedays.net with an 18°C base temperature. ⁷Köppen Climate Classification; ⁸Months where the average daily maximum temperature exceeds 30°C; Source: worldweather.wmo.int; ⁹>0.1mm of rain, Source: www.bbc.co.uk/weather; ¹⁰Value calculated for 500km² area around the city center as shown in Figure 3 with incomplete data.

Lyon

Lyon is a historical city, developed in traditional European style. It is the capital of the Rhône-Alpes region and is the second biggest urban area in France after Paris, with a city of Lyon population of 0.5 million, a Grand Lyon population of 1.5 million, and a Lyon Urban Area population of nearly 2.2 million (compared with Paris' 10.3 million inhabitants (INSEE, 2015)). Lyon is a typical European city that existed through centuries of cultural and social evolution. Also akin to many European cities, the Central Business District (CBD) of Lyon, “Part-Dieu” (the second largest business district in France, which also houses a major shopping center), is not located in its historical center of the “Presqu’île”. The historical center has turned into a major commercial area (shops and restaurants), institutional area (City Hall, museums), and residential area (with 5-8 story buildings). The original city of Lyon arguably possesses Jacobs' conditions, but the Grand Lyon demonstrates elements of modernist design, especially in the suburbs with its infamous *banlieues* (i.e. low-income neighborhoods with high crime rates). For a compelling historical account of Lyon, see Pelletier *et al.* (2007).

Lyon's population since 1841 (as well as the Rhône Department, an administrative area larger than the Grand Lyon) is presented in the time series in Figure 2. The populations of Lyon and the Rhône Department have been relatively stable with steady increases since the 1840s.

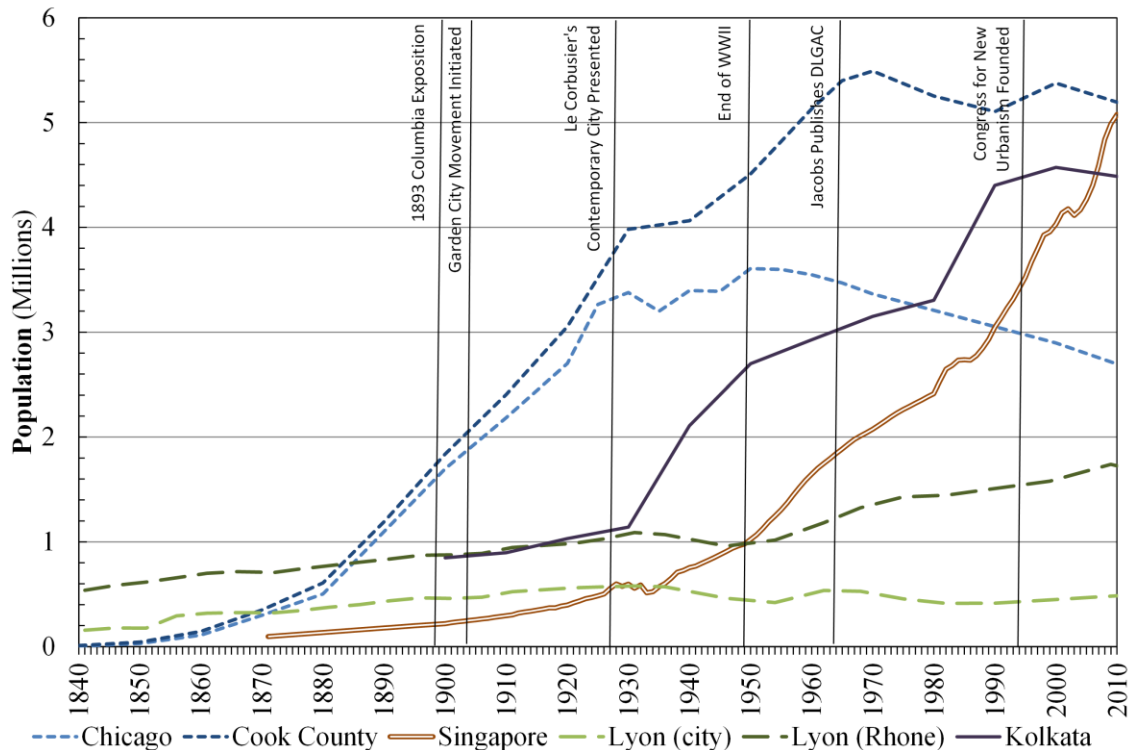


Figure 2: Evolution of population. Sources: Lyon & Rhone (Annuaire-Mairie, 2013; INSEE, 2013), Chicago & Cook County (US Census, 2013; IGPA, 1973), Singapore (Populstat, 2013; World Bank, 2013a), Kolkata (Cox, 2012).

The relatively stable population over the past century suggests that the city's approach to infrastructure development/use is in a maintenance/redevelopment phase. This is sometimes at the expense of historical neighborhoods with former Mayor Louis Pradel's major infrastructure undertakings in the 1960s and 1970s. Nonetheless, Lyon has retained much of its historic building stock, including the St-Jean neighborhood with its Roman and medieval heritage. Lyon's population reached 75% of its peak population in the 1920s, suggesting that much of its infrastructure was established prior to widespread personal mobility, limiting the potential for low-density housing. Additionally, this presents an opportunity for mixed-age buildings, though tracking redevelopment of buildings quantitatively is difficult. As well, this indicates that broader urban form was primarily decided in an era of reduced mobility, high density development (a preponderance of mid-rise buildings), and lower per-capita energy consumption (relative to the modern context). For the Grand Lyon region, automobiles are the primary mode of transportation by providing 58% of all trips, though this mode share decreases to 44% for the older, denser city of Lyon (UrbaLyon, 2011).

Lyon's climate requires space heating and, to a lesser extent, space cooling. Most heating is provided through natural gas and heating oil, contributing to the community GHG total. There are few physical constraints on growth, with surrounding agricultural land allowing for the potential of urban expansion. Most of the growth, however, has historically followed the two rivers, the Rhône and the Saône, notably due to easy access to water transportation modes, thus providing an incentive for relatively dense land-use.

Chicago

Chicago is a contemporary American city, located within Cook County, Illinois. The CBD is second in the US for employment totals (New York City being the largest; Demographia, 2006). Chicago was home to the famous 1893's Columbian Exhibition, which provided inspiration to the monument-focused City Beautiful movement, through its primary planner Daniel Burnham (Jacobs 1961, p.24. The broader Cook County's population more or less stabilized in the 1970s, experiencing its most rapid population growth in the early-to-mid twentieth century; as a result, the urban form follows the modernist thinking popularized during this growth era. Chicago's CBD is predominantly occupied by commercial buildings, high-rise residential buildings and institutions. The City of Chicago reached its peak population in 1950 (3.6 million) and has gradually declined since (McClendon, 2013). Much of the growth over the past 50 years has occurred in the suburban areas surrounding Chicago, akin to most cities in North America, and symptomatic of the well-documented urban decline phenomenon (Glaeser and Kohlhase, 2003; Burchfield *et al.*, 2006). Chicago is of particular interest for this study since it possesses both traditional-style planning (e.g., North of the Chicago River) that diligently follows Jacobs' conditions as well as massive suburban development and sprawl. A short, yet thorough, account of Chicago can be found in Mills (2001).

Chicago's population has stabilized in recent decades, suggesting that infrastructure projects are currently focused on redevelopment and maintenance. Cook County entered the 4th quartile of its peak population in the 1940s, allowing for age diversity in the building stock. An important point to note is that simultaneous growth and decline in population occurred in Cook County and Chicago, respectively, after World War II, suggesting a migration to the suburban areas of the population. Declines in the population in recent years (observed predominantly in the City of Chicago, but also in Cook County) also point to declining density. In Chicago, private automobiles are the dominant mode choice, providing for close to three-quarters of all trips (note that this value is lower relative to the entire Chicago region, where the car provides for 86% of the trips). Considering this, along with the post-war suburban migration, an energy and GHG intensive urban form (low-density, suburban living) has resulted in the region's transportation sector.

Chicago's eastern boundary is strictly maintained by Lake Michigan, though its expansion to the relatively flat agricultural land surrounding it has allowed a great deal of growth of single-family housing in its suburbs and cities within its commutershed (e.g.

Naperville, Arlington Heights). Its climate is dominated by winters, which warrant significant space heating, driving GHG emissions from heating fuels, and can also influence transportation mode selection.

Singapore

Singapore has a compelling history, evolving from developing to developed country status in less than 50 years. Located in the Singapore Strait, it was a British colony for nearly 150 years before it first joined Malaysia in 1963, to then become independent in 1965. Its population increased nearly threefold from 1.9 million in 1965 to 5.2 million in 2011 as it can be seen from Figure 2. In the same time period, Singapore's GDP increased by a staggering factor of 246 and its GDP per capita increased by a factor of 90 in real terms (World Bank, 2013). To achieve such growth, Singapore has invested heavily in its infrastructure and in research and development. It effectively shifted its main economy of "low-end commerce" (EDB, 2015) to a diverse and developed economy where both the industrial and financial sectors thrive. The government also established a massive public housing scheme under the *Housing Development Board*, housing about 82% of the residential population and reaching 88% home ownership rates in 2010 (SingStat, 2011). Jacobs' concepts are ingrained in planning these housing projects, which also include "various commercial, recreational, and social facilities and amenities" (HDB, 2014). In fact, the Singapore planning authority, the Urban Redevelopment Authority (URA, 2015), established a distinct zoning code for "Commercial & Residential" developments. These mixed-used zones can be found everywhere in the island (see Singapore Master Plan 2014 (URA 2014)). Today, Singapore is generally seen as a model for growth for many cities in developing countries. For a fascinating historical account, the reader is referred to Lee Kuan Yew's memoirs (Yew, 2000).

During its transition to developed-country status, Singapore has witnessed a substantial population increase, with an average and sustained per annum rate of 2% since 1960. However, Singapore is currently facing two major demographic challenges, an aging population coupled with a low fertility rate (1.2 compared to the replacement rate of 2.1), which will likely impact its future population growth (NTPD, 2013). The city's growth has occurred predominantly in the post-WWII era, a characteristic that in many countries would have meant low-density housing development; however, an exception is observed in Singapore thanks to government intervention. Much of Singapore's public and private housing is high-density, exhibited in multi-unit towers (Yuen, 2005). Given the lower floor space per unit and lower transportation energy demand observed, this type of development can facilitate lower GHG emissions as well as exhibit the density condition

Expectedly, public transportation is the main mode of travel in Singapore. Singapore is known for implementing strong road policies (such as its Electronic Road Pricing and comparatively high vehicle taxes; Debnath *et al.*, 2011). While Schafer and Victor (2000)

showed that economic development (i.e., GDP per capita) tends to be positively related to motorized kilometers traveled, this does not seem to apply to Singapore; it retains the highest GDP per capita of all four cities (see Table 4) while having lower levels of automobile use. The apparent success of Singapore's approach both resides in infrastructure investment (i.e., ample public transit options) and strong travel demand management policies (i.e., by making vehicle ownership prohibitively expensive).

Singapore's climate can be described as tropical (warm and humid), which has the potential to limit active transportation and, correspondingly, eyes on the street. However, the share of walking trips suggests this is not the case. Geographic constraints on its growth (being an island city-state) has necessitated a measured development of available land resources. In addition, given Singapore's limited energy resource wealth has shaped energy use planning (Chou, 1985).

Kolkata

Founded by the British in 1690, Kolkata has spent much of its history under colonial rule. The city served as the British administrative capital in India from 1773 until 1911 (when the capital was relocated to New Delhi), yet it remains an economic hub for the northeastern region of the country (Bhattacharya 2007; Bhatta, 2009). The city saw its most significant expansion during the 20th century; Kolkata Municipal Corporation's (KMC) population growth increased steadily during the 1900's (from under a million to over 4.5 million by the turn of the century), with waves of new inhabitants made up of refugees and migrants from surrounding regions during the post-colonial period (Cox 2012; Banerjee and Das, 2006). An even greater share of regional population increase in the last half century has been concentrated in its suburban fringe (Bhattacharya, 2007; Cox, 2012). Urban form has followed the contemporary British model of the era, such as the inclusion of monumental buildings that were the foci in the European areas of the city. The early development of the city during the colonial era led to the formation of dense, multi-use areas (e.g. Gariahat, Park Street). An effort has been made to preserve this character, as has been observed in other colonial administrative capitals (such as Vientiane, Lao PDR; Long 2002). For a more detailed account of Kolkata's planning history, see Datta (2012).

Kolkata's population has significantly increased since 1930 (by a factor of nearly 4), as shown in Figure 2. While it seems to have stabilized in the 2000s, one should note that this data only shows population levels in the city of Kolkata (KMC), while its four neighboring regions have seen double digit growth since 1990 (Census of India, 2011). This spectacular demographic increase over the past century presents a challenge to planners, since it imposes stress on the urban economy, infrastructure, and energy demand. An indication of the difficulty the KMC has had in addressing the influx of inhabitants is the share of the population living in informal dwellings; in 2001, nearly a third of the population in the KMC lived in slums (Kundu, 2003).

Public transportation dominates all other modes in Kolkata, likely due to economic constraints; regardless, congestion remains an issue due to limited road coverage (6% total land area, relative to Chicago's 12%) and high population density (Bardhan *et al.*, 2011; Governance Knowledge Centre, 2008; Nowak & Greenfield, 2012).

No major geographic constraints in the region immediately surrounding the KMC exist to present a barrier to its spatial expansion, though the economic and energy challenges that the city faces inhibit the low density development prevalent in jurisdictions that are well-served by passenger vehicles. The relatively warm climate limits the demand for heating fuels, though its high number of CDDs and increasing income provide conditions for rises in electricity demand for space cooling, in addition to other consumption-related electricity grid carbon emissions.

Framework for Comparing Jacobs' Conditions and GHG Emissions

To compare the four cities, we have selected three dimensions that are both pertinent to Jacobs' conditions for diversity as well as to low-carbon cities. These three dimensions are:

1. Population and Density
2. Infrastructure Development/Use
3. Climate and Landscape

Elements of both dimensions one and two are commonly used to consider matters around urban energy use and GHG emissions (Chavez and Ramaswami, 2013; Kennedy *et al.*, 2009, Baur *et al.*, 2014). Population dynamics and population density are related to Jacobs' density condition. A number of studies have attempted to demonstrate the importance of population density in reducing energy use and associated GHG emissions (Kennedy *et al.*, 2009; Norman *et al.*, 2006; Newman and Kenworthy, 1989)

The second dimension is assessed through an examination of infrastructure development, transportation mode share, and road density, exploring Jacobs' conditions on short blocks. Additionally, through an examination of population growth over time and density, inferences are made on the age of the building stock (this data is unavailable at the urban scale for the cities being studied). To do this, we quantify the stages when each quartile was reached relative to the city's peak population. The Infrastructure Development/Use dimension also illustrates the indirect relationships with the other two conditions in that these both have a need for pedestrian activity, which further drives eyes on the street.

Although atypical in urban planning comparisons, Climate and Landscape can have tremendous impacts on decisions related to GHG mitigation and the manifestation of Jacobs' conditions (the humid climate in Singapore may be a deterrent to walking, for instance). From the perspective of the conditions for diversity, the implications of climate on pedestrian traffic (street users) and their resultant "eyes on the street" can be

substantial (Chen and Ng, 2012; Nankervis, 1999). For example, studies in temperate climates suggest trips by active modes of transportation are sensitive to cold and warm weather conditions (Miranda-Moreno and Lahti, 2013; Saneinejad *et al.*, 2012; Bergström and Magnusson 2003). Additionally, urban form (and, consequently, GHGs in alignment with Jacobs' conditions) can be influenced by landscape, as physical constraints on development such as mountains or water bodies (such as is observed in Vancouver by Davis and Schaub (2005); see further discussion of Singapore and Chicago below).

Naturally, many more dimensions can be applied, including zoning, local policies, economic activity, amongst many others; however, these three were selected at present due to data availability and their applicability in aggregate form. A summary of the relevant factors within each criterion is provided in Table 3, along with relevant urban metrics for quantifying these. Associated conditions for diversity and drivers of GHG emissions are also presented.

Table 3: Summary of key data used in the three dimensions for assessing the relationship between Jacobs' conditions for diversity and GHG emissions

Dimension	Related Metric	Associated Conditions for Diversity	Associated Driver of GHG Emissions
Population and Density	<ul style="list-style-type: none"> Urban population (metro and region) Population density 	<ul style="list-style-type: none"> Density 	<ul style="list-style-type: none"> Total energy demand Building energy use (dwelling size)
Infrastructure Development /Use	<ul style="list-style-type: none"> Transportation mode share Road density Eras of population growth 	<ul style="list-style-type: none"> Short blocks Mixed building age Density (indirect) Multiple uses (indirect) 	<ul style="list-style-type: none"> Transportation energy demand Building energy use
Climate and Landscape	<ul style="list-style-type: none"> Heating/cooling degree days Hot months Annual wet days 	<ul style="list-style-type: none"> Density (indirect) Multiple uses (indirect) 	<ul style="list-style-type: none"> Building energy demand Transportation energy demand (indirect)

Census data from national statistical organizations are the primary source used for data used in this framework. Where this information was unavailable (e.g. data on municipal level gross domestic product (GDP), mode share), grey literature sources were consulted (see Table 2). Weather data is obtained from reputable sources (degreedays.net, World Meteorological Organization, British Broadcasting Corporation) rather than national weather data, to ensure consistent methodologies were used across the four cases. For the road density, geographic information systems (GIS) data was downloaded from

the open access openstreetmap.org platform in shapefile format. The analysis was performed using ESRI's ArcGIS.

Assessment of Jacobs' Criteria within Four Cities

The following is an analysis of the performance of the four case study cities as they relate to the dimensions for assessing a city's adherence to Jacobs' conditions for diversity (provided above). This is predominantly done with the data collected in Table 2, whose relevance to Jacobs' conditions is described in Table 3.

Population and Density

Population and population density values for all four cities and their regions are listed in Table 2. In terms of population, Chicago, Kolkata and Singapore are larger cities, each with about 5 million inhabitants, while Lyon is relatively small with around 1.5 million inhabitants. Naturally, population levels also vary depending on the regional extent that is being considered; for instance, the Chicago Metropolitan Statistical Area is reported to have 9.5 million inhabitants in 2013 (US Census, 2013) while the City of Chicago and Cook County were roughly one fourth and one half of this figure respectively in 2008 at 2.7 million and 5.2 million, respectively (see Table 2). Perhaps more importantly, historical population growth needs to be considered, displayed in Figure 2; as cities grow, their infrastructure stocks develop in tandem (or at least attempt to), influenced by changing planning and development trends (i.e., urban densities of the era, buildings constructed according to regulations of the day).

In Figure 2, major urban planning milestones are indicated to give some insight of the urban design trends of the era. Moreover, one can also get an impression of the population quartiles discussed in the previous section, which have a direct connection with land-use, as well as access to energy and transportation, and suggest the scale of infrastructure-of-the-day solutions that would have been applied. For example, we can infer that, during the divergence of population growth/decline between Cook County/Chicago from the 1930's onwards, auto-centric infrastructure dominated development.

Examining population densities Kolkata leads, followed by Singapore, Lyon, and Chicago. The case of Singapore is somewhat unique since, as an island city-state, its growth is constrained and its population is mostly concentrated in high-rises (Yuen, 2005). In contrast, Chicago is the least-dense city studied, although its density is higher than most US cities (US Census, 2013).

GHG emission data and a comparison of population density ranking (along with metrics from the other dimensions) are provided in Tables 4 and 5 respectively. The impact of population density on key metrics of sustainability (energy use, greenhouse gas

emissions) is well known (Newman and Kenworthy, 1989; Norman *et al.*, 2006; Codoban and Kennedy, 2008) and relates to Jacobs' conditions.

Although looking at densities of specific neighborhoods is more relevant to test the presence of Jacobs' conditions, citywide values provide some insights about the overall state of a city. It can be observed from Table 4 that density aligns with GHG emissions as well as transit/active mode shares.

Table 4: Comparison of rankings for per capita GHG emissions and indicators of Jacobs' conditions

City	Per Capita GHGs ¹	GHGs from Buildings	GHGs from Transport	Transit / Active Mode Share	Population Density	Road Density
Grand Lyon	2	2	3	3	3	2
Chicago	4	4	4	4	4	1
Kolkata	1	1	1	1	1	3
Singapore	3	3	2	2	2	4

¹Oldest ranked first.

Similar to the historical perspective section, current density values can help determine what types of policies or infrastructure projects can be more effective. Arguing for higher densities in Kolkata may not be as relevant as in the suburban areas of Lyon and Chicago. However, as discussed in the introduction, development density in the spirit of what Jacobs suggests (e.g., those promoted by transit-oriented design or LEED-ND) can translate into improved GHG emissions performance in cities.

Infrastructure Development /Use

Transportation typically accounts for about one third of urban GHG emissions in developed cities and is also directly linked with the conditions for mixed uses, short blocks, and sufficient population density; these conditions tend to favor active and public transportation. Focusing more closely on transportation infrastructure, we calculated road densities for the four cities from openstreetmap data. Figure 3 shows road density for the four cities, where each square represents 1 km². The black circles around the four cities represent exactly 500 km², there were added to facilitate visualizing the relative extent of each city. The grid shades are associated with street density, in km of road per km², with the intent to represent Jacobs' condition of short blocks; the darker the color, the greater the concentration of streets and, presumably, the shorter the blocks within this grid square.

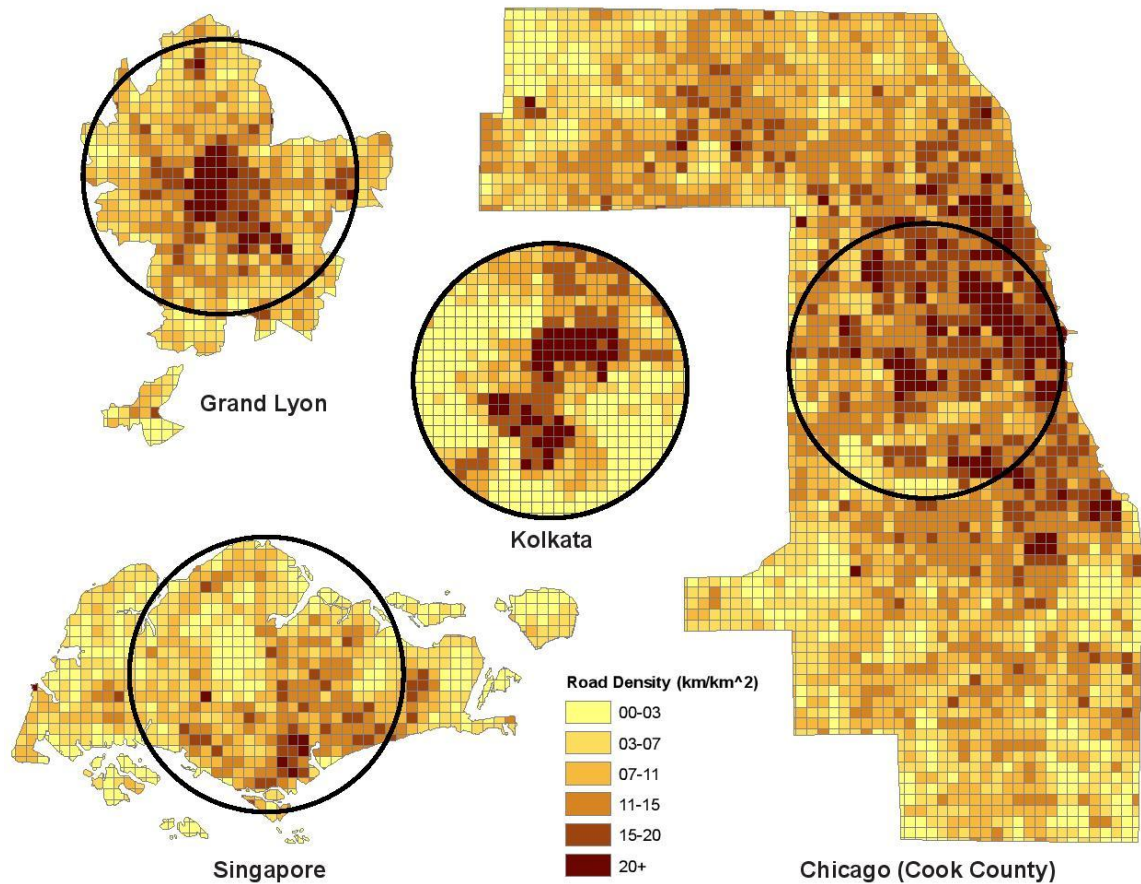


Figure 3: Map of road density. Source: OpenStreetMap Note: Data for Kolkata is incomplete; as a result, only the 500km² area centered on the downtown is shown.

One of the first observations we can make relates to the sheer size of the territories. Cook County, which represents about 15% of the complete Chicago Metropolitan Area, dwarves the three other cities. The Grand Lyon and Singapore share a relatively similar size, while the Kolkata Metropolitan Area (not completely shown) is about three times larger than the Grand Lyon.

Average road densities for the four cities were also calculated and they are shown in Table 2. With the exception of Kolkata for which accurate map data is not available, the GHGs from transport align with road densities, when ranking road densities lowest to highest and GHGs lowest to highest (see Table 4; note that, in the table, road density is ranked highest to lowest, in keeping with the Jacobs condition for short blocks). This agrees with the fact that road density may be either a driver and/or an outcome of transportation energy demand (Barr 2000; Cervero 2003; Noland 2001; Su 2010). The city of Chicago, located in Cook County, has the highest road density (10.18 km/km²). Although some areas in the figure are artificially inflated by the presence of urban expressways, the grid system tends to favor high road densities. Advocating for smaller blocks by buildings more roads may actually promote more passenger vehicle trips (Barr 2000; Cervero 2003; Noland 2001; Su 2010). Once again, however, the sheer size of the

Chicago region is a major deterrent to transit use. This is specifically relevant when many residents from the suburban areas that have low road densities travel to the CBD.

The next highest road densities are in Grand Lyon, Kolkata and Singapore, respectively. The differences between Singapore (6.75 km/km^2) and the Grand Lyon (9.87 km/km^2) are fairly substantial and may be instructive. Lyon shows much higher road densities in its central grid cells, which favor walk-trips and offer easier access to transit stops, owing to its long history (i.e. establishing its infrastructure without the broader commuter catchments enabled by motorized transportation). Singapore, on the other hand, has developed more recently, and has a relatively low road density throughout its entire area. Additionally, Singapore has a much lower vehicle ownership rate per capita than other countries of its income level (see Figure 4), thanks to policies in place to limit growth in this mode share (Olszewski 2007; Santos et al. 2010). Given this controlled low vehicle ownership rate (151 per 1000 people; relative to France's 582 per 1000 people), a high road density is simply not needed (neither are other passenger vehicle-related infrastructure). As well, Singapore has housing complexes that also integrate commercial space (see "The Four Cities" section above). Per Jacobs' first condition, this mixture of uses promotes walking trips that are therefore short and not necessarily on paved roads that would be shown on the online road density Figure.

Due to the lack of data for Kolkata, limited observations can be made from the map. Moreover, the value of 8.22 km/km^2 shown in Table 2 is misleading due to incomplete road and administrative data in the GIS files available. This value may be overestimating the actual road density since the full KMC is not included. As importantly, we have found through personal experience that paths intended for non-vehicle traffic tend not to be captured through OpenStreetMap, such as alleyways and other pedestrian paths, although they have an important function.

While Jacobs emphasizes the many benefits of short blocks and walkable cities in general, these can also provide upward pressure on emissions from transportation in two ways. Short blocks could lead to greater number of intersections, leading to an increased idling relative to longer blocks with fewer intersections. An example of the implications of idling on GHG emissions has been presented for New Delhi, India; 9% of total transportation emissions in the city were attributed to vehicles idling at intersections (Bhandari et al. 2013). At the same time, many studies have found that increases in roadway capacity leads to greater absolute transportation demand (Barr 2000; Cervero 2003; Noland 2001; Su 2010), though greater roadway density is also often associated with higher population density (as well as greater access to mixed uses) which provides lower VKT per capita (Cervero and Murakami 2010). The offsetting of transportation energy demand through an increase in pedestrian trips encouraged by road density may compensate for increases in GHG emissions, though this warrants further investigation. As well, *pathway* density should be emphasized over road density, with improved connectivity for active modes of transportation (cycle paths, pedestrian alleys, etc.) taking priority over the motor vehicle network.

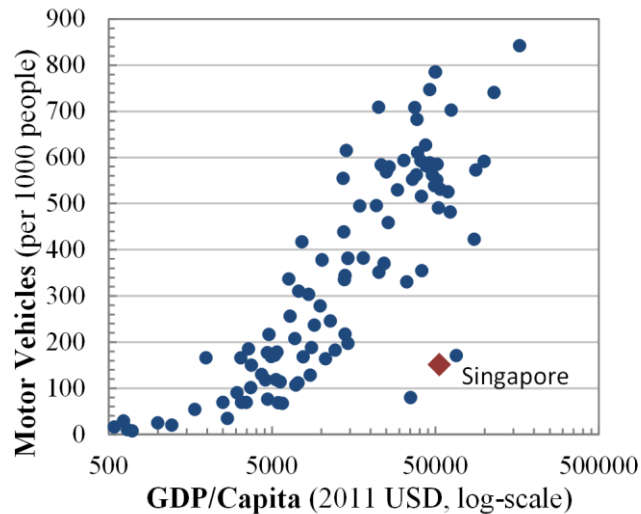


Figure 4: Motor Vehicle per 1000 People vs GDP per Capita, 2011 (Source: World Bank, 2015a; 2015b)

Climate and Landscape

Although climate may not be explicitly related to Jacobs' conditions, it can have a significant impact on diversity, urban form, and planning choices. Climate greatly influences energy needs of cities and their residents, which was briefly discussed in the context of the four cities in the previous section. This is particularly true in extreme-weather climates, where temperature or precipitation events may reduce pedestrian trips; cities with mild climates may observe a greater increase in the pedestrian mode share from improved sidewalk infrastructure than those with more severe climates. Examination of the number of “wet days” (where precipitation exceeds 0.1mm) and monthly average temperatures can provide insight on extreme events within our profiled cities (Tables 2).

From a GHG perspective, climate and energy use are intrinsically related, with energy required for space conditioning of buildings. Typically, the number of heating degree days (HDD) and cooling degree days (CDD) are used to assess the importance of climate on energy for space conditioning (see Table 2). Moreover, past studies have highlighted the importance of climate on energy consumption and associated GHG emissions (Kennedy *et al.*, 2009). Energy demand related to space conditioning requires attention, especially in cities with higher annual HDDs due to the comparatively higher energy intensity per unit of area for providing space heating versus cooling (Sivak, 2013). Studies have also suggested that cities with higher numbers of HDDs (such as Lyon and Chicago) can experience switches in mode from active to public or private transportation during the winter months, thus reducing “eyes on the street” and total available users (Miranda-Moreno and Lahti, 2013; Saneinejad *et al.*, 2012; Bergström and Magnusson 2003). The same may occur in summer months in cities with high CDDs, as it is the case in Singapore and Kolkata, but walking and cycling can be encouraged through measures

such as incorporation of street trees, covered/conditioned walkways, etc. (Foltete and Piombini, 2007; Johansson and Emmanuel, 2006).

Arguably, with a humid subtropical climate, no hot months and relatively few wet days, Lyon offers the best conditions for walking and cycling; coupled with its high density and short blocks, Jacobs' conditions and lower transportation energy demand are further encouraged. Chicago tends to experience extreme conditions in winter and summer, making the space-conditioned automobile a haven for its residents; this can further increase transportation GHG emissions. As mentioned, Singapore has provided some of Jacobs' conditions while accounting for its hot climate (i.e. by integrating commercial activity in public housing), serving as an example to Kolkata and other tropical cities in developing nations.

The density condition imposes a challenge in warmer regions; a number of anthropogenic sources of heat (buildings providing thermal mass, air conditioners expelling heat from building interiors, etc.) can increase the level of discomfort and cause an absolute increase in space cooling demand (Quah and Roth 2012). However, as stated earlier, Ko (2013) suggests that more dense urban settings result in lower cooling energy demand per household unit.

Low-Carbon Systems and Jacobs' Conditions for Diversity

Considering this work attempts to understand the intersections between Jacobs' principles and low-carbon cities, this section focuses on urban GHG drivers that are within the control of decision-makers that influence the urban realm. Areas that need improvement must be examined within a local context, instead of implementing one overarching planning strategy to all cities/neighborhoods. This section summarizes the relationship between Jacobs' conditions and their GHG implications relative to the three dimensions.

Accounting for the local context is important because the relationship between Jacobs' conditions and urban sustainability is non-linear; the application of one single condition can have multiple environmental benefits/detriments. To give a classic example, increasing population density will not only discourage driving and potentially reduce energy use per unit floor area (used for space conditioning), it can also increase accessibility of retail accessibility (Cervero and Murakami 2010). Additionally, an increase in energy demand to other goods and services (i.e., rebound effect) can occur due to reduced expenditures on transportation (Wiedenhofer et al. 2013). Identifying where cities can achieve the greatest net-benefit from these non-linear relationships may be key to achieving more sustainable outcomes.

We have argued that the presence of Jane Jacobs' conditions should be reflected in lower urban energy use and GHG emissions. Table 4 shows total and per capita emissions for the four cities, as well as a breakdown of emissions by sector. To demonstrate the perceived relationship between Jacobs' conditions and GHGs, rankings

of the case study cities' performance in per capita emissions and metrics described above (see Table 3) are presented in Table 4. As will be discussed below, this seems to coincide with the central hypothesis that Jacobs' conditions correspond with low-carbon urban systems.

Table 5: Greenhouse gas (GHG) emissions and economic data for the four studied cities

Metric	Grand Lyon¹	Chicago (city)²	Kolkata³	Singapore⁴
Total (Mt CO ₂ e) (Inventory Year)	7.6 (2006)	33.29 (2010)	9.33 (2007-08)	37.76 (2000)
Per capita (t CO ₂ e)	6.06	12.35	1.83	7.57
Transport per capita (t CO ₂ e)	1.76	3.83	0.33	1.16
Buildings per capita (t CO ₂ e)	1.03	3.62	0.35	1.13
By sector	40.9% Industry + Energy 29.1% Transport 17% Residential 12.7% Commercial + Institutional 0.4% Agriculture	39.8% Electricity Use 31% Transport 24% Natural Gas 1.6% Water (all) 2.7% Solid Waste 0.4% Agriculture	54% Industrial 19% Residential 18% Transport 9% Commercial	55.3% Electricity Generation 27.7% Industries 15.3% Transport 0.9% Residential 0.8% Commercial
GDP/Cap (USD, 2012) ⁵	41,038	54,953	3,127	62,523
GDP/Cap Growth (USD, 1993-2007) ⁵	+1.9%	+2.0%	+5.0%	+3.8%
GHG/GDP (kg ⁶ /\$2012)	0.15	0.22	0.59	0.12

Source: ¹Lyon & Grand Lyon (Grand Lyon, 2009a; Grand Lyon, 2009b); ²Chicago & Cook County (CMAP, 2012); ³Kolkata Municipal Corporation (ICLEI, 2009); ⁴Singapore (NEA, 2010); ⁵GDP data taken from Brookings Institution (2012); ⁶it should be noted that emissions were of the inventory year, while GDP are for the year 2012 - error will be introduced as a result; for example, Kolkata's emissions per unit of GDP may be higher, given that economic growth has been greater than population growth in the past decade.

A first look at per capita emissions tells us unsurprisingly that Kolkatans are the lowest emitters, while Chicagoans are the highest emitters. Here again, the context of each city must be taken into account. For example, the Lyonnais benefit from a much cleaner electrical grid than the others, which helps maintain lower per capita emissions intensity in spite of it providing 28% of their energy usage. In 2009, grid emissions factors were estimated to be 30 kgCO₂/MWh compared to 559, 717, and 1000 kgCO₂/MWh for Chicago, Singapore, and Kolkata, respectively (CARMA, 2015). As a

city-state, per capita values for Singaporeans may be skewed since they include all national industries, unlike other urban inventories where regional specialization (as well as NIMBYism) may exclude important carbon-intensive sectors from inventories. Contrarily, Singapore may actually exclude certain carbon-intensive sectors due to its chosen economic specialization and geographic constraints.

Examining residential data GHG data, Chicago stands out with emissions that are more than three times Singapore (the next highest) even though the latter has newer buildings. Chicagoans are penalized in this comparison by their cold climate since they require more natural gas to heat their homes, representing 24% of the total emissions. It is possible that the availability of older buildings in accordance with Jacobs' may result in higher GHG emissions, as older buildings tend to be more energy intensive (for illustrations, see "Residential Sector" Table 9, OEE, 2012; and graph 5g, Department of Energy and Climate Change, 2013). These results suggest that the preservation of old buildings does not necessarily predestine a city to high building sector emissions. Other factors such as economic activity, climate, quality of the building stock, and carbon intensity of energy sources are likely more important. Additionally, in a social welfare state where governments are able to subsidize costs for occupants of newer buildings so as to encourage both varied population and businesses, new buildings may not pose the same diversity-deadening effect that Jacobs' observed. Further, from a policy perspective, ordinances that require reporting of energy performance of commercial/residential buildings can provide incentive for landlords of older buildings to maintain higher energy performance that would otherwise occur.

Focusing on transportation emissions (as these have the potential to be most directly influenced by Jacobs' conditions), the historic energy scarcity or passenger vehicle ownership may also influence the GHG emissions currently reflected by these municipalities. For example, given that the era in which much of the development in Kolkata and Lyon occurred, where there was limited passenger vehicles ownership during periods of population growth. Kolkata's rate of vehicle ownership in 2009 was roughly one-fifth of the Illinois average in 2010 (Bureau of Applied Economics & Statistics, 2012; US Department of Transportation, 2011). Given that Kolkata's vehicle ownership recently reached this relatively low level, the city has mostly developed during an era where most citizens could only travel by public or active modes of transportation, with urban form matching this constraint.

While the transport emissions can be compared more objectively, they simply tend to follow the transit mode share figures from Table 2, which we feel reflect the adherence to Jacobs' conditions. Transport emissions may also be telling of the urban form since longer trips are needed to reach a destination, thus arguably reflecting density and morphology (Bechle *et al.*, 2011). Consequently, with 3.83 tCO₂e per capita and the relatively high automobile mode share, we can infer that Chicago has not adopted Jacobs' conditions to the same extent that Singapore, Kolkata, and Lyon have; however, it must be reiterated that these values may reflect the non-linear relationship mentioned above.

The influence of economic factors in GHG emissions must not be neglected, given the correlation between income and emissions observed elsewhere (Kennedy et al, 2009; Ramaswami and Chavez 2013). As shown in Table 4, Kolkata's emissions per unit of GDP are less impressive than is suggested by the per capita figure, likely due to the prevalence of high-carbon fuels (e.g., coal) in the city's energy supply. Assuming that an environmental Kuznet's curve will apply for GHG emissions in the Indian case (see Lapinskienė, Tvaronavičienė, & Vaitkus, 2014), a decoupling of economic growth and carbon emissions is likely occur at some point, though the timing of this is uncertain. As a result, increases in GHG emissions per capita can be expected to climb in Kolkata.

One point worth noting from Table 4 is that Kolkata consistently ranks well both in the metrics representing Jacobs' conditions and GHG emissions (on a per capita basis). While much of this can be attributed to low levels of income, policies that preserve these both Jacobs' conditions and low emissions during the expected era of economic growth will be important. Pricing roads (as Singapore did), preserving old buildings (along with the density they provide, as was done in Chicago and Lyon), and maintaining multiple uses of buildings (which all three have achieved) will be vital to this long-term effort.

It is worth highlighting that in the IPCC Fifth Assessment Report, Seto et al. (2014) present four metrics of urban form that influence GHG emissions. These metrics align well with Jacobs' conditions: density (condition for concentration of users), land-use mix (condition for attracting different users), connectivity (condition for short blocks), and accessibility (a combination of the three stated here). This provides additional support for the argument that Jacobs' conditions are an important consideration when planning the low-carbon city.

Conclusion

The main goal of this paper was to investigate the intersection of Jane Jacobs' conditions and low-carbon urban systems by studying four very different global cities. First, we listed Jacobs' conditions for diversity, discussing how they relate to the overarching goal of reducing lower energy use and GHG emissions. Second, we provided a brief historical overview of four case study cities and discussed the influence of their development on drivers of GHG emissions. The cities were then analyzed using three dimensions: *Population and Density*, *Infrastructure Development/Use*, and *Climate and Landscape*, to explore how Jacobs' conditions have manifested themselves and how this has affected their GHG emissions. Ultimately, the contribution of this work is the exploration of how Jacobs' conditions are exhibited in the four case study cities and the examination of how they influence GHG emissions in each case. We suggest that all four conditions for diversity can have a positive influence on GHG mitigation and that cities that display macro-scale characteristics indicative of the presence of Jacobs' conditions benefit from lower carbon emissions.

Urban design professionals can take this conclusion from a general perspective, bearing in mind that Jacobs' conditions are manifested in many different ways in the case study cities. This is particularly relevant when considering historical, and climatic and landscape factors; for example, as an older, expansive city with a dense, low-rise core and relatively mild climate, Lyon exhibits Jacobs' conditions in a different way from Singapore, which is tropical, physically constrained, and has seen more recent infrastructural growth and contains many high rise buildings. In fact, the four cities selected in this study differ in many respects (eras of development, economic conditions, policy approaches, physical landscapes, etc.). Strategies to make them low-carbon must therefore be adapted to their individual contexts.

The four cities have different population densities, owing to the varying contexts of their growth. As well, they diverge in their road density, climate and reliance on passenger vehicles. We point to the relationship between carbon emissions and the presence of Jacobs' conditions in these dimensions through recent GHG inventories of the study cities. As Table 4 demonstrates, agreement is observed with our proposed metrics of Jacobs' conditions and the GHG performance of these cities.

An examination of infrastructure shows that eras of growth, technological choices, and policy/market forces can influence the extent to which a city exhibits carbon intensive infrastructure. For example, old buildings did not necessarily result in Lyon having high building sector GHGs per capita. However despite its tendency towards low-rise, dense construction in the old city, more sprawling development along its periphery pushed its transportation emissions higher. In the end, a city like Lyon can still have relatively low overall GHG emissions while maintaining eyes on the street (pedestrians), mixture of building ages, and short blocks.

With respect to climate, research suggests cities that experience more extreme conditions may have to contend with a stronger tendency towards passenger vehicles over public/active transportation. However, Singapore's policies of restricting automobile mode share demonstrate an approach that cities can use to overcome this, and low transportation-related emissions can result.

Furthermore, the relationship between Jacobs' conditions and low-carbon cities is not straightforward and presents many non-linearities. For instance, building shorter blocks may encourage walking and deter auto use, and thanks to this increase in walking, it can also support new commercial activity (contributing to Jacobs' mixed land-use condition); however, creating shorter blocks may increase vehicle idling, spur energy demand in others sectors of the economy, as well as boost VKT as the availability of roadways increases. To improve the carbon outcomes, transportation planners should focus on greater pathway density for active modes of transportation, rather than road density. Further, Kolkata, which exhibits Jacobs' conditions under the metrics assessed here as well as low levels of GHG emissions, will be challenged to maintain these as its infrastructure expands along with its economy. Overall, current development in emerging economies, such as Kolkata, will undoubtedly also lead to an increase in energy

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consumption, and in the absence of low-carbon energy adoption, higher per capita GHG emissions. Development that considers Jacobs' conditions can mitigate some of the long-term growth in GHGs, though reducing energy intensity of urban form.

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